2006 South Bay Science Symposium
for the
South Bay Salt Pond Restoration Project

Presentation Synopses

Edited and Compiled by
Lynne Trulio, Lead Scientist
South Bay Salt Pond Restoration Project
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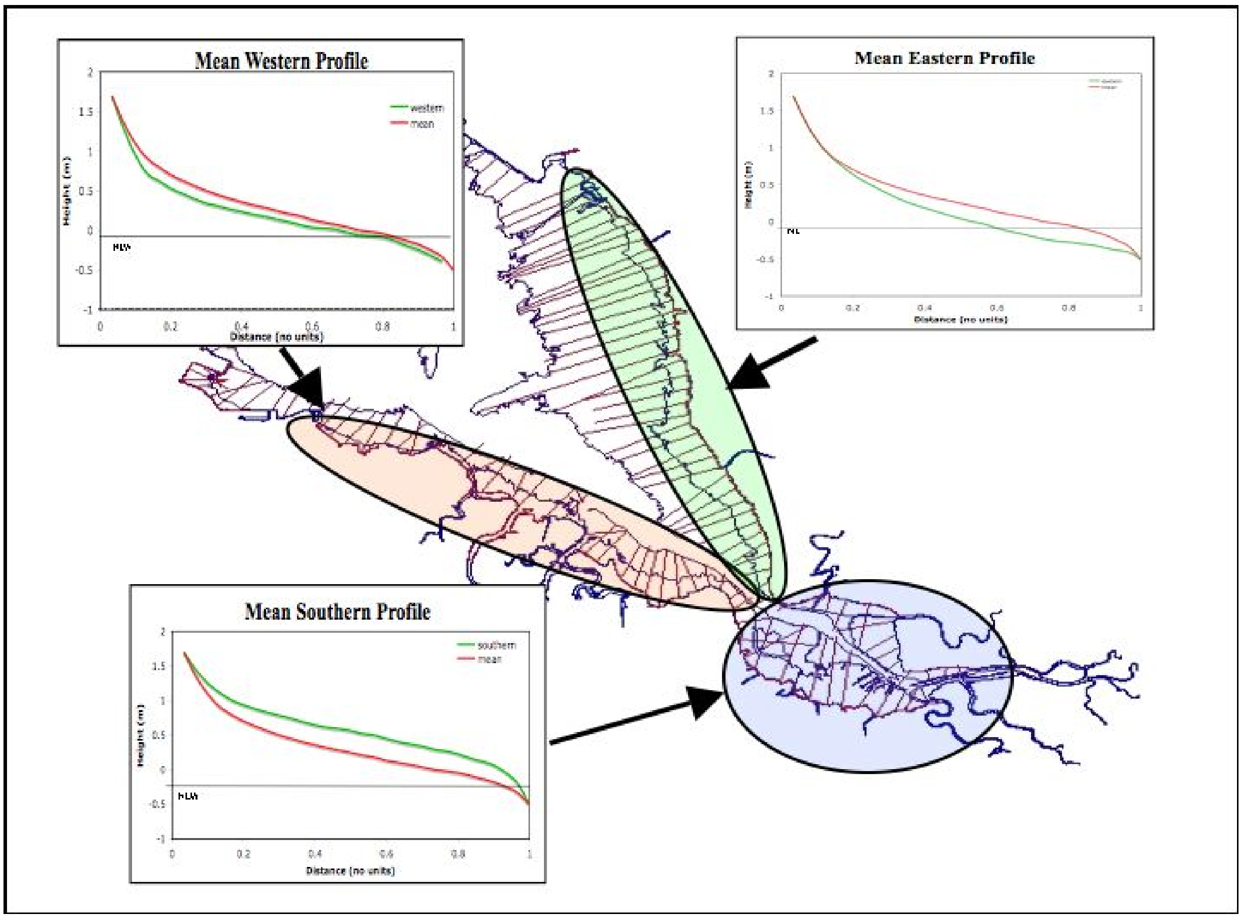
The 2006 South Bay Science Symposium was held on June 6, 2006 in the Martin Luther King, Jr. Library on the San Jose State University campus. The purpose of the day-long event was to bring forward the most recent research relevant to restoration of the South San Francisco Bay.

The majority of the presenters at the Symposium distilled their talks into the synopses provided here. These summaries are designed to inform researchers, managers, and the public about the wide range of scientific research focused on South Bay ecosystem restoration.

2006 Science Symposium Synopses: Contents

HYDROLOGY
AND
SEDIMENTATION



From: Bearman, et al. (this document)

Factors Controlling Mudflat Morphology in South San Francisco Bay

Josh Bearman[1], Amy Foxgrover[1&2], Carl Friedrichs[1], and Bruce Jaffe[2]

[1]Virginia Institute of Marine Science, Gloucester Point, VA 23062; jbearman@vims.edu; cfried@vims.edu,
[2]US Geological Survey Pacific Science Center, Santa Cruz, CA 95060; afoxgrover@usgs.gov; bjaffe@usgs.gov

Intertidal zones - areas exposed at low tide and inundated at high tide - are often overlooked regarding their importance to the biology and morphology (shape) of coastal systems. As essential habitat for benthic (bottom-dwelling) organisms, these areas provide a food source and staging area for migratory bird species and act to dampen wave and wind energy, thereby lessening coastal erosion.

Previous studies have shown that mudflats with convex profiles indicate accretional, sediment-rich environments usually associated with calm, tidally-dominated systems. These mudflats help to mitigate shoreline erosion by dampening wave energy, and also by providing wide areas for biologic use. Concave profiles, conversely, indicate erosional, sediment-starved conditions and wind/wave-dominated areas. Such mudflat shapes increase wave energy and lead to higher rates of shoreline erosion.

The recent ecological and physical history of the San Francisco Bay is intimately tied to human activity. In response to massive landscape scale activities, from hydraulic gold mining and salt pond leveeing of the mid-1800s to more recent water diversion projects, the rates and manner of sediment transport and deposition patterns have changed, all of which is reflected in the morphology of intertidal and tidal landforms (mudflats and marshes). Due mainly to salt pond leveeing and residential development, tidal marshland in the South Bay – south of the Dumbarton Bridge – has decreased 80% from the 2000 km^2 present in the original 1850s USCGS bathymetric survey. This loss of marshland was accompanied by a 40% drop in the area of fringing mudflats. This research is the first leg in a larger project that seeks to examine the morphologic characteristics and evolution of intertidal mudflats in South San Francisco Bay, using seven sets of bathymetric data between the years of 1858 and 2004.

With the current restoration of the Alviso, Ravenswood, and Warm Springs salt pond sites already underway, it is important to establish a baseline model of the current and past morphology and morphologic response of the South Bay mudflats so that any future change can be put in a larger context for comparison. The United States Coastal and Geodetic Survey and its predecessors have, since the early periods of western colonization, conducted surveys of the San Francisco Bay in order to map the water depths and shape of the estuary bottom – the bathymetry. Using an historic dataset compiled, digitized, geo-referenced, and analyzed in Foxgrover (2004), the morphology of the intertidal zones can be further analyzed and compared both within a single dataset as well as between different time periods.

Using ARC GIS software, cross-sectional lines, spaced roughly 500m apart, were drawn from mean high water to below lower low water in order to capture the full extent of the mudflat in the 1983 dataset. The cross-sections were analyzed using empirical orthogonal functions: a process that compares individual cross-sections to a mean profile shape, and identifies the major components of variation present. Through this analysis, it was determined that the South Bay mudflats varied significantly in their degree of convexity or concavity. Further, the South Bay can be split into three distinct areas of mudflat morphology – NE of the Dumbarton Bridge, South of the Dumbarton Bridge, and NW of the Dumbarton Bridge.

Figure 1 shows the study area of the South Bay, cross-sectional lines, and the three morphologic regions. The graphs show the mean shape of those mudflats for which the principal components suggests a strong physical forcing for each of the three regions in green, plotted against the mean mudflat profile of the entire South Bay for 1983. In comparison to the mean mudflat shape, the Eastern flats show a more concave profile in their lower portions, the Western flats are more concave in their upper portions, and the Southern flats are more convex across the entire profile. These findings are consistent with historic wind and current trends, as well as trends of local erosion deposition recently discussed in Jaffe & Foxgrover (2006).

Ongoing research is focusing on (1) refining the process of drawing the cross-sectional lines to better define the mudflat limit, (2) spatial comparisons of each data set to better determine if the morphologic regions found in this study hold throughout the history of bathymetric measurements in South Bay, and (3) a temporal comparison across the different data sets to see if there are observable trends in mudflat morphology and response to human forcings. Ultimately, we hope to be able to make predictions of mudflat response to salt pond breaching.

As stated earlier in this write-up, it is important, in the face of impending salt marsh restoration, to understand the baseline morphologic behavior of the intertidal areas which fringe the management zones; tidal flats and tidal marshland are connected both through hydrodynamics and ecology. Given that there will be some alteration of tidal prism and sediment dynamics with the breaching of subsequent salt pond levees, it is useful to know how the system has been behaving under “normal” conditions up to this point.

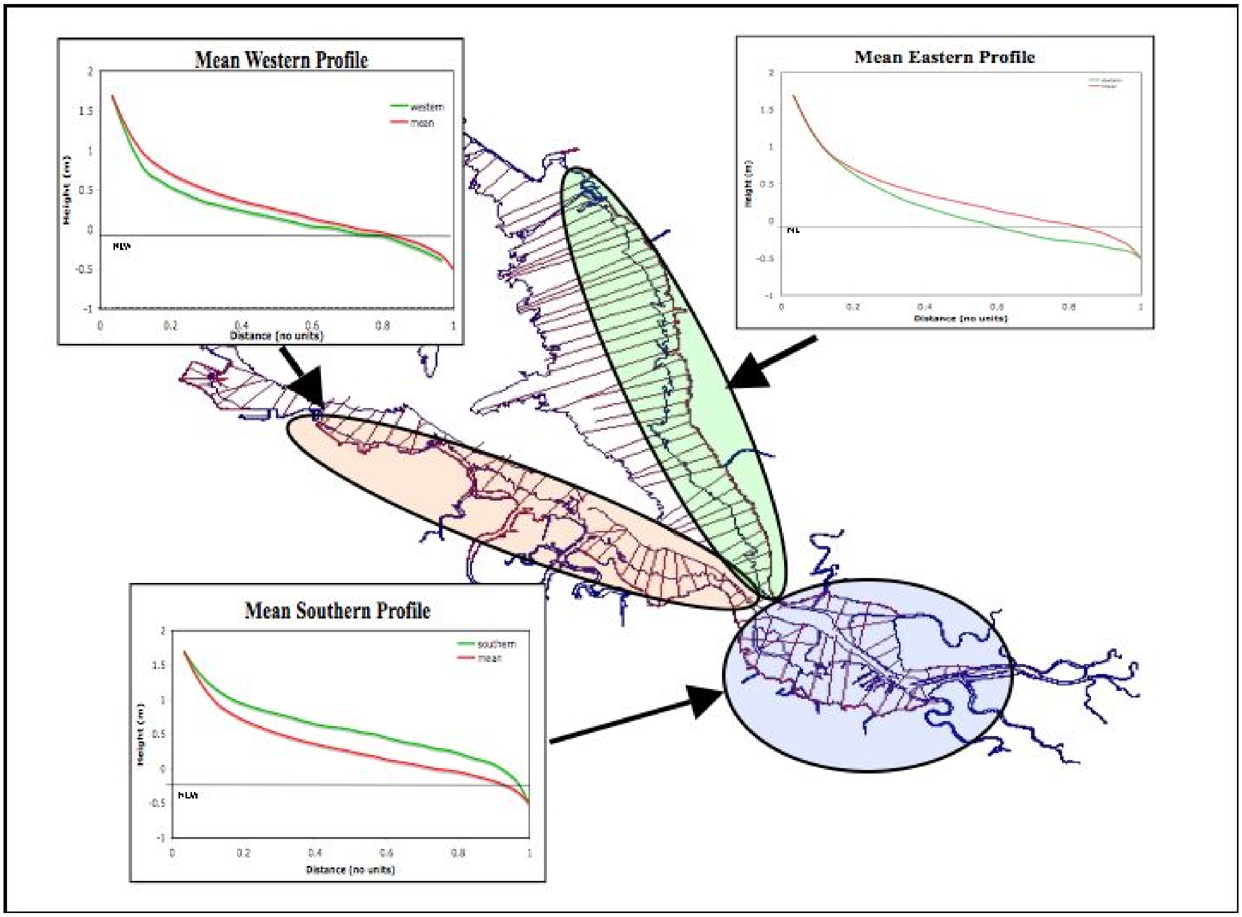


Figure 1: South Bay tidal flats can be broken into three distinct regions of morphology, designated by the three colored circles. The accompanying graphs show the mean mudflat profile for each region (green) plotted against the mean mudflat profile of the entire South Bay (red).

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Sediment Deposition in Restored South Bay Salt Marshes: How Much is Enough?

John Callaway[1], V. Thomas Parker[2], and Lisa Schile[2]

[1]Department of Environmental Science, University of San Francisco, 2130 Fulton St., San Francisco, CA 94117; callaway@usfca.edu
[2]Department of Biology, San Francisco State University, 1600 Holloway Ave., San Francisco, CA, 94123; parker@sfsu.edu and lschile@sfsu.edu

In the South Bay salt ponds, as well as in natural marshes around San Francisco Bay, elevation is a critical factor that determines how often areas are flooded by the tides. Sites that are flooded frequently by the tides are typically dominated by mudflats because regular flooding creates a stressful environment for plant establishment and growth, even for salt marsh plants that are adapted to tolerate occasional tidal flooding. At elevations slightly higher than mean sea level, plants begin to colonize and salt marshes develop. Over time, relative marsh elevations and rates of tidal flooding can change. These shifts are affected by a range of factors including global sea-level rise and sediment compaction, which reduce elevation and lead to an overall increase in rates of tidal flooding. Sediment accumulation and the buildup of soil roots and rhizomes, on the other hand, can increase elevation and reduce rates of tidal flooding. Relative differences in these dynamics will be critical in determining the future elevation of the restored South Bay salt ponds. Many ponds in the South Bay have subsided anywhere from 30 to 200 cm (1 to 6 feet) and will need to accumulate substantial sediment in order to build elevations to a point where plants can establish.

In order to provide initial information on sediment dynamics in newly restored salt ponds, we have been evaluating sediment accumulation rates at 3 ponds, A19, A20 and A21, also known as the Island Ponds, adjacent to the town of Alviso in the Don Edwards San Francisco Bay National Wildlife Refuge. These are the first salt ponds to be restored as part of the South Bay Salt Pond Restoration Project. We are focusing on one of the sites, Pond A21, which is located at the confluence of Coyote Creek and Mud Slough. At Pond A21, we are monitoring sediment accumulation rates using a variety of methods at 37 stations in order to identify factors that may cause shifts in sediment dynamics across the pond. The Island Ponds have a dense layer of gypsum, a natural salt that precipitates as part of the salt production process, covering areas that were tidal marsh prior to their use for salt production (Fig. 1). This thick, dense gypsum layer is up to 25 cm (10 inches) thick, and we can directly measure the amount of sediment that has accumulated above this layer. In addition, we have established sturdy PVC posts at each station and are documenting how quickly the posts are buried (or uncovered) as new sediment is deposited (or eroded) at the site. The stations were monitored one and three months after the levees were breached, re-connecting the site to the tides. Measurements will continue over the next several years to evaluate the site as it develops towards elevations that will allow for plant establishment within these ponds.

Our preliminary results indicate that there has been substantial sediment accumulation within Pond A21 during the first three months after the levees were breached (as measured in June 2006). Many of the stations near the levee breaches had accumulated 3-7 cm (1.18 to 2.76 inches) over this three-month period. While this may not seem like high rates of sediment accumulation, most natural marshes would accumulate 1-3 mm (0.04 to 0.12 inches) over this same time period. Sedimentation rates were variable across the salt pond. The highest rates occurred at the lowest elevations, which were also closest to the levee breaches. At higher elevations, the rates of sediment build-up were lower but are sufficiently high to continue building elevations within the ponds.

These preliminary results provide a first indication of potential sediment dynamics within the restored ponds and indicate that it is likely that the Island Ponds will rapidly increase in elevation. Over time, these high rates of sediment accumulation should slow as the site stabilizes at elevations where marsh plants become established. In addition, rates of sediment accumulation will need to be monitored when larger-scale restoration efforts are undertaken in order to evaluate if there are any changes in sedimentation rates as larger and larger areas of salt ponds are restored.

Figure 1. Initial conditions with gypsum layer (at top) and conditions after a year of sedimentation at pond A21.

Estimating Sediment Supplies from Local Watersheds to Intertidal Habitats of San Francisco Bay

Laurel M. Collins, collins@lmi.net, Watershed Sciences, Berkeley, CA

Introduction. As sea level rises, the intertidal habitats of San Francisco Bay also rise due to peat production (the below-ground accumulation of living and dead plant roots), the surface deposition of pant detritus, and the deposition of inorganic sediment, mainly sands, silts, and clays. As the rate of sea level rise increases, the demand for inorganic sediment also increases to maintain tidal elevations. Past literature emphasizes the role of Sierran rivers as the most important sources of inorganic sediment for San Francisco Bay. (Krone 1979, Ingram and Lin 2002), while the role of local watersheds received scant attention. Recent studies show, however, that local watersheds can provide large amounts of sediment to the intertidal zone (Watson 1994, Malamud-Roam 2006, McKee 2006, SEC 2006). The following brief account of recent sediment yield studies from the Bay Area provides further evidence that local watersheds are playing a major role in the formation and natural maintenance of intertidal habitats, especially as influenced by modern changes from recent and legacy land use impacts.

Alameda Creek. A sediment budget for Alameda Creek (1970 to 2005) was developed by Watershed Sciences (Collins 2006a) for the Alameda County Flood Control and Water Conservation District based upon four datasets: 1) dredging volumes and cross section surveys from the County for the 12 mi Alameda Creek Flood Control Channel; 2) U.S. Geological Survey discharge and sediment records for the Niles Canyon gage; 3) Weiss Associates (2004) Study of the Sunol Dam Removal for the San Francisco Public Utility Commission (SFPUC); and 4) SFPUC bathymetry records of Sunol and San Antonio Reservoirs.

Alameda Creek watershed drains to the Bay through a constructed flood control project. The USGS stream gage at Niles is just upstream of the project. The total watershed area upstream of the gage is 700 mi^2, yet the area that contributes sediment (the “sediment shed”) is only 309 mi^2 due to several large reservoirs that disconnect and trap sediment from Alameda Creek. Calaveras, San Antonio, and Lake Del Valle Reservoirs trap sediment at a rate of about 194,000 yd^3/yr. Conversely, channelization and connection of streams previously disconnected in the Livermore-Amador Valley, plus artificial drainage of the Valley’s natural sediment sinks, including the historical Tulare Lake, have dramatically increased sediment supplies to Arroyo de la Laguna that now serves as a principal sediment conduit to Alameda Creek.

Alameda Creek delivers about 125,300 yd^3/yr of sediment to the Niles gage and the flood control channel. About 50,300 yd^3/yr of this sediment (40% of total load) is stored in the flood control channel, and about 25,000 yd^3/yr (20% of the total) has been dredged to maintain flood capacity. This means that Alameda Creek tends to deliver about 50,000 yd^3 /yr of sediment to the Bay. This sediment supply, if spread over just the intertidal habitats within one mile of the mouth of Alameda Creek, would raise them about 15 mm/yr, which is almost 10x the current rate of sea level rise (Byrne et al. 2001) and 1.5x the maximum rate predicted for the end of this century by global climate change models (IPCC 2007).

Sonoma Creek. As part of a TMDL study for the Regional Water Board, Watershed Sciences helped develop a sediment budget for the 127 mi^2 Sonoma Creek watershed (SEC 2006). Two methods were used to calculate long-term (1845 to 2000) sediment yield in the Sonoma watershed, which does not have any large reservoirs. The two methods provided very similar estimates of average total sediment yield, suggesting that much of the sediment eroded from the watershed is trapped within the adjoining tidal sloughs and intertidal habitats, and that due to extensive channel incision and floodplain disconnection, very little sediment storage is occurring in the uplands.

The first method focused on the amount of sediment eroded from the watershed. An empirical model was developed from extensive field measurements to predict sediment yield from channel bank erosion and bed incision based upon geomorphic context and drainage network length. Landslide sediment supply was determined by field measurement and stereo photo analysis. Sediment supply rates from sheetwash were modeled by the Sonoma Ecology Center, and road-related sediment supplies were modeled by Martin Trso, P.G. These combined methods indicate that the watershed yields about 111,200 tons/yr.

The other method focused on the amount of sediment trapped in the intertidal zone and diked baylands along Sonoma Creek, including sediment deposited on the diked baylands during flood events, deposited on tidal marshlands, or dredged from tidal sloughs for building adjacent artificial levees. Based on this method, the Sonoma Creek watershed yields 105,940 tons/yr +/- 30 percent or 96,306 yd^3/yr with an estimated 20 percent supplied to San Pablo Bay. If the proportion supplied to the Bay were spread over just the intertidal habitats within one mile of the mouth of Sonoma Creek, they would rise at a rate of about 6 mm/yr, which is about 3x the current rate of sea level rise and more than half the greatest rate of sea level rise predicted for this century due to global warming.

<u>Crow Creek and the San Lorenzo Creek Watershed</u>. The 11 mi^2 Crow Creek watershed is the only remaining large tributary of San Lorenzo Creek that has not been dammed. Watershed Sciences estimated long- and short-term sediment yields from the Crow Creek watershed for Alameda County, based upon a sediment source analyses (Collins 2006b). For 17 years (1962 to 1974), sediment yield averaged 46,400 yd^3/yr. The long-term (1835 to 2000) yield was about 24,300 yd^3/yr. Crow Creek watershed supplies a high proportion of fine sediment partly because its geology is prone to earthflow landslides, but also from increased erosion rates associated with historical and current land use.

More than 60% of the greater San Lorenzo Creek watershed is upstream of Cull Creek and Don Castro Reservoirs. Cull Creek watershed sediment yield was estimated to be about 27,600 yd^3/yr in 1980, when the trap efficiency of the Cull Creek Reservoir was about 88% (ACFCWCD 1980). The sediment yield into Don Castro Reservoir might be greater because its sediment shed is larger. Both reservoirs are nearly filled with sediment and therefore have very low trap efficiencies.

The rate of sediment delivery to the Bay from the San Lorenzo watershed has not been estimated. However, given low trap efficiencies of the reservoirs, that the channels downstream of them are incised and have minimal sediment storage, and that the 5-mi flood control channel leading to the Bay has not required dredging, then it might be assumed that the delivery to the Bay is at least equal to the yield from Crow Creek watershed. A substantial delta is forming at the mouth of San Lorenzo Creek. This amount of sediment spread across the intertidal habitats within one mile of the mouth of the creek would raise them about 7 mm/yr, which is more than 3x the current rate of sea level rise and more than half the greatest rate predicted for this century due to global warming.

<u>Comparing Watershed Yields Based on Land Lowering Rates</u>. The land lowering rate of a "sediment shed" is calculated by dividing its sediment yield by its surface area. This allows comparisons of sediment yield for watershed of different sizes. Differences in lowering rates are largely attributed to differences in geology, land use, and tectonic uplift. Figure 1 shows lowering rates for lands upstream of reservoirs (derived from bathymetric data) and for a few local watersheds where sediment budgets have been constructed. Missing from this kind of larger picture of the Bay, is a comprehensive analysis of the amount of sediment that actually reaches and is deposited on its intertidal habitats from local streams.

<u>Conclusions</u>. Sediment source analyses and simple sediment budgets indicate that local watersheds can yield substantial volumes of sediment to San Francisco Bay. These estimates justify more exacting studies of the sources of sediment in intertidal zones, where the expectation is that the relative abundance of local sediment will decrease with distance away from its source. The tidal flats and marshes farthest from any local watershed might entrap a mixture of sediments from many sources, including re-suspended sediments from other tidal flats and Delta throughput. Intertidal habitat along the tidal reaches of local creeks might rely almost entirely on sediment from their own watersheds. A comprehensive Bay-wide analyses of the various sources of intertidal sediment would likely show that conservation of the Bay's intertidal habitats in the long-term will depend on how local watersheds are managed as sediment sources.

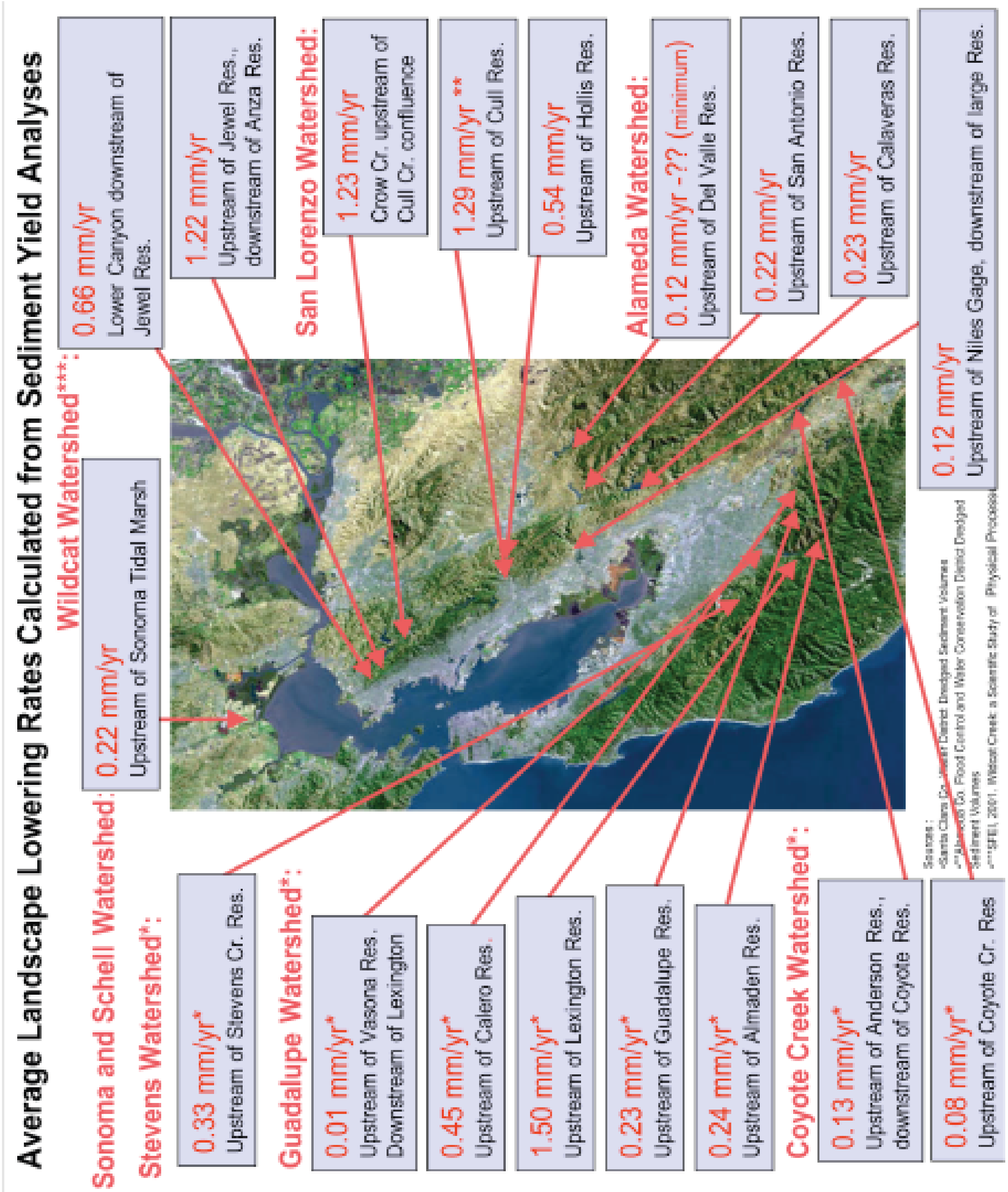

Figure 1. Average lowering rates for lands upstream of reservoirs (derived from bathymetric data) and for a few local watersheds where sediment budgets have been constructed.

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Hydrodynamic Connectivity between Shallow and Deep Environments: A First-order Control on Phytoplankton Blooms in South San Francisco Bay

Lisa V. Lucas (llucas@usgs.gov) and Janet K. Thompson, U.S. Geological Survey,
Jeffrey R. Koseff and Stephen G. Monismith, Stanford University

Before restoration of tidal action to its salt pond areas began, South San Francisco Bay (South Bay) was comprised of primarily two habitat types: the deep (10-15 m) central channel and the shallow (~2 m) shoals on either side (Fig. 1). Except for isolated special studies, measurements of water quality and biota in the South Bay are generally from the deep channel (http://sfbay.wr.usgs.gov/access/wqdata/). The main questions driving this study were: 1) Can processes in the seldom-studied shoals affect the phytoplankton measured in the channel? 2) Do processes in one compartment (channel or shoal) represent a more important control on system-wide phytoplankton bloom dynamics than processes in the other compartment?

A simplified conceptual model of the South Bay helps us understand how one compartment may influence the other and why one compartment may be more influential on the overall system than the other (Fig. 2). The base of the aquatic food web, phytoplankton, are suspended, single-celled plants. As such, they require light for photosynthesis and growth, and they provide sustenance to grazers within (zooplankton) and at the bottom (clams) of the water column. In a depth-averaged sense and for a given turbidity, light is greater and photosynthesis is generally faster in the shallow water. And the time necessary for a given community of bottom-dwelling clams to filter through the entire overlying water column is shorter in shallower water. The inverse relationship between important depth-averaged biological rates and water column depth means biology will generally be faster in the shallows (Lucas and Cloern 2002; Lucas et al. 2008).

Hydrodynamic processes (e.g., tidal and wind-driven currents and vertical turbulent mixing) regulate the rate of phytoplankton transport between different light/grazing regimes. Numerous processes can induce lateral transport between channel and shoals. Vertical turbulent mixing can provide communication between the upper and lower water column. Density stratification, which occurs primarily in the channel due to variations in salinity or temperature, can inhibit vertical mixing, thereby isolating phytoplankton in the upper water column from the light-poor, clam-rich lower region.

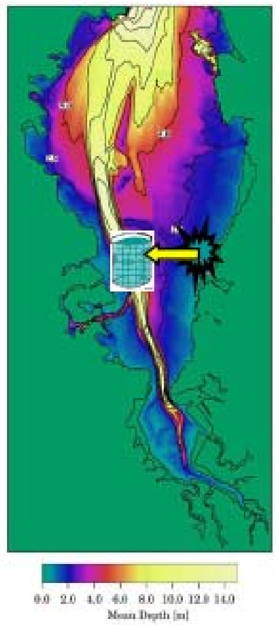

Fig. 1. Bathymetry contours of South San Francisco Bay, before opening of salt ponds. Overlain graphics suggest that processes in one portion of SSFB (e.g. shoals) can influence measurements taken in other location (e.g. channel).

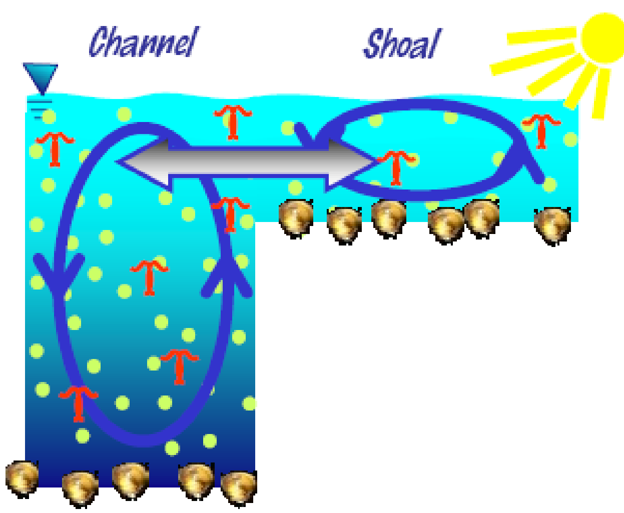

Fig. 2. Graphical depiction of conceptual model for phytoplankton dynamics in South San Francisco Bay. This is an idealized vertical-lateral cross-section of a deep channel and shallow shoal, between which hydrodynamic processes cause exchange of phytoplankton biomass (green dots). Other important processes include grazing by zooplankton (red suspended organisms) and clams (brown organisms at bottom), light driven photosynthesis and growth of algal cells, and vertical turbulent mixing (blue ovals and arrows).

We developed a Pseudo-two-dimensional (Pseudo-2D) numerical model of an idealized channel connected to an idealized shoal (Lucas et al., 2008). This numerical model captured vertical variability in relevant processes but assumed each major compartment to be horizontally homogeneous. The Pseudo-2D model incorporated all the processes contributing to variability in phytoplankton biomass that were included in the conceptual model discussed above: light-driven growth of phytoplankton, grazing on phytoplankton by zooplankton in the water column, grazing by clams at the bottom of the water column, vertical turbulent mixing of phytoplankton, vertical density stratification (only in the channel), and horizontal transport between the channel and shoal. The purpose of the model was to test the sensitivity of the combined channel-shoal system to various processes in each compartment and to address the two key questions above.

The first major lesson from the modeling study was that remote processes can control locally measured quantities. Model results showed that, for typical early spring conditions in the South Bay, zero lateral exchange of phytoplankton biomass between the shoal and channel allows a bloom to build up in the shoal, with no bloom developing in the channel. If exchange is turned on, biomass grown in the shoal is exported to the channel and induces a bloom there (Lucas et al., 2008).

The second major lesson was that shallow water processes drive system-level (channel and shoal) phytoplankton blooms in the South Bay, and deep water processes only modulate system-wide blooms. Modeled bloom development in both the channel and shoal were highly sensitive to even small changes in turbidity and clam grazing rate in the shoal. On the other hand, turbidity, grazing rate, and stratification in the channel could not control system-wide bloom occurrence, but modulated the magnitude of the bloom (Lucas et al., 2008). Measurements from an associated field study were generally consistent with model findings and showed large lateral gradients in phytoplankton biomass, with highest biomass generally over the shoals; this observation is consistent with the notion of shallow water driven phytoplankton blooms (Thompson et al., 2008).

What are the implications of these findings for a changing South Bay? This study taught us that shallow habitats can be especially influential for phytoplankton because some key biological reaction terms are fastest in shallow water. Therefore, modifications to the Bay that increase shallow water could increase the area of habitat with fast processes, and those processes may represent either growth or loss. This study also taught us that hydrodynamically connected habitats can strongly influence each other. Therefore, to understand observed variability within a habitat, we may need to look beyond the habitat's boundaries to the conditions within adjacent, connected environments.

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Discharge of Water and Suspended Sediments to the South Bay from Coyote Creek and Guadalupe River Watersheds: Water Years 2003 – 2005.

Lester J. McKee (PhD)

Watershed Program, San Francisco Estuary Institute, Oakland, Ca 94621; Lester@sfei.org; www.sfei.org

Conceptually, marshes on the edge of the San Francisco Bay can receive sediment from both fluvial (rivers, creeks, and storm drains) and tidal (Bay) sediment sources. Managers concerned with the restoration and maintenance of marshes are challenged with determining the amount and quality of sediment derived from each of these important sources. For the South Bay Salt Pond Restoration Project, Alameda Creek, Coyote Creek, and the Guadalupe River are the 1st, 2nd and 4th largest tributaries that enter San Francisco Bay from the Coast Range and together comprise 82% of the South Bay drainage area south of Alameda Creek on the East Bay and San Francisquito Creek on the Peninsula. The U.S. Geological Survey (USGS) in partnership with San Francisco Estuary Institute (SFEI), with funding from the Clean Estuary Partnership (CEP), the Regional Monitoring Program (RMP), Santa Clara Valley Water District (SCVWD), United States Army Corps of Engineers (ASACE), the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), and the South Bay Salt Pond Restoration Program, have been measuring suspended sediment discharge in Coyote Creek and Guadalupe River. Alameda County staff, in partnership with the USGS, have been monitoring suspended sediments in Alameda Creek.

The objective of this paper -is to provide information on the amount, seasonality, and quality of fine suspended sediments entering South San Francisco Bay from Coyote Creek and Guadalupe River. These watersheds will be compared to a small 2.15 km^2 watershed near Fremont to help us to understand the potential supply of sediment from the smaller watersheds that drain the remaining 18% of the South Bay land area. The data available to inform this discussion are those collected by USGS and its funding partners during Water Years (WYs) 2000 - 2005. A water year starts on October 1st of each year and ends on September 30th of the following year and the year is denoted by the ending date. Data on sediment quality are derived from studies conducted by SFEI and its partners for WYs 2003 - 2005. Both USGS and SFEI efforts to characterize these river systems continued during WY 2006, but these data are not yet finalized for publication.

Water discharge during this period was generally below average. Annual suspended sediment loads varied in a single watershed by as much as 22 times (Table 1). This variation may seem large, but for Bay Area river systems this not the case. For example, a watershed like the Guadalupe River would likely exhibit a variation of closer to 2,000 times from the driest year to the wettest year under its full range of flow conditions. This lack of observed variability compared to the reasonably hypothesized variability means that, with the current data, it is very hard to predict what the average or total sediment flow might be over the planning horizon for salt pond restoration. What we can say is that it is likely larger than the numeric averages calculated from the existing data (again see Table 1). On average, approximately 95% of the annual sediment transport occurred during the winter season in Coyote Creek, Guadalupe River, and the small Fremont watershed, as is the norm in the Bay Area (McKee et al., 2003). Thus, it seems likely that sediment supply from rivers, creeks, and storm drains to restoration sites would also be winter dominated. Since the Coyote Creek gage is located in the the South Bay waters close to the Bay margin, which means that some of the sediment mass shown in Table 1 is mechanically removed before it reaches the Bay or a potential restoration site. This may be advantageous if the sediments removed are contaminated with mercury or other urban pollutants.

Suspended sediment grain size is mostly fine (<0.0625 mm). Greater than 90% of suspended sediment in both Coyote Creek and Guadalupe River is silt and clay size material and 88% of suspended sediment is <0.02 mm in the Guadalupe River. The Fremont watershed differs slightly relative to Coyote Creek and Guadalupe River due to its small watershed size and steep stream slope; only 77% of suspended sediment transported is finer than 0.0625 mm. These data suggest that most of the suspended sediment loads are likely to pass through dredged channels and onto the Bay margin where they might be available for wetland maintenance or restoration.

Mercury concentrations in suspended sediments are approximately 10x greater in the Guadalupe River (2 mg/kg on average) compared to Coyote Creek (0.2 mg/kg on average). The Guadalupe River is known to be contaminated by mercury associated with the New Almaden Historic Mining District (now the Quick Silver County Park), whereas Coyote Creek mainly receives mercury from atmospheric and urban sources, and mining sources are minor. It is reasonable to assume that sediment in the Fremont watershed would also exhibit low in mercury concentrations although we presently have no data to support this hypothesis. Other small urban watersheds on the Bay margin of the South Bay where there is a history of industrial activity might exhibit particulate mercury concentrations that are intermediate between Coyote Creek and Guadalupe River, but again there is no data to determine the hierarchy of contamination.

Although we are lucky to have very good quality USGS water and suspended sediment data records for several of the South Bay watersheds, data interpretation is made difficult by short records (2-4 WYs), which were 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.

Table 1. Annual measured suspended sediment load variation (metric tonnes) in three South Bay watersheds. The average was calculated on the basis of data collected and, given climatic variability, is not reflective of the longterm average or even the relative contributions from each system.

	Coyote Creek at Highway 237 ($830\ km^2$)	Guadalupe River at Highway 101 ($414\ km^2$)		Zone 6 Line B at Warm Springs Boulevard ($2.15\ km^2$)
Water Year	Suspended Sediment	Suspended Sediment	Bed Load Sediment	Suspended Sediment
2000				19,696
2001				8,402
2002				906
2003		10,807		
2004	6,571	8,579		
2005	10,162	4,918	1,509	
Average	8,367	8,101		9,668

References

McKee, L., Leatherbarrow, J., Pearce, S., and Davis, J., 2003. A review of urban runoff processes in the Bay Area: Existing knowledge, conceptual models, and monitoring recommendations. A report prepared for the Sources, Pathways and Loading Workgroup of the Regional Monitoring Program for Trace Substances. SFEI Contribution 66. San Francisco Estuary Institute, Oakland, Ca.

Sediment Supply and Demand for Salt Pond Restoration

David H. Schoellhamer (dschoell@usgs.gov), James L. Orlando, Scott A. Wright, and Larry A. Freeman, U.S. Geological Survey, Sacramento, California

The South Bay Salt Pond Restoration Project will breach levees to restore tidal action to salt ponds. Sediment that enters a restored pond through a breach will tend to deposit on the bottom because the water velocities in the pond will be less than in the adjacent sloughs and South Bay. Thus, a restored pond will accumulate or 'demand' sediment and the elevation of the pond bottom will increase. Restored pond elevations must be greater than mean tide level (MTL) to allow vegetation to grow and create the desired tidal marsh. Sediment will come from tributary streams and the South Bay. Restoration success depends on sufficient sediment supply to meet the sediment demand created by restoring tidal action to subsided ponds. If sediment demand is greater than supply, existing habitats could erode.

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). The relations between streamflow and sediment supply determined by Porterfield have been the only means available to estimate present (2006) sediment supply from the watershed. In this study, we compared recently measured sediment loads with water year 1958-1962 measurements to determine if sediment supply from the watershed has changed and whether the 1958-1962 relations are still valid. We also compared recent sediment supply to pond volume below MTL to determine if the local watershed provides enough sediment to fill the ponds.

To test how well 1958-1962 relations estimate sediment supply today, we compared measured sediment supply from the Guadalupe River (Fig. 1) in water years 1958-1962 and 2003-2005. During the 45-year interval between measurements, sediment supply decreased by a factor of four for high flows and a factor of eight for low flows (Fig. 2). Urbanization of the watershed has likely decreased erodible surface area. Thus, we can not depend on sediment-supply data and relations from South Bay watersheds circa 1960 and current data are needed.

Sediment demand was estimated by measuring and calculating the pond volume below MTL, equal to 31 to 33 million m^3, over 99% within the Alviso ponds (Fig. 1). The five most subsided ponds contain one-half of this volume. Thus, most ponds are high enough or nearly high enough to support tidal marsh now and restoration of only a few deep ponds would increase sediment demand and potentially erode existing habitat.

The pond volume below MTL is over 1,000 times greater than the volume of sediment supplied from the watershed in a year. The measured sediment load from the 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 or 0.024 million m^3. To successfully restore the deep Alviso ponds within a century, about 30 million m^3 of additional sediment from the Bay is needed.

These results provide several lessons for resource managers restoring tidal marsh in the South Bay:

- Gages to measure sediment supply from the watershed are needed.
- Sediment demand is not a deterrent to restoration of most ponds.
- Restoration of the most subsided ponds would increase sediment demand and potentially erode existing habitat.
- When the first deep pond is restored, use adaptive management to monitor whether erosion is a problem and to determine whether additional deep ponds can be restored without eroding existing habitat.

References

Porterfield, G., 1980, Sediment transport of streams tributary to San Francisco, San Pablo, and Suisun Bays, California, 1909–1966: U.S. Geological Survey Water-Resources Investigations Report 80-64, 91 p.

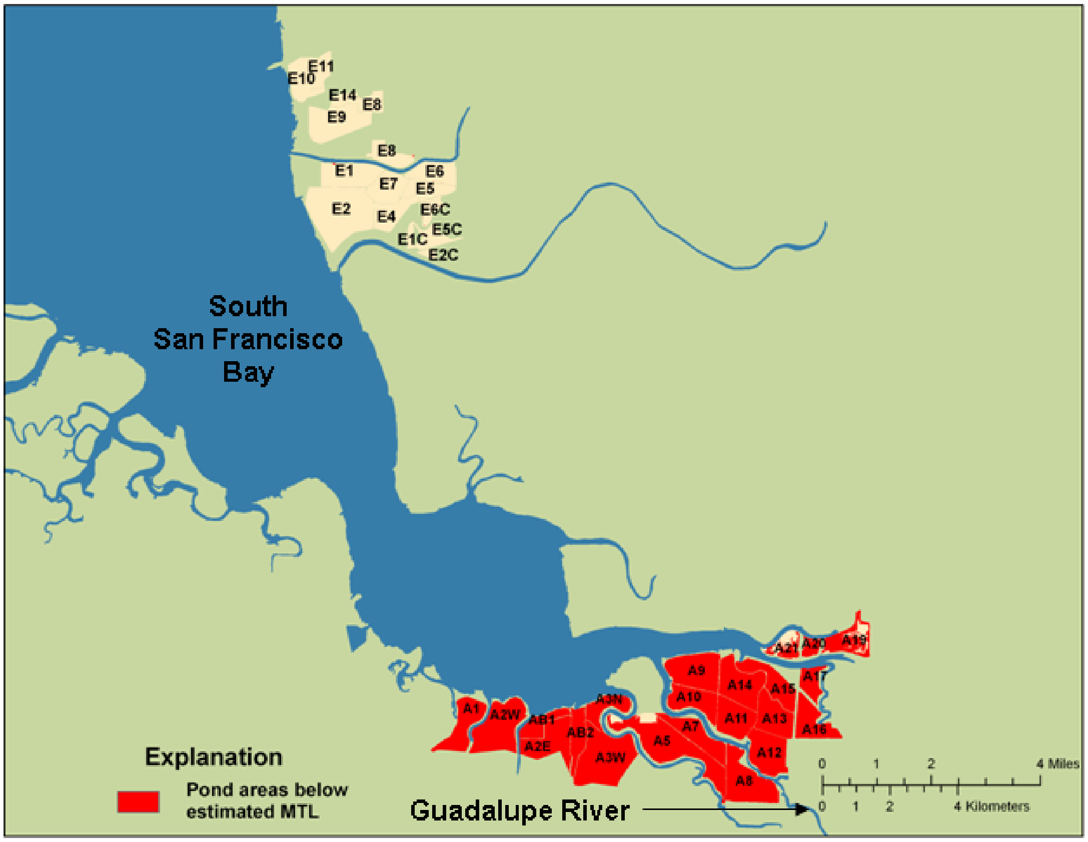

Figure 1. Alviso (A) and Eden Landing (E) salt ponds. Pond areas below mean tide level (MTL) are in red and those at or above MTL are shown in tan.

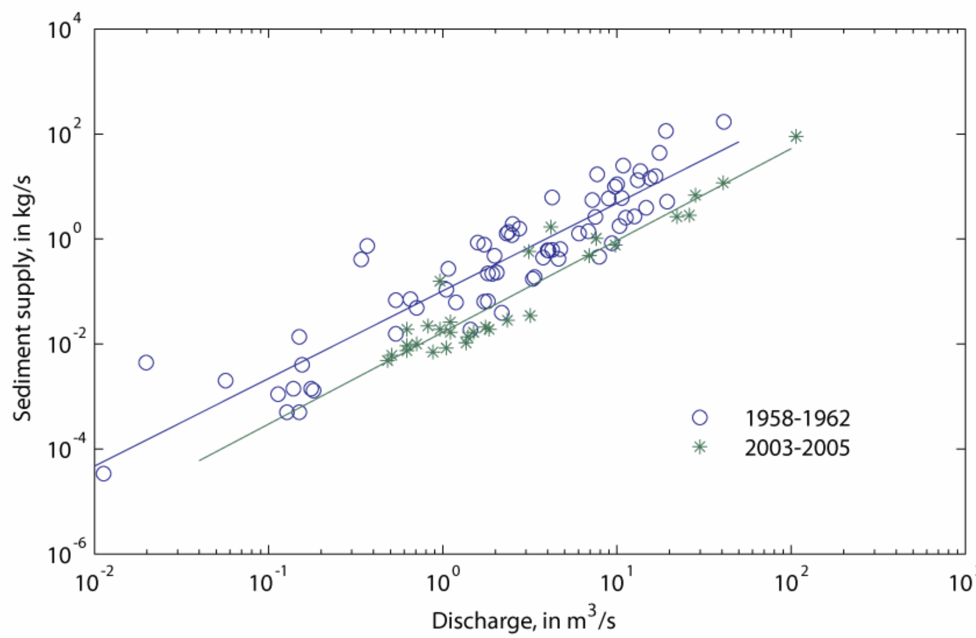

Figure 2. Suspended sediment supply, Guadalupe River, water years 1958-1962 and 2003-2005.

Degradation of Water Quality by Bird Feces in and around Managed Wetlands

Gregory G. Shellenbarger[1], and Alexandria B. Boehm[2]
[1]US Geological Survey, CA Water Science Center, Placer Hall, 6000 J Street, Sacramento, CA 95819, (916) 278-3191; gshellen@usgs.gov
[2]Dept. of Civil and Environmental Engineering, RM. 189, Jerry Yang & Akiko Yamazaki Environment & Energy Building, Stanford University, Stanford, CA 94305-4020

This abstract was written in 2006 when the study was underway. The study was completed in 2007. Full details about the work are available in the following reference or by contacting Greg Shellenbarger for a copy of the published article:

Shellenbarger, G.G., N.D. Athearn, J.Y. Takekawa, and A.B. Boehm. 2008. Fecal indicator bacteria and *Salmonella* in ponds managed as bird habitat, San Francisco Bay, California. Water Research, 42: 2921-2930. (doi:10.1016/j.watres.2008.03.006)

The South Bay Salt Pond Restoration Project in San Francisco Bay is a multi-faceted project with a major goal of habitat restoration. Habitats that support resident and migratory birds, in particular, are considered to be of high ecological value. Another goal of the restoration project is to provide public access and recreation in the project area. Several of the Alviso salt ponds, which are in a publicly-accessible section of the Don Edwards San Francisco Bay National Wildlife Refuge within the project area, are currently home to year-around bird residents as well as large numbers of seasonally migrating or wintering waterfowl.

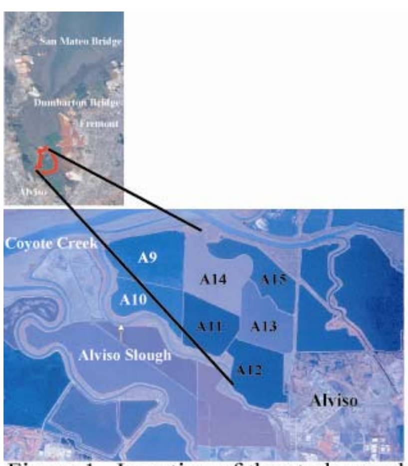

Figure 1. Location of the study ponds A9 and A10 and adjacent sloughs at the southern end of San Francisco Bay.

Bird feces can carry fecal indicator bacteria (FIB), specifically total coliforms (TC), *Escherichia coli* (EC), and *Enterococcus* (ENT), that are identical to the FIB in human waste. Although FIB generally are not themselves pathogenic, they indicate the potential presence of pathogens and epidemiological studies show that exposure to FIB during recreation in water correlates with increased risk of acquiring various diseases, including gastrointestinal and respiratory illnesses. Although past epidemiological studies were conducted in water polluted by sewage and urban runoff, but not specifically in bird-feces-polluted waters, bird feces-polluted waters also may pose a threat to human health. There are a number of diseases that potentially can be transmitted from birds to humans, including salmonellosis and campylobacterosis (infectious agents *Salmonella* spp. and *Campylobacter* spp., respectively).

Both *Salmonella* and *Campylobacter* have been isolated from bird feces that were deposited in the environment along wetlands in southern California.

Because of the large, seasonal bird populations in the Alviso pond system and the fact that some of the Alviso ponds now discharge to sloughs, there is potential for the discharged water to be of reduced quality, as indicated by the presence of FIB. In addition, recreation in or around the ponds creates a potential route of human exposure to FIB and pathogens by way of incidental ingestion or inhalation of slough or pond water.

Two ponds in the Alviso pond system, A9 and A10, and the adjacent sloughs (Coyote Creek and Alviso Slough) serve as the study area for this project. Four weekly sampling events for the winter sampling period took place in February and March 2006. Water samples were collected from 10 locations adjacent to the levee in each pond and from 5 locations in the adjacent sloughs (one sample from Coyote Creek and four samples from Alviso Slough). Five additional water samples were collected to analyze for the presence of *Salmonella*; two were collected from each pond, and one was collected from Alviso Slough. Samples for *Salmonella* were not collected during the first weekly sampling event. Sampling was done during nighttime high tides to minimize the potential for sunlight to reduce the bacterial concentrations. Some replicate samples for FIB analysis were collected to document the variability associated with the collection and enumeration methodologies. Water samples were analyzed for FIB using Colilert®[1] (TC and EC) and Enterolert™ (ENT), which are commercially available analytical microbial test methods that are listed by the EPA as approved for compliance monitoring. *Salmonella* presence or absence was determined using modified EPA Method 1682, and presumptive positive isolates were confirmed using Polymerase Chain Reaction (PCR) techniques. Bird use of the ponds was determined by conducting high-tide bird surveys on the ponds. The surveys typically were conducted during the day preceding each nighttime water-sampling event.

The relationship between winter and summer bird use of Alviso ponds A9 and A10 and FIB concentrations in these ponds and their adjacent sloughs currently is being examined. Preliminary results from the winter sampling period show that 89 to 100 percent of the slough samples and 0 to 28 percent of the pond samples exceeded the California water-quality standards for recreational marine contact (REC-1) for TC, EC, or ENT. Average TC concentrations always were higher in

[1] The use of firm, trade, and brand names in this document is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Pond A9 than in Pond A10 (as was the bird use), while average EC and ENT concentrations typically were similar in the two ponds. Bird use of the sloughs was not measured. FIB concentrations showed a relatively strong negative correlation with salinity. The human pathogen *Salmonella* was isolated from two of three slough samples and from one of 12 pond samples. Additional analysis of FIB concentrations and bird use of the ponds will be performed after the summer sampling period is completed.

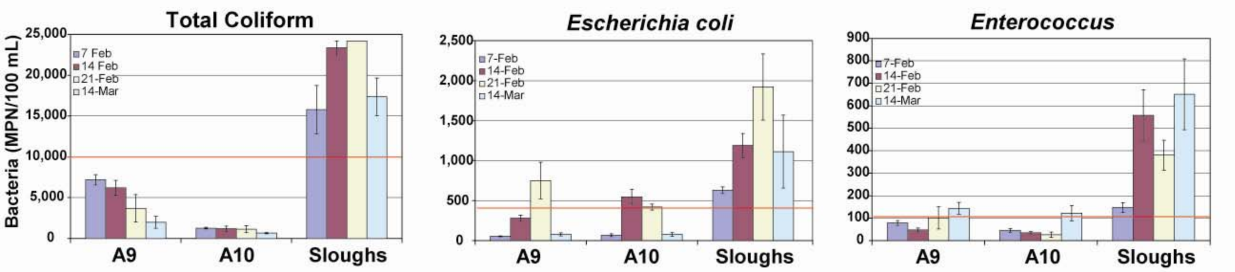

Figure 2. FIB results from winter sampling in Ponds A9, A10, and the adjacent sloughs. Bacterial counts are presented using Most Probable Number (MPN), a statistical estimate of the bacterial count. The red horizontal line on each plot represents the California REC-1 standard for each indicator. Error bars depict one standard error.

This initial study is intended to explore the potential link between bird use of the Alviso ponds and the water quality in the ponds as measured by FIB. Although this study is still underway, the preliminary results suggest that, at least during the winter, FIB concentrations in the ponds are lower than those in the sloughs. Water that discharged from the ponds during this period likely would not have an adverse effect on water quality in the slough. High FIB concentrations in the sloughs can come from local or upstream and watershed sources (Guadalupe River watershed) that are habited by birds and mammals. In addition, *Salmonella* was isolated from pond and slough water. The risk associated with recreation in the presence of *Salmonella* in these habitats, however, has not been determined.

Coyote Creek and the Island Ponds: Tides, Salinity and Suspended Sediment

Mark Stacey & Lissa MacVean, Civil & Environmental Engineering Department, University of California, Berkeley; mstacey@berkeley.edu

The South Bay Salt Pond Restoration Project involves the restoration of habitat that has a surface area comparable to the portion of South San Francisco Bay south of the Dumbarton Narrows (see first inset in Figure 1). As such, the connection between the restoration project and the estuary holds the potential to significantly alter the estuarine system itself, including changes to tidal dynamics, the salinity distribution, sediment dynamics, and the ecosystem as a whole. To understand how restoration at the scale of the adjoining estuary may alter the estuarine system, we have undertaken a series of studies in Lower Coyote Creek adjacent to "the Island Ponds" over the past year to examine how breaching of those ponds influenced Coyote Creek.

Data Collection. In winter and spring of 2006 (early March until mid-May), during the period that the Island Pond breaches were opened, we deployed instruments at 3 stations along the axis of Lower Coyote Creek (Figure 1). At each station, we collected time series of velocity, salinity, temperature, depth and optical backscatter. At station 1, an RD Instruments Acoustic Doppler Current Profiler (ADCP) collected profiles of water velocity every 10 minutes and conductivity-temperature-depth-optical backscatter sensors (CTD-OBS) were deployed both near the bed and near the surface (10 minute resolution). At the other two stations, rather than velocity profiles, two point velocity measurements were made using Sontek and Nortek acoustic Doppler velocimeters (ADVs; bursts every 5-10 minutes) and co-located CTD-OBS sensors measured salinity, temperature, depth and optical backscatter every 10 minutes. All data streams returned complete, although there are intermittent periods of bad data from one of the CTD sensors.

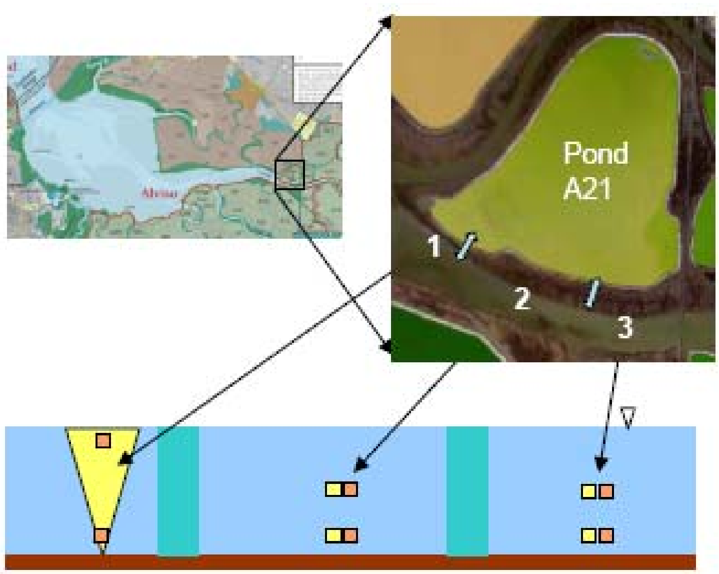

Figure 1. Experiment location and Instrument Deployment. Three instrument locations noted, schematic in lower panel represents ADCP profiler and two CTD-OBS sensors at station 1 and two point velocity measurements with CTD-OBS at stations 2 and 3.

Tidal Dynamics and Salinity Distribution. The observations collected in winter and spring of 2006 spanned a large freshwater flow event on April 1. We will therefore present our analyses for "dry" and "wet" periods, with the dry period preceding the April 1 runoff event and the wet period being the weeks following that event. During both periods, the tidal dynamics are representative of a standing wave in Coyote Creek, with velocity and depth out of phase (Figures 2a and 2c). The result is that high water in Coyote Creek, which is when waters are likely to exchange into the Island Ponds, occurs at the end of the flood tidal phase.

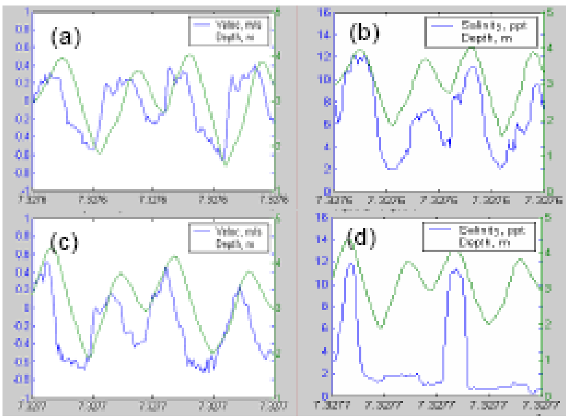

Figure 2: Time series of depth and velocity (panels (a) and (c)), and depth and salinity (panels (b) and (d)) measured at station 2 during dry conditions (panels (a) and (b), March 23-24) and wet conditions (panels (c) and (d), April 3-4).

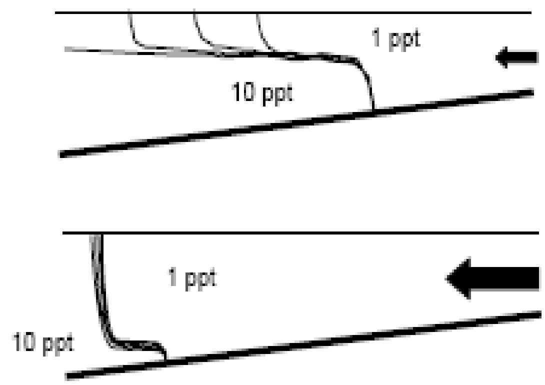

Figure 3: Schematic of salinity distribution in Coyote Creek. Upper panel shows moderate flows, lower panel for high flows.

The transport of scalars by the tidal currents can be illustrated by looking at the time variability of salinity. In Figures 2b and 2d, salinity and depth are seen to be in phase, with the highest salinities occurring at high water. This is representative of tidal advection of the salinity gradient in Lower Coyote Creek, such that the waters adjacent to the Island Ponds at high water appear are sourced from down-estuary.

Comparing "wet" and "dry" periods, we see a profound difference in the salinity distribution. Although the peak salinities are not that different between these two periods (Figure 2b compared to Figure 2d), the wet period has a much more compressed salinity field. Vertical salinity differences at each station (not shown) indicate a strongly stratified water column during the "dry" periods, but a more well-mixed water column following the run-off event on April 1. These observations lead us to hypothesize a salinity distribution as shown in the schematic of Figure 3, which shows a strongly stratified salt wedge during the dry periods, but the wedge is pushed down-estuary during the wet periods and a sharp salinity front results.

Suspended Sediment. The extreme salinity variations evident in Lower Coyote Creek and the associated salinity gradients allow us to use salinity as an indicator of water source, with more saline waters being "bay" waters and fresher waters being "upstream" waters. The upstream waters, however, have multiple sources, including wastewater returns and the natural watershed. To distinguish these sources, we look at the relationship between temperature and salinity (Figure 4). During dry periods (Figure 4a and 4b), only two distinct water masses are evident: warm, fresh waters sourced from upstream and cool, saline waters sourced from down-estuary. During wet periods (Figures 4c and 4d), however, a 3rd water mass is evident which is cool and fresh; we hypothesize that this represents the runoff from the Coyote Creek watershed, while the warm, fresh waters are more likely wastewater returns.

This structure allows us to distinguish between sources of suspended sediment as well, which is color-coded in Figure 4. We find that the highest suspended sediment concentrations are, in fact, associated with the cool, fresh water that are suggestive of the watershed. Unfortunately, these high suspended loads are adjacent to the Island Ponds at low water, and are unlikely to be exchanged with the restoration sites. Instead, the high water periods in lower Coyote Creek are associated with the cool, saline water mass, so suspended sediments in the water column at that time are more likely sourced from down-estuary.

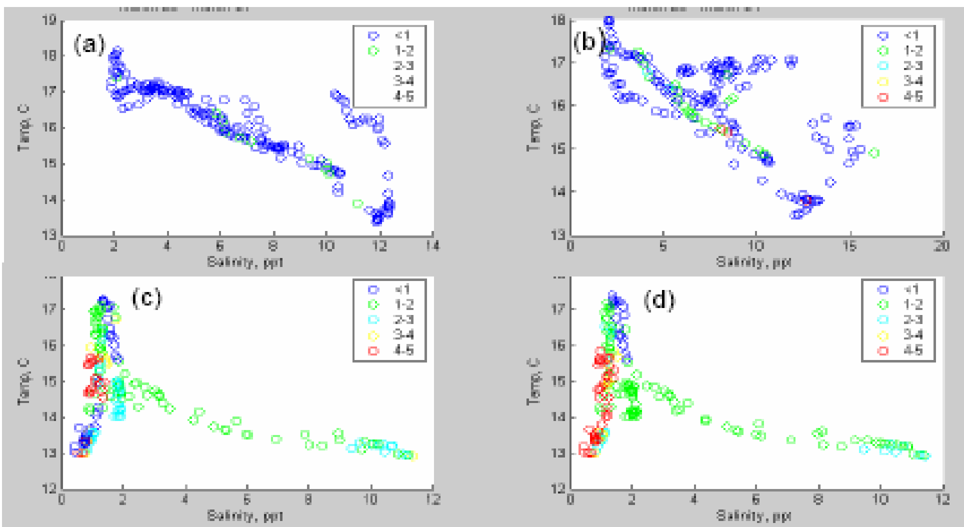

Figure 4: Relationship between temperature and salinity for dry conditions (panels (a) and (b)) and wet conditions (panels (c) and (d)) at station 3 (near-bed sensors in (a) and (c); upper sensors in (b) and (d)). Colors indicate suspended sediment concentration.

Summary and Conclusions. Tidal dynamics in Lower Coyote Creek are characterized by a standing wave that advects scalars such as salinity and suspended sediment along the creek. High water occurs very near the end of flood tide, and we suspect that this period dominates the transport into the restoration sites. As a result, the Island Ponds should receive maximum salinity waters and estuarine-sourced sediments. The return flow from the ponds to the channel is expected to occur later in the ebb tide, which creates the potential for tidal trapping of salt by the ponds leading to additional salt intrusion into Lower Coyote Creek. Unfortunately, the freshwater flow event of April 1 overwhelmed this subtle signal, and we will have to rely on modeling analysis to explore this effect. From the perspective of suspended sediment, we believe that temperature-salinity water mass analysis holds promise in diagnosing the sources of sediment, and it suggests that watershed sourced sediments flow past the restoration site and must be recycled in the estuary before making it to the Island Ponds. This hypothesis will be explored further with a study in fall of 2006 that looks at flow through one of the breaches in detail.

VEGETATION

From: Binard, et al. (this document)

Vegetation Coverage in Cooley Landing Salt Pond Restoration Area, Menlo Park, CA

Kinsley Binard[1], Kenneth Chiang[1], Michael Rafferty[1], Phillip Greer[2], and Justin Semion[2]
[1]S. S. Papadopulos & Associates, Inc., San Francisco and [2]WRA, Inc., San Rafael, California

The Cooley Landing salt pond restoration area is located adjacent to the San Francisco Bay within the Ravenswood Open Space Preserve in Menlo Park, CA (Fig. 1). In the 1950s, a levee was constructed around the perimeter of a tidal wetland to form the 115-acre Cooley Landing salt production pond. Salt production was discontinued at the site in the 1980s and the site was purchased by the Midpeninsula Regional Open Space District (MROSD). MROSD allowed wetland mitigation to occur at Cooley Landing and in 2000, tidal circulation was re-introduced to the Cooley Landing restoration site (see photo). Tidal marsh restoration is expected to benefit a range of wildlife species, particularly the endangered California clapper rail (*Rallus longirostris obsoletus*) and the salt marsh harvest mouse (*Reithrodontomys raviventris*)

The restoration activities were expected to lead to sediment deposition and re-establishment of the tidal marsh surface and tidal marsh vegetation within a 10-year monitoring period. By restoring the connection with the Bay, restoration managers expected re-establishment of natural slough channels and full tidal circulation in the wetland. Biological aspects of the restoration were addressed with specific goals for native and non-native vegetation coverage as shown in the table below.

Variable	**Performance Criteria**
Native Vegetation	>10% salt marsh plant cover at end of Year 1, >40% cover at end of Year 3, >60% cover at end of Year 6 and >70% cover at end of Year 10.
Non-Native Vegetation	Less than 5% cover at project completion.

In order to meet the hydrological goals for the site, the Bay-side levee was lowered and breached at two historical channel locations. Natural channel development was encouraged by constructing “training berms” to direct tidal flows into the remnant natural channels and by constructing “cut-off berms” to block flows to the borrow ditches in the pond interior, which had been created when the perimeter levee was constructed. Based on monitoring conducted to date, the restoration project has been successful in creating the appropriate hydrologic conditions. The breach inlet channels have evolved rapidly and the re-occupation of the remnant historic channel system in the site interior has extended to the most upstream reaches of the channel system. Tidal circulation and sediment delivery to the marshplain have improved in response to tidal channel evolution, and tidal exchange is now comparable to natural marshes in the South Bay. The Cooley Landing restoration design has also successfully prevented significant channel formation in the borrow ditch along the outboard levee. Due to sedimentation, elevations in portions of the site are appropriate for establishment of marsh vegetation.

Despite the apparent success of the restoration project from a hydrologic perspective, the project has not been successful from a biological perspective. By 2006, the restoration project had not met the interim criteria for vegetative cover. Accretion rates on the marsh surface were lower than predicted for the first three years of monitoring resulting in little expansion of existing pickleweed (*Salicornia spp.)* cover at higher elevations and persistence of substantial subtidal areas. Areas that have accreted above Mean Sea Level have been colonized by both the native Pacific cordgrass (*Spartina foliosa*), and the non-native Atlantic smooth cordgrass (*Spartina alterniflora*) and its hybrids. *S. alterniflora* existed on the outboard portion of the levee surrounding the restoration area prior restoration activities and control of this cordgrass was a condition of project permits. Efforts to eradicate *S. alterniflora* and its hybrids in the restoration area have been ongoing. However, with existing regional conditions non-native *Spartina* cover threatens the ability of this project to reach its objectives.

S. alterniflora and its hybrids are invasive species threatening the San Francisco Bay Estuary. *S. alterniflora* is native to the East Coast and was reportedly introduced to the San Francisco Bay as part of early experimental marsh restoration projects. *S. alterniflora* readily hybridizes with and out-competes the native Pacific cordgrass, threatening the native cordgrass with local extinction. *S. alterniflora* and its hybrids are "threatening the ecological balance of the estuary and are likely to eventually cause the extinction of native Pacific cordgrass, choke tidal creeks, dominate newly restored tidal marshes, and displace thousands of acres of existing shorebird habitat" (Invasive Spartina Project, 2003). The non-native cordgrass and its hybrids are found on state, federal, municipal, and private lands and are spreading rapidly threatening the nearly 40,000 acres of tidal marsh and 29,000 acres of tidal flats that comprise the shoreline areas of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, Sonoma, and Sacramento counties (Invasive Spartina Project, 2003). *S. alterniflora* is able to colonize at lower elevations than native *Spartina*. This ability makes the newly restored tidal wetland, due to its lower substrate elevations, highly susceptible to invasion by *S. alterniflora* and its hybrids.

In 2001, agencies administered an initial application of herbicide to combat non-native *Spartina*, but plans for subsequent applications were cancelled as a result of a court decision, Headwaters Inc. vs. Talent Irrigation Districts, in early 2001. During the period when herbicide application was not allowed, manual control of all known *S. alterniflora* stands within the project area was conducted. The manual control plan consisted of mowing mature stands prior to seed formation and removing seedlings including rhizomes using a shovel, but these efforts were not adequately effective. In 2003, a transect along the inner levee in the southeast portion of the restoration area indicated an increased presence of non-native *Spartina* in the restoration area.

The Invasive Spartina Project (ISP), administered by the California Coastal Conservancy, is a coordinated regional effort among local, state and federal organizations dedicated to the elimination of non-native species of *Spartina*. Following the court decision, the ISP began the process of applying for a programmatic Statewide General NPDES Permit for use by agencies and land-owners that use aquatic herbicides for the control of *S. alterniflora*. This NPDES permit was obtained in 2004.

In 2004, with coverage under the NPDES permit obtained by the ISP, herbicide applications were re-initiated. With guidance from the ISP, herbicide treatments occurred in August 2004, September 2005, and August 2006 (Fig. 2). Efficacy of efforts through 2005 were low and, in 2005, a more effective herbicide, Imazapyr, was approved for use. Use of this new herbicide, along with improved application techniques including helicopter spraying of stands located in the inaccessible areas of the restoration site, are expected to result in better control.

These eradication efforts, however, will not ensure that non-native performance criteria for the project will be met, as ongoing colonization from the regional infestation of non-native cordgrass is likely to be a problem beyond the control of project managers. As the marsh surface in the pond accretes, the site will continue to be prime habitat for *S. alterniflora*. Currently Cooley Landing has approximately 46% coverage of salt marsh vegetation leaving over 62 acres for potential establishment of *Spartina*. The amount of *S. alterniflora* and its hybrids in the restoration area has increased every year since 2001 and project maintenance costs, originally estimated between $2,000 and $4,000 per year, have increased to more than $20,000 annually to deal with the invasion of *S. alterniflora* and its hybrids.

Overall, the restoration activities have been successful in converting the approximately 115 acres of the former Cooley Landing salt pond from degraded mudflat, open water, and muted tidal wetland habitat to fully tidal salt marsh habitat. The project has been successful in creating the appropriate hydrologic and geomorphic conditions to support marsh function and development. However, it is unlikely that the restoration project will meet its required performance criteria of 70% total vegetative cover and less than 5% non-native vegetation at the end of the 10-year monitoring period. The site has experienced lower than expected accretion rates resulting in slow expansion of coverage by vegetation requiring higher elevations and the continued presence of substantial subtidal areas. The regional infestation of *S. alterniflora* and its hybrids has impacted the restoration area and despite continued on-site eradication efforts, control of *S. alterniflora* and its hybrid clones on adjacent properties and regionally will likely be necessary before the vegetative performance criteria can be met.

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Invasive Spartina Project, 2003, Final Programmatic Environmental Impact Statement/ Environmental Impact Report San Francisco Estuary Invasive *Spartina* Project: *Spartina* Control Program, September.

Figure 1. Cooley Landing Salt Pond

Figure 2. Treating for non-native *Spartina*.

Marsh Plant Associations of South San Francisco Bay: 2005 Comparative Study

John Bourgeois, Ron Duke, Pat Boursier and Donna Ball, H.T. Harvey & Associates, 3150 Almaden Expressway, Suite 145, San Jose, California 95118

Acknowledgements: Neal Van Keuren, San Jose/Santa Clara Water Pollution Control Plant, Environmental Services Department, City of San Jose

Large-scale plant community changes in the remaining marshes of South San Francisco Bay were first observed in the 1970s. 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 using color infrared satellite imagery 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 (Alviso Slough) (Figure 1). Brackish marsh plant associations dominated the upper reaches of the Main Study Area, as well as the Reference Area. The transition reach segments comprise a mix of brackish and salt marsh while the lower reach segments are primarily dominated by salt marsh plant species (Figure 2). Although a similar distribution of habitats is noted in the Reference Area, brackish marsh habitats comprise a much greater proportion there than in the Main Study Area.

New marsh formation. The surface area of marsh habitat has increased by approximately 344 acres between 1989 and 2005 within the Main Study Area (upper, transition, and lower reaches combined). During the same period, approximately 90 acres of new marsh has formed in the Reference Area. This equates to a 26% increase in marsh acreage in the Main Study Area and a

54% increase in marsh acreage in the Reference Area between 1989 and 2005. An additional 200 acres of new marsh was documented in the Main Study Area between 1972 and 1989. Most of this marsh formation is occurring in the lower reach of the Main Study Area along Coyote Creek near Calaveras Point. Sediment accretion, and the resulting new marsh formation in this area, demonstrates the dynamic nature of marshes within the South Bay.

Marsh conversion. Within the Main Study Area, 94.3 acres of net conversion from salt marsh habitat to brackish marsh habitat has occurred since 1989, with most of this conversion occurring within the transition reach. In the Reference Area, 31.5 acres of net conversion from salt marsh habitat to brackish marsh habitat has occurred since 1989, with most of the conversion occurring in the middle portion of the Reference Area. This represents a much greater relative percentage in net conversion of salt marsh compared to the overall amount of salt marsh habitat within the Reference Area (35%) than within the Main Study Area (10%). Overall, the entire study area has become less saline since 1989, and the newly-forming freshwater marsh habitat in both the Reference Area and the Main Study Area indicates that freshwater influences are affecting all marshes in the vicinity.

Conclusions. Overall gains in salt marsh habitat in the last five years, particularly from 2001 to 2005, highlight the influence of multiple factors affecting changes in marsh vegetation communities in South San Francisco Bay. Primary among these factors is the increase in sedimentation resulting from the decrease in tidal prism (the volume of water that moves in and out of an area on a tidal cycle) that occurred when the salt ponds were levied off from the Bay. The plant community shifts, especially in the transition reach of the Main Study Area, demonstrate the dynamic nature of marsh response to reductions in salinity related to a changing tidal prism and freshwater inputs. As tidal restoration of former salt ponds in the South Bay occurs, we expect to observe shifts back toward salt marsh habitat. However, tidal restoration will increase tidal prism and may therefore also result in losses of some of the newly formed fringe marshes.

Application to the South Bay Salt Pond Restoration project. Historically, tidal marshes were the dominant habitats throughout much of the South San Francisco Bay. Coyote Creek and the adjacent channels, subject to tidal action, had abundant water flow in from, and out to, the Bay. This water flow continually scoured the channels and kept them relatively free of sediment. Prior to the 1940s, these channels were quite broad with extensive salt marshes on either side. After levees were built in the 1940s to create salt ponds, the dynamics of water flow began to change. In the 65 or so years since the construction of the levees, Coyote Creek has undergone dynamic changes, both physical and biological. Our long-term monitoring has shown that the marshes in the South Bay are quite dynamic and respond annually to changes in the physical environment, and geomorphic changes play a critical role in the distribution of marsh vegetation. A better understanding of the dynamic nature of these marshes is important in projecting future habitat development under the various restoration scenarios.

Update for 2008: There had previously been a net conversion from salt to brackish marsh since the beginning of this study in 1989. However, for the first time since this study began, we observed a large-scale conversion of brackish marsh to salt marsh (221.5 acres) during the 2007 monitoring year, and that conversion was prevalent across the entire Main Study Area. This large-scale conversion comprises the largest such shift seen since the study began in 1989. For more details, see the 2007 Comparative Study at http://www.sanjoseca.gov/esd/marsh-studies.asp.

Figure 1. 2005 Marsh Habitat Types of South San Francisco Bay

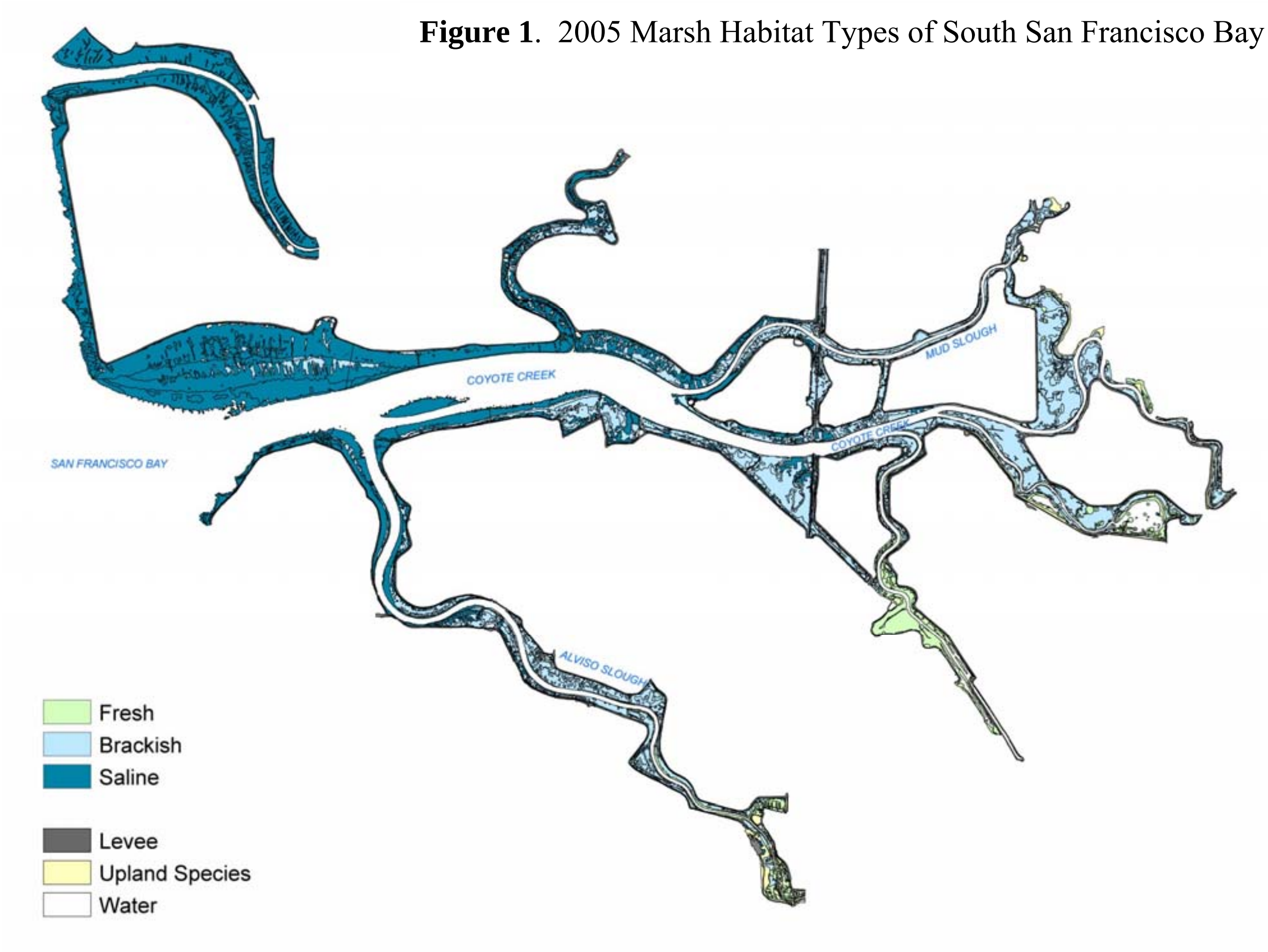
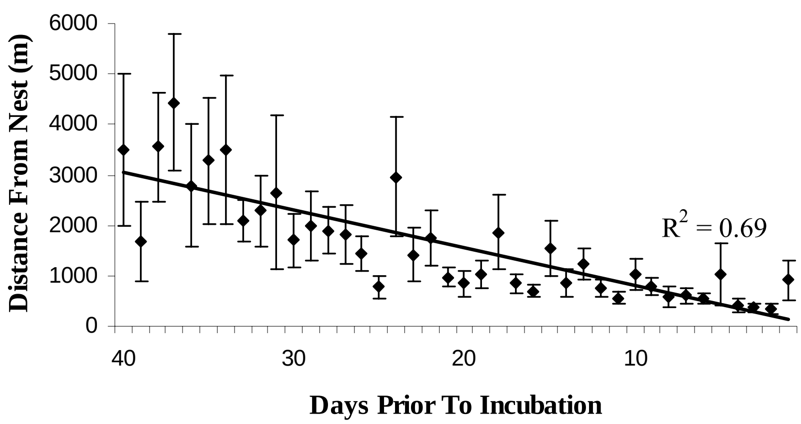


Figure 2. Salt Marsh at Calaveras Point.

WILDLIFE



From: Demers, et al. (this document)

Mercury Levels and Growth Rates of Forster's Tern Chicks in San Francisco Bay

Josh Ackerman[1], Collin Eagles-Smith[2], Terry Adelsbach[2], Julie Yee[3]

[1]U. S. Geological Survey, Western Ecological Research Center, Davis Field Station, One Shields Avenue, University of California, Davis, CA 95616, jackerman@usgs.gov
[2]U. S. Fish and Wildlife Service, 2800 Cottage Way, Suite W-2605, Sacramento, CA 95825
[3]U. S. Geological Survey, Western Ecological Research Center, 3020 State University Drive East, Modoc Hall, 3rd Floor, Room 3006, Sacramento, CA 95819

We examined mercury concentrations and growth rates of Forster's Tern chicks at four nesting colonies in the San Francisco Bay as part of a CalFed-supported study to examine mercury risks to avian reproduction. Using mark-recapture methods, we captured, banded, weighed, and measured 680 Forster's Tern chicks and recaptured 610 marked chicks in 2005. We captured all chicks within each breeding colony by hand every other week at Salt Ponds A1 and A8 (South Bay, Alviso salt pond complex) and weekly at Salt Pond A16 (South Bay, Alviso salt pond complex) and Salt Pond 2 in the Napa-Sonoma Marsh salt pond complex (North Bay). For each chick, we estimated age using a multiple regression developed from a subset of our data that included chicks with known hatching dates. We then calculated mass, wing, culmen, and tarsus growth rates. For mercury analysis, we collected down feathers from the rump when chicks were first captured (to represent mercury levels in the egg) and collected fully grown feathers from the breast of recaptured chicks (to represent mercury accumulated after hatching). We also collected blood and analyzed livers in a subset of these chicks.

Figure 1. Forster's Tern nest with two chicks hatching.

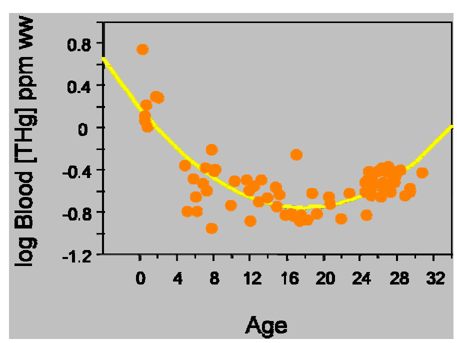
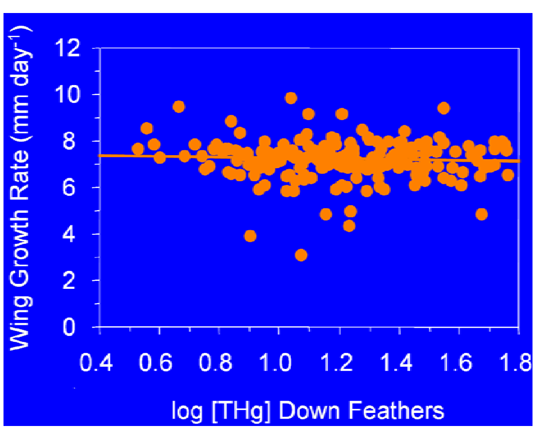


Figure 2. Total mercury concentrations in Forster's Tern chick blood as they age from hatching (0 days old) to fledging (about 28 days old).

Total mercury concentrations in the chicks' blood declined rapidly as they aged and grew feathers, but then increased just before fledging when their feather production slowed (line fitted with a second-order polynomial; R^2=0.62, N=75, P<0.0001).

Methyl mercury concentrations in collected chick livers differed among colonies (ANOVA: $F_{2,14}$=18.4, P=0.0001). However, chick growth rates were not related to methyl mercury concentrations in collected chick livers (all P>0.15). Furthermore, we found no relationship between wing growth rates of mark-recaptured chicks and total mercury concentrations in chick down (N=211, R^2=0.01, P=0.97), but we did find a negative relationship between mercury concentrations and wing growth rates in fully grown chick feathers (N=191, R^2=0.04, P=0.01).

These results indicate that even though mercury concentrations differed among sites, they did not appear to strongly influence Forster's Tern chick growth rates. However, we caution that we have not examined several other potential effects that mercury can have on reproduction, such as chick survival. Future studies are needed to assess the full range of effects mercury can have on avian reproduction because the observed mercury concentrations in Forster's Tern chicks are near adult toxic threshold levels. Such high mercury concentrations highlight the need to monitor this avian life stage during salt pond restoration activities, which could alter mercury dynamics within the estuary.



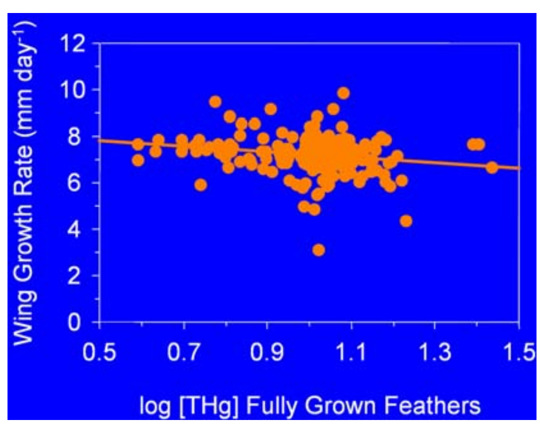


Figure 3 & 4. Total mercury concentrations in Forster's Tern chick down and fully grown feathers and their corresponding wing growth rates.

Mercury Accumulation in Black-necked Stilt Chicks in San Francisco Bay

Josh Ackerman[1], Collin Eagles-Smith[2], John Takekawa[3], and Terry Adelsbach[2]

[1]U. S. Geological Survey, Western Ecological Research Center, Davis Field Station, One Shields Avenue, University of California, Davis, CA 95616, jackerman@usgs.gov
[2]U. S. Fish and Wildlife Service, 2800 Cottage Way, Suite W-2605, Sacramento, CA 95825
[3]U. S. Geological Survey, Western Ecological Research Center, San Francisco Bay Estuary Field Station, 505 Azuar Drive, Vallejo, CA 94592

The San Francisco Bay has a legacy of mercury contamination from both mercury mining and gold extraction and this pollution may reduce reproductive success of some waterbirds breeding within the estuary. We examined mercury accumulation and depuration in Black-necked Stilt chicks (*Himantopus mexicanus*) as they aged, and used radio-telemetry to determine rearing sites for dietary uptake of mercury.

In 2005 and 2006, we collected Stilt chicks throughout the growth period from hatching to fledging during a two-week period from two sites in the South San Francisco Bay. The first site was New Chicago Marsh in the Alviso salt pond complex and the second site was Salt Pond 6A in the Eden Landing Ecological Reserve salt pond complex. New Chicago Marsh is known to have higher levels of mercury due to contaminated sediments, whereas Eden Landing salt ponds have lower mercury levels. After we captured stilt chicks, we sampled blood and feathers for total mercury concentrations. We also used radio-telemetry to track Stilt chicks from hatching until they fledged to determine sites of dietary mercury uptake. We attached tiny (<0.8 g) radio transmitters containing thermistor switches to the back of chicks with sutures and tracked radio-marked chicks daily from trucks equipped with dual 4-element Yagi antenna systems.

Figure 4. A Black-necked Stilt chick being raised in New Chicago Marsh.

Radio-marked Stilt chicks generally stayed and foraged near their nest site in New Chicago Marsh until they either fledged or were depredated. These results indicate that any accumulation of mercury as they aged came from within New Chicago Marsh. Although we did not radio-mark Stilt chicks at Eden Landing Ecological Reserve, we assumed that Stilt chicks there behaved similarly and remained near their site of hatching.

Total mercury concentrations in chick's blood declined rapidly as they aged, likely a result of mercury being deposited into growing feathers. As chicks continued to grow near the time of fledging and feather growth slowed, blood mercury concentrations increased rapidly as fewer growing feathers were available to sequester mercury (Fig. 1). This relationship occurred at both the high mercury study area in New Chicago Marsh (R^2=0.63, N=33, P<0.0001) and the lower mercury site at Eden Landing Ecological Reserve (R^2=0.46, N=29, P=0.001).

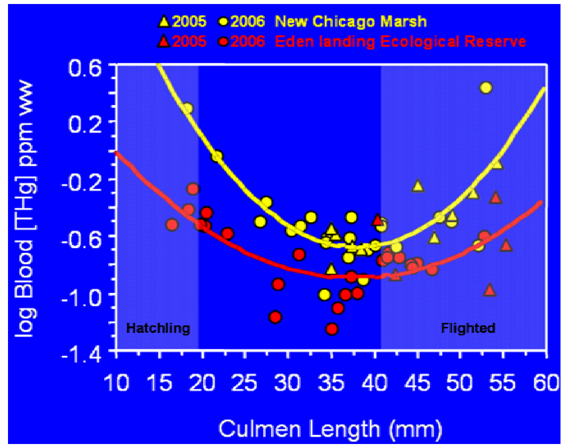


Figure 5. Total mercury concentrations in Black-necked Stilt chick blood from hatching to fledging at a high mercury contaminated area in New Chicago Marsh and a lower mercury area in Eden Landing Ecological Reserve.

We also assessed mercury concentrations in chick feathers, where much of the body burden of mercury can be harmlessly deposited during periods of feather growth. Total mercury concentrations were higher in down feathers collected just after hatching (N=63) than in fully grown feathers collected when chicks were more than two weeks old (N=15; $F_{1,76}$=5.86, P=0.02). Down feathers represent mercury burdens present in the egg, whereas fully-grown feathers likely represent mercury burdens present during growth as well as mercury acquired from dietary intake after hatching.

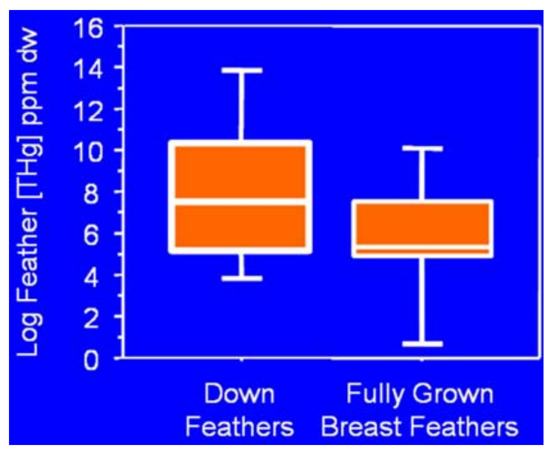


Figure 6. Total mercury concentrations in Black-necked Stilt chick feathers sampled either at hatching (down feathers) or when they were fully grown (breast feathers).

Our data indicate that Stilt chicks in the South San Francisco Bay depurate mercury into feathers as they grow, and then rapidly accumulate mercury just before and during fledging when feather growth slows. This pattern occurred at both high mercury and low mercury sites. Mercury concentrations in very young chicks and chicks close to fledging approached adult toxic threshold levels, whereas chicks that were one-to-three weeks old had lower levels of mercury due to depuration of mercury into growing feathers. Our results suggest that current mercury exposure levels may cause reproductive impairment in locally breeding waterbirds in the San Francisco Bay.

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

Josh Ackerman[1] and John Takekawa[2]

[1]U. S. Geological Survey, Western Ecological Research Center, Davis Field Station, One Shields Avenue, University of California, Davis, CA 95616, jackerman@usgs.gov
[2]U. S. Geological Survey, Western Ecological Research Center, San Francisco Bay Estuary Field Station, 505 Azuar Drive, Vallejo, CA 94592

The California Gull breeding population in the South San Francisco Bay salt ponds has increased exponentially by 25 fold over the past two decades, from <1,000 breeding birds in 1982 to over 25,000 in 2005 (Figure 1; Strong et al. 2004, San Francisco Bay Bird Observatory, unpublished data). The South Bay Salt Pond Restoration Project is initiating plans to restore 16,000 acres of salt ponds into tidal marsh or other habitats, which will likely cause the 25,000 breeding gulls to move to new nesting sites in these areas. In so doing, the gulls may displace the current populations of native breeding waterbirds. In addition, California Gulls are voracious predators and directly impact native breeding waterbirds by depredating eggs and chicks.

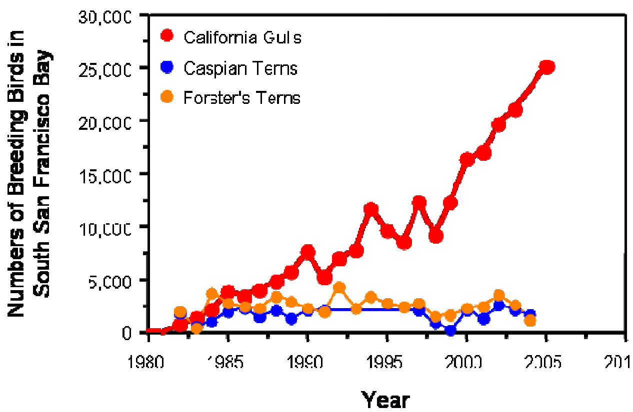


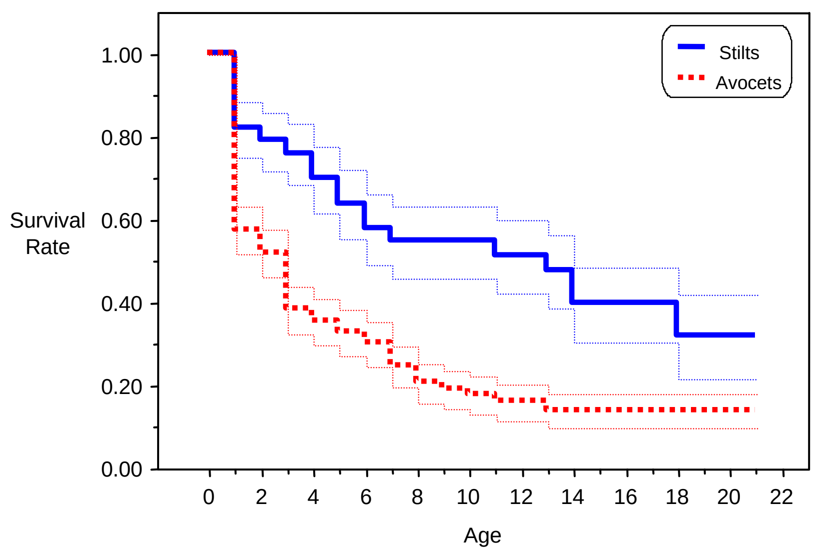
Figure 7. California Gull breeding populations have increased rapidly overly the past two decades while Caspian Tern and Forster's Tern populations have not. Data from Strong et al. 2004 and San Francisco Bay Bird Observatory.

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 pond complex (i.e., Salt Ponds 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) than in Salt Pond A8 for Terns (73%) and Avocets (35%), indicating higher nest predation rates in Salt Pond A8. We also deployed 18 nests containing fake plasticine eggs in Salt Pond A8 and used tooth or beak marks to identify the type of nest predator. All nine 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, currently estimated at over 18,000 breeding gulls.

To study chick survival, we radio-marked 74 Avocet chicks (in Salt Ponds 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%). Survival rates of Avocet chicks did not differ among Salt Ponds A8 and A16. Predation on Avocet chicks was mainly caused by avian predators (74%), mammals (16%), snakes (5%), and found down animal burrows (5%). The main avian predator of Avocet chicks was California Gulls, which depredated 39% of all chicks. 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 the longest 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.

Figure 2. Chicks were radio-marked at hatching and tracked until their fate was determined. Pictured here is a newly hatched Avocet chick with a tiny radio-transmitter attached to its back.

Figure 3. Survival rates of avocet and stilt chicks through 21 days after hatching estimated using telemetry.



Our data indicate that California Gulls are the major predator of Avocet chicks, but not Stilt chicks, and that gull predation on eggs can reduce the nesting success of Avocets and Terns, especially in Salt Pond A8, which is located near the large breeding population of California Gulls in Salt Pond A6. 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. Our data also illustrate the importance of habitat juxtaposition for successful breeding. Managers should consider arranging habitats so salt ponds with nesting islands are in close proximity to marsh habitats with emergent vegetation where shorebirds can find escape cover from aerial predators (similar to the positioning of Salt Pond A16 and New Chicago Marsh).

Space Use of American Avocets in South San Francisco Bay, California

Scott A. Demers and Mark A. Colwell, Wildlife Department, Humboldt State University, 1 Harpst Street, Arcata, CA 95521 (Current address: H. T. Harvey & Associates, 983 University Ave., Bldg D, Los Gatos, CA 95032)
John Y. Takekawa, U. S. Geological Survey, Western Ecological Research Center, San Francisco Bay Estuary Field Station, 505 Azuar Drive, Vallejo, CA 94592
Josh T. Ackerman, U. S. Geological Survey, Western Ecological Research Center, Davis Field Station, 1 Shields Ave, UC Davis, Davis, CA 9561

Understanding the space use of wetland-dependent species, such as the American avocet (*Recurvirostra americana*), is critical for the conservation and management of wetland habitats. The San Francisco Bay, California, is a site of hemispheric importance to migrating shorebirds (Stenzel et al. 2002) and has the largest known breeding population of American avocets on the Pacific coast (Rintoul et al. 2003). The majority of wetlands in San Francisco Bay have been highly modified, in part for the creation of salt evaporation ponds. Research has shown that avocets utilize artificial salt pond habitat for breeding, foraging, and roosting (Takekawa et al. 2001; Rintoul et al. 2003). As part of the South Bay Salt Pond Restoration Project, efforts are now underway to alter thousands of hectares of salt ponds to tidally influenced marsh. These changes to the estuary system will have unknown effects on shorebird populations, including resident avocets. Research on the space use and habitat requirements of American avocets in the San Francisco Bay would be beneficial for the conservation and management of this species.

Home range analysis is the most common method for examining space use by individuals (Plissner et al. 2000). Home range has been defined as the area used by an animal during normal activities such as food gathering, mating, and caring for young, with the exclusion of migration, emigrations, or erratic wanderings (Burt 1943; Brown and Orians 1970). Areas of high or concentrated use, greater than the expected uniform distributions, are considered core areas (Samuel et al. 1985).

In order to examine the space use of American avocets, we captured and radio-marked avocets in the spring of 2005 and 2006 with rocket-nets and net launchers at four roosting sites in the San Francisco Bay Estuary (Fig. 1). Radio-marked avocets were tracked using truck-mounted null-peak telemetry systems (Fig. 2). Additionally, direct visual observations were used to confirm breeding stages of marked birds and to locate their nesting site.

Figure 1. A radio-marked American avocet. **Figure 2.** Truck-mounted null/peak system.

Our results indicate that space use and movements vary with life-history stage (Fig. 3). As expected, core use areas during the incubation stage centered on nest locations. Pre-breeding home ranges (2347 ha) and core areas (443 ha) were greater than during the incubation stage (1322 and 259 ha, respectively), and brood-rearing home ranges (1090 ha) and core areas (246 ha) were similar to incubation stage. Post-breeding home ranges (3597 ha) and core areas (678 ha) were, in turn, greater than pre-breeding and incubation stages. Most avocet nests (93%) were located within their pre-incubation core area boundaries, whereas only 36% of nests were within post-breeding core areas. Additionally, distance between daily location and future nest sites decreased significantly as the number of days prior to incubation decreased, indicating that avocets were prospecting future nest sites, or engaged in pair-bonding behaviors prior to nesting (Fig. 4). Since the San Francisco Bay is characterized by a Mediterranean climate receiving nearly all rainfall during the cooler winter months, it is likely that avocets visit nesting sites in the late winter as water levels drop and temperatures increase.

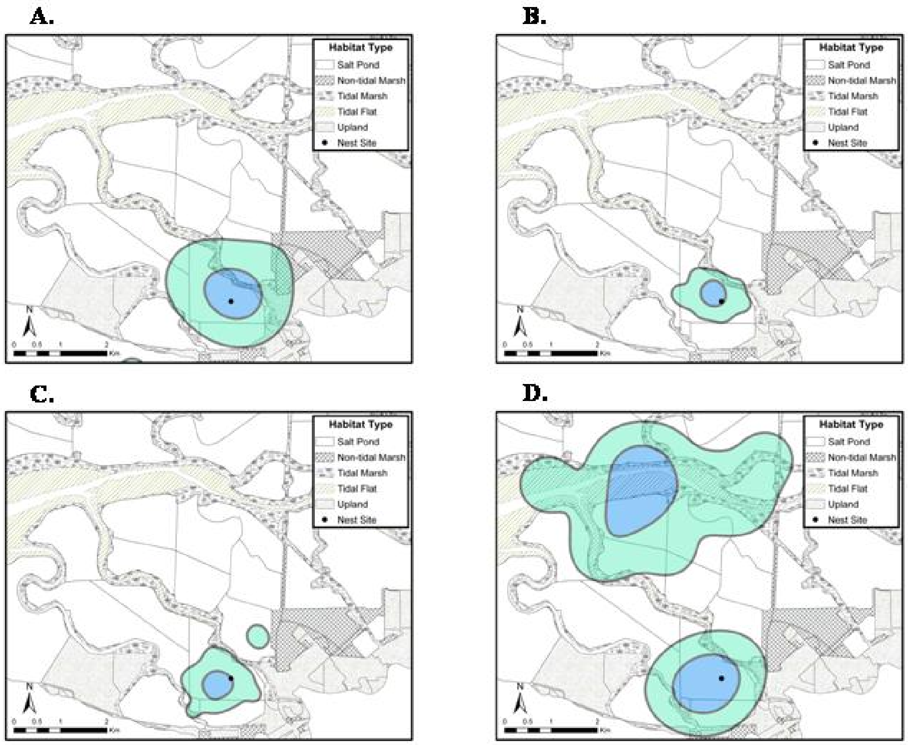


Figure 3. Home range and core area size fluctuations of a representative American avocet during four breeding stages (A. pre-incubation, B. incubation, C. brood-rearing, D. post-breeding) in the South San Francisco Bay, California, USA. The nest site, represented by the dark point, was located in Pond A8.

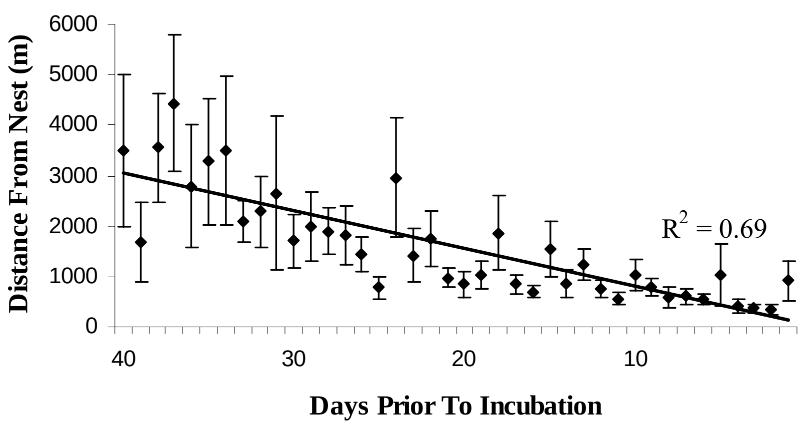


Figure 4. Relationship between mean (± SE) distance from nest and days prior to incubation during the pre-incubation stage for American avocets in South San Francisco Bay, California, 2005-06.

Our study illustrated that breeding stage influences the space use patterns of avocets in South San Francisco Bay. Understanding shifts in space use may help managers elucidate which regions or habitats are critical for avocets at different stages in the annual cycle. Also, it is possible to assess what risks avocets are exposed to at different times of the year. For instance, radio-telemetry location data, can determine where and when avocets are exposed to mercury and other environmental contaminants (Ackerman et al. 2007). Perhaps most importantly, refuge managers in the San Francisco Bay can manipulate wetland conditions during the nest prospecting period of the pre-incubation stage to improve breeding conditions for avocets.

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Mercury Concentrations in Pre-breeding and Breeding Forster's Terns

Collin Eagles-Smith[1], Josh Ackerman[1], and Terry Adelsbach[2]

[1]U. S. Geological Survey, Western Ecological Research Center, Davis Field Station, One Shields Avenue, University of California, Davis, CA 95616
ceagles-smith@usgs.gov

[2]U. S. Fish and Wildlife Service, 2800 Cottage Way, Suite W-2605, Sacramento, CA 95825

Forster's Terns (*Sterna forsteri*) are among the most abundant waterbirds known to breed in the San Francisco Bay Estuary, with substantial colonies in the North and South Bay, as well as smaller groups scattered throughout the Central Bay and Delta. They are also are one of the most at-risk bird species in the Estuary with respect to mercury (Hg) contamination. Their risk status results mainly from their foraging ecology. Forster's Terns prey almost exclusively on fish and occupy a relatively high trophic position. They also generally forage along the Bay margins where mercury availability is greatest as a result of both source inputs and geochemical characteristics. However, these birds are migratory and overwinter outside the Estuary where their mercury exposure may be significantly reduced. To assess the impact of foraging in the Estuary on tern Hg burdens, we examined mercury concentrations in Forster's Terns during the pre-breeding and breeding time periods and evaluated how their concentrations differed when they arrive in the Estuary relative to when they are close to leaving.

We captured Forster's Terns from the Don Edwards National Wildlife Refuge during pre-breeding (April) and breeding (June) time periods in 2005 and 2006. Pre-breeding birds were captured with remote-detonated net launchers, whereas breeding birds were captured on their nests with self-triggering treadle traps. We collected blood

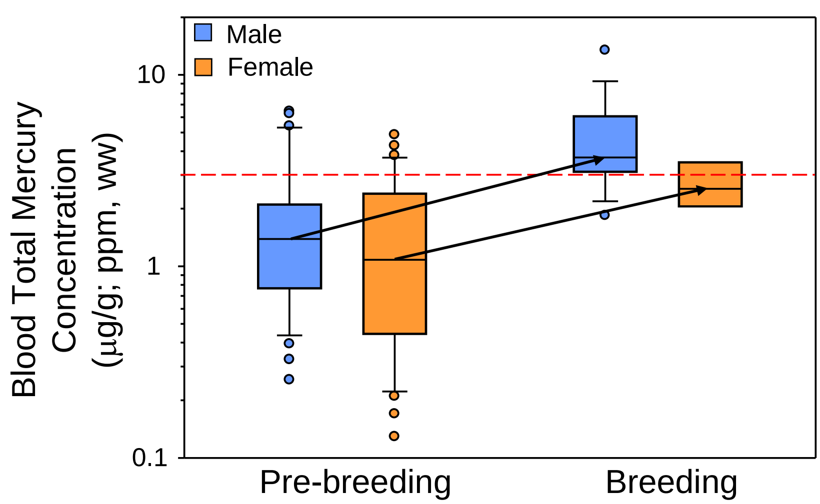

Figure 1. Mercury concentrations in blood of male and female Forster's terns in the South San Francisco Bay Salt Ponds during pre-breeding and breeding time periods

from the brachial (wing) vein in each bird using syringes 25 gauge needles and analyzed blood samples for total mercury at the USGS Davis Field Station Mercury Lab using a DMA-80 mercury analyzer. Liver samples were also collected from each bird and analyzed for total and methyl mercury.

We found that blood mercury concentrations increased nearly three-fold between the pre-breeding (1.17 ± 0.11 ppm) and breeding (3.42 ± 0.58ppm) time periods (ANOVA: $F_{2,98} = 29.93$, $P < 0.0001$; Figure 1). Mercury concentrations did not differ between pre-breeding males (1.32 ± 0.20ppm) and females (1.04 ± 0.15ppm), but breeding males (4.29 ± 0.48ppm) had mercury levels that were nearly twice those of females (2.43 ± 0.44ppm). In terms of risk, we found that 14% of prebreeding birds exceeded the toxic effects threshold (3 ppm), whereas more than half of the breeding birds (64%) had blood mercury concentrations that place them at high risk for mercury toxicity. In addition, nearly all the breeding males (78%) exceeded the toxic threshold, whereas only 30% of the breeding females were above this value.

Many birds have the ability to convert methyl mercury to inorganic mercury in their livers as a method for reducing mercury toxicity. We examined %MeHg, the proportion of total mercury (THg) that is composed of methyl mercury (MeHg) in tern livers and found that % MeHg ranged from less than 50% to 100%. Moreover we also found that liver demethylation followed a threshold model where at low liver THg levels (< 8ppm dw) % MeHg remained constant, but declined appreciably with increasing THg levels above 8 ppm dw (Figure 2). Finally, we found that mercury concentrations were highly correlated between liver and blood ($r^2 = 0.87$; Figure 3), indicating that either tissue can be used to assess short-term mercury exposure in Forster's terns.

Our results indicate that there may be substantial risks to the reproductive success of Forster's Terns nesting in the Estuary as a result of mercury contamination. We also show that mercury concentrations increase dramatically between when they arrive in the Estuary in April, and once they have spent enough time foraging in the Estuary to approach equilibrium with their surroundings. These results also indicate that mercury depuration appears to occur rapidly once the birds leave the Estuary, likely through excretion in feathers during a post-breeding molt (Ackerman et al 2008). It is unclear why mercury concentrations in males increase to a greater

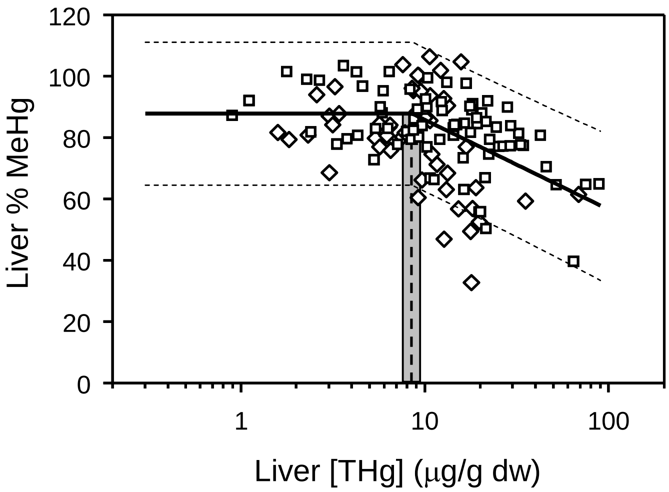

Figure 2. The proportion of mercury in liver composed of methylmercury (%MeHg) declines with increasing liver THg concentrations above a threshold of 8ppm dw. From Eagles-Smith et al. 2008a.

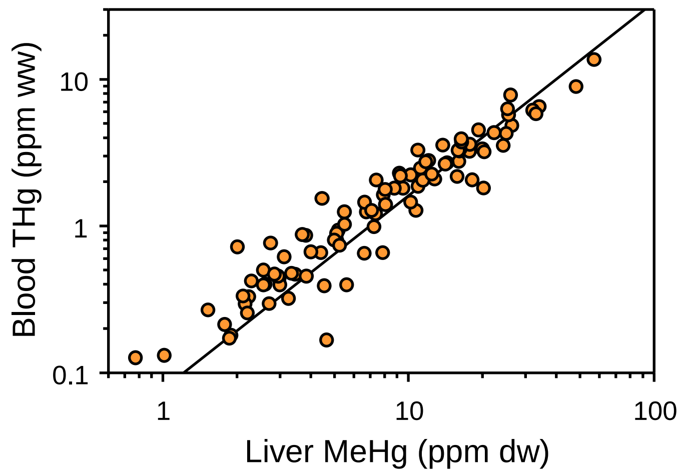

Figure 3. Mercury concentrations in Forster's tern blood are highly correlated with methylmercury concentrations in the liver, indicating that blood can be used as an indicator of liver MeHg bioaccumulation. From Eagles-Smith et al. 2008b.

extent than females, but it may be related to depuration of female mercury into eggs. Although the concentrations we found were substantially elevated (particularly for breeding birds), the fact that the proportion of methyl mercury relative to total mercury in the liver decreases with increasing mercury concentrations suggests that these birds are actively working to reduce the toxicity of accumulated mercury. Further study is needed to assess the degree to which birds such as the Forster's Tern are able to detoxify their accumulated burdens of mercury in the Estuary.

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Mercury Concentrations Vary Among Waterbird Foraging Guilds and Locations in San Francisco Bay

Collin Eagles-Smith[1], Josh Ackerman[1], Susan De La Cruz[2], Terry Adelsbach[3], John Takekawa[2], and A. Keith Miles[1]

[1]U. S. Geological Survey, Western Ecological Research Center, Davis Field Station, One Shields Avenue, University of California, Davis, CA 95616,
[2]U. S. Geological Survey, Western Ecological Research Center, San Francisco Bay Estuary Field Station, 505 Azuar Drive, Vallejo, CA 94592
[3]U. S. Fish and Wildlife Service, 2800 Cottage Way, Suite W-2605, Sacramento, CA 95825,
ceagles-smith@usgs.gov

Mercury contamination is an issue of concern in the San Francisco Bay Estuary as a result of historic gold and mercury mining in the tributaries that drain to the Bay. When mercury is converted by microbial activity to its organic form, methyl mercury, it becomes a potent neurotoxin and bioaccumulates to high concentrations up the food chain. Many waterbirds in the Estuary are at particular risk to mercury because they feed at relatively high trophic levels and often forage along the Bay margins where methyl mercury production and/or availability may be elevated. To assess mercury risks to Estuary-dependent birds, we examined mercury concentrations in five different species common to the Estuary that represent three distinct trophic guilds: Shoreline foragers [American Avocet (*Recurvirostra americana*) and Black-necked Stilt (*Himantopus mexicanus*)], diving benthivores [Surf Scoter (*Melanitta perspicillata*)], and surface water fish-eaters [Forster's Tern (*Sterna forsteri*) and Caspian Tern (*Sterna caspia*)].

During the prebreeding seasons in 2005, we sampled liver tissue in each species from several regions of the Bay. Avocets, Stilts and Terns were sampled in North Bay (Napa Marsh), Central Bay (Eden Landing Ecological Reserve), and South Bay (Don Edwards National Wildlife Refuge) sites, whereas Scoters were sampled in the North Bay, Central Bay, and Suisun Bay. Liver samples were analyzed for methyl mercury and concentrations were compared among species and regions.

We found that liver methyl mercury concentrations differed significantly among species ($F_{4,200}$ = 19.43, $P < 0.001$) and were highest in the fish-eating terns. Mercury concentrations increased in the following order: American Avocets, Surf Scoters, Black-necked Stilts, Caspian Terns, and Forster's Terns (Figure 1). Mercury concentrations also showed significant variation among regions, with Avocets, Stilts and Terns from the South Bay elevated relative to north and central bay regions (Figure 2a – 2c). For Scoters, liver methyl mercury concentrations were highest in Suisun Bay (Figure 2d).

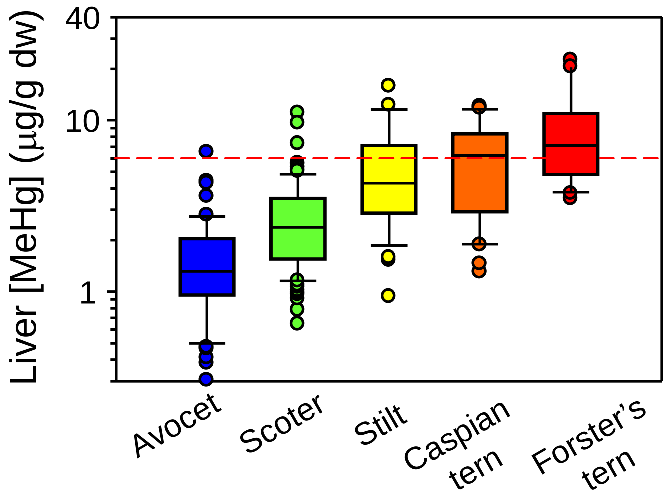

Figure 1. Liver methyl mercury concentrations in pre-breeding waterbirds from the San Francisco Estuary. Center box lines represent median values. Box boundaries represent 25th and 75th percentiles, and whiskers represent 10th and 90th percentiles. Red hatched line represents the liver toxicity threshold.

The toxicological significance of mercury is difficult to detect in the wild because the effects that are generally manifested at environmentally relevant concentrations are subtle and tend to be linked to behavior. We used the previously established lowest observable adverse effects level (LOAEL) benchmark of six parts per million (ppm) as the threshold for individual-level impacts from mercury contamination to assess potential risk to the Estuary's avi-fauna. A significant proportion of Caspian and Forster's Terns and Black-necked Stilts (60%, 50%, and 33%, respectively) exceeded this threshold. Less then 10% of the Avocets and Scoters sampled exceeded this threshold, suggesting that they are at much lower risk to mercury contamination.

Regionally, mercury contamination was highest in the South Bay for Terns, Stilts, and Avocets, and Suisun Bay for Scoters. For all species except Stilts, mercury concentrations were generally higher in the North Bay than the Central Bay. The fact that the northern and southern regions of the Estuary exhibited higher mercury concentrations is likely reflective of tributary input from the Delta and Napa River, and Guadalupe River, respectively.

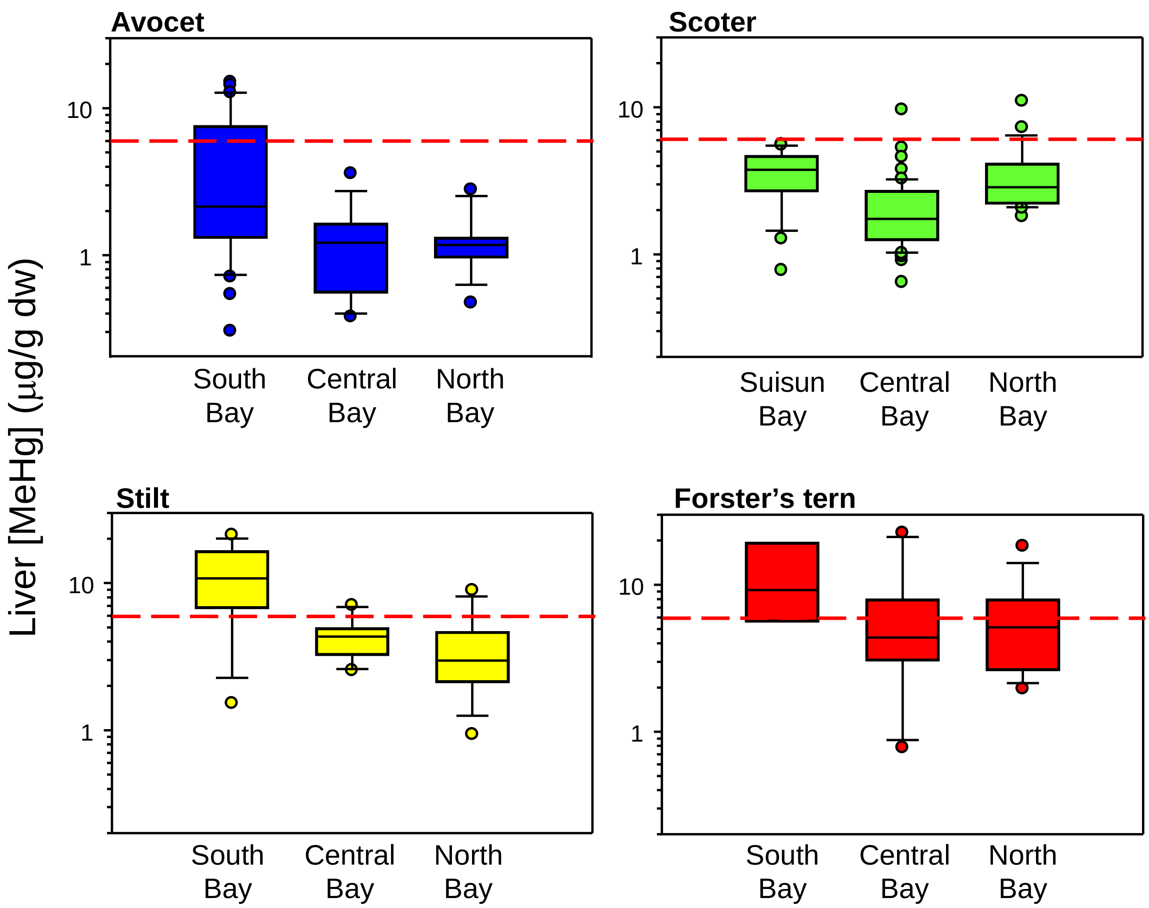

Figure 2. Site-specific liver methyl mercury concentrations in: a) American avocets; b) surf scoters; c) black-necked stilts; d) Forster's tern. Red hatched line represents the liver toxicity threshold.

Our results suggest that pre-breeding birds dependent upon the Estuary are at risk for reproductive impairment due to mercury toxicity. In addition, the bird species that are most dependent on marsh habitats, such as Forster's Tern and Black-necked Stilts, are at the highest risk to mercury exposure, likely a result of enhanced methyl mercury production in those habitats. As habitat restoration continues in the Estuary and the extent of salt marsh along the borders increases, it will be important to continue to monitor reproductive success and mercury exposure in waterbirds in order to assess how risk varies over time.

Fish Species Assemblages and Water Quality Characteristics of Salt Ponds and Sloughs in South San Francisco Bay

Francine H. Mejia and Michael K. Saiki

U.S. Geological Survey, Biological Resources Division, Western Fisheries Research Center-Dixon Duty Station, 6924 Tremont Road, Dixon, CA 95620, USA

This study was conducted to better understand the fishery resources inhabiting salt ponds targeted for restoration to tidally influenced wetlands, and associated tidal creeks and sloughs (collectively referred to as "sloughs"). The ponds, which are located within the Alviso and Eden Landing salt pond complexes in South San Francisco Bay, were originally constructed and operated for commercial salt production. Specific objectives of the study were as follows: (1) to characterize fish species assemblages in selected ponds and sloughs; and (2) if two or more species assemblages were identified, to determine if their compositions were influenced by water quality or other environmental variables. Fish were sampled with gill nets and minnow traps at roughly three-month intervals from March 2004 to June 2005. A total of 5,142 fish representing 16 families and 23 species was captured (Table 1; also see Mejia et al. [2008]). Gill nets captured mostly topsmelt (*Atherinops affinis*), northern anchovy (*Engraulis mordax*), and leopard shark (*Triakis semifasciata*), whereas minnow traps captured mostly rainwater killifish (*Lucania parva*) and longjaw mudsuckers (*Gillichthys mirabilis*). Cluster analysis of presence-absence data for the various fish species indicated that at least two species assemblages were present, one characteristic of the ponds and the other characteristic of the sloughs. "Pond" fishes were represented by 12 species, whereas "slough" fishes were represented by 22 species. Except for bay pipefish (*Syngnathus leptorhynchus*), which was unique to ponds, all species present in ponds also were in sloughs These results indicate that the pond species assemblage was derived from the slough species assemblage. According to canonical discriminant analysis (CDA), four environmental variables were useful for discriminating between the two species assemblages. The variable containing the most discriminatory power was the Index of Habitat Connectivity (IHC), a measure of the minimum distance that a fish must travel to reach a particular pond from the nearest slough. Apparently, as fish from sloughs enter and move through interconnected ponds, environmental stress factors increase in severity until only the more tolerant species remain. The single most likely source of stress is salinity because this variable contributed nearly as much as IHC in discriminating between the two species assemblages. Water temperature and dissolved oxygen concentration also seemingly contributed to overall stress on fishes, although their effects were less pronounced than that from salinity. The restoration of former salt ponds to tidal wetlands might benefit recreational and commercial fisheries in San Francisco Bay by increasing the production of fish-forage organisms, and by providing new rearing habitats for juvenile fish.

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Table 1. Number (N) and percent (%) of fish captured with gill nets and minnow traps from the Alviso and Eden Landing complexes during March 2004-June 2005.

Family	Species	Common name	Gill net		Minnow trap	
			N	%	N	%
Atherinidae	*Atherinops affinis*	Topsmelt	2,793	65.1	9	1.1
Atherinidae	*Atherinops californensis*	Jacksmelt	3	<0.1	0	0.0
Atherinidae	*Menidia audens*	Mississippi silverside	0	0.0	6	0.7
Carcharhinidae	*Triakis semifasciata*	Leopard shark	282	6.6	0	0.0
Catostomidae	*Catostomus occidentalis*	Sacramento sucker	3	0.1	0	0.0
Clupeidae	*Alosa sapidissima*	American shad	46	1.1	0	0.0
Clupeidae	*Clupea harengus*	Pacific herring	15	0.4	0	0.0
Clupeidae	*Dorosoma petenense*	Threadfin shad	2	<0.1	0	0.0
Cottidae	*Leptocottus armatus*	Pacific staghorn sculpin	48	1.1	5	0.6
Cyprinidae	*Cyprinus carpio*	Common carp	1	<0.1	0	0.0
Embioticidae	*Cymatogaster aggregata*	Shiner perch	24	0.6	0	0.0
Engraulidae	*Engraulis mordax*	Northern anchovy	862	20.1	0	0.0
Fundulidae	*Lucania parva*	Rainwater killifish	0	0.0	343	40.2
Gasterosteidae	*Gasterosteus aculeatus*	Threespine stickleback	0	0.0	2	0.2
Gobiidae	*Acanthogobius flavimanus*	Yellowfin goby	72	1.7	93	10.9
Gobiidae	*Clevelandia ios*	Arrow goby	0	0.0	4	0.5
Gobiidae	*Gillichthys mirabilis*	Longjaw mudsucker	10	0.2	390	45.7
Gobiidae	*Tridentiger bifasciatus*	Shimofuri goby	0	0.0	1	0.1
Moronidae	*Morone saxatilis*	Striped bass	107	2.5	0	0.0
Myliobatidae	*Myliobatis californica*	Bat ray	3	0.1	0	0.0
Osmeridae	*Spirinchus thaleichthys*	Longfin smelt	6	0.1	0	0.0
Pleuronectidae	*Platichthys stellatus*	Starry flounder	11	0.3	0	0.0
Syngnathidae	*Syngnathus leptorhynchus*	Bay pipefish	1	<0.1	0	0.0
		Total	4,289	100.0	853	100.0

California Clapper Rails in San Francisco Bay: Modeling habitat relationships at multiple scales to guide habitat restoration and eradication of non-native *Spartina*

Hildie Spautz [1,2], Jennifer McBroom [1,3], Nadav Nur [4], Katy Zaremba [1], Jules Evens [5], Joy Albertson [6], Steve Bobzien [7], and Mark Herzog [4]

[1] San Francisco Estuary Invasive *Spartina* Project, 2560 Ninth St. Suite 216, Berkeley, CA 94710; [2] P.O. Box 2330, El Cerrito, CA 94530; [3] Olofson Environmental, Inc., 2560 Ninth St Suite 216, Berkeley, CA 94710; [4] PRBO Conservation Science, 3820 Cypress Drive, #11, Petaluma, CA 94954; [5] Avocet Research Associates, P.O. Box 839, Point Reyes Station, CA 94956; [6] Don Edwards San Francisco Bay NWR, P.O. Box 524, Newark, CA 94560; [7] East Bay Regional Park District, 2950 Peralta Oaks Court PO Box 5381 Oakland, CA 94605. Lead author contact: hspautz@earthlink.net

There are numerous factors threatening the future health of tidal marsh ecosystems in the San Francisco Bay Estuary, including the invasion of non-native species, sea level rise, environmental contaminants, and other factors associated with historical habitat loss, fragmentation, and ongoing environmental degradation (Gutenspergen & Nordby 2006, Takekawa et al 2006). The control and eradication of non-native cordgrass, *Spartina alterniflora* (and its hybrids with the native *Spartina foliosa)* is a high priority of regional scientists and policymakers, due to the potential major long-term loss of structural and biological diversity associated with the plants' ability to grow at lower elevations in tidal mudflats than native cordgrass. Regional non-native *Spartina* control efforts were initiated in 2004, led by the State Coastal Conservancy's San Francisco Estuary Invasive *Spartina* Project (ISP). One unexpected outcome of the non-native *Spartina* invasion is that the endangered California Clapper Rail (*Rallus longirostris obsoletus*) has colonized invaded marshes that would appear to be otherwise poor habitat, apparently being attracted to these sites by the unusually tall and dense plant structure associated with the non-native *Spartina* hybrids. This association between the non-native *Spartina* and the Clapper Rail has created a unique set of issues for non-native *Spartina* removal, because the benefits to the entire ecosystem of controlling the *Spartina* invasion need to be weighed against the localized losses of Clapper Rails and their habitat.

Restoring tidal marsh habitat that supports the California Clapper Rail and other special status species is a major goal for the ISP, the South Bay Salt Pond Restoration Project, and other regional restoration and management programs. However, planning has been premised on assumptions about Clapper Rail habitat use that have not previously been studied or quantified. In particular, the impacts on rail populations of both tidal marsh restoration and non-native

Spartina spread and control, considered individually or together, have not been previously studied. Updated quantitative information about general Clapper Rail habitat requirements, responses to restoration, and responses to the non-native *Spartina* invasion, such at those presented here, will facilitate the improvement of strategies for invasive *Spartina* control and the design of tidal marsh restoration projects.

To this end, we are exploring a number of hypotheses related to Clapper Rail habitat use in Central and South San Francisco Bay, including the following: 1) that large contiguous areas of highly-channelized marsh are likely to have the highest California Clapper Rail densities; 2) that sparsely vegetated low marsh (such as that found within and adjacent to channels and within the *Spartina* zone), and high marsh with dense vegetation are both important to rails; 3) that Clapper Rail population densities tend to be significantly higher in small, low elevation, non-native *Spartina*-invaded patches than they would be if the non-native *Spartina* were not present; and 4) that eradication of invasive *Spartina* may result in localized decreases in rail abundance, particularly in marshes where invasive *Spartina* comprises a relatively large proportion the vegetation. We also wanted to know whether rail populations were sensitive to marsh fragmentation, marsh size, or type of surrounding land use, to which other species of San Francisco Bay Estuary tidal marsh birds have been shown to be sensitive (Spautz *et al.* 2006), but which have not been previously studied in detail for Clapper Rails.

We modeled Clapper Rail habitat relationships using a combination of Clapper Rail survey data collected at 44 sites, including several sites under restoration, in Central and South San Francisco Bay in 2005 (Figure 1), habitat data we collected in the field, and site characteristics generated from aerial photos using the latest Geographic Information System (GIS) technology. Variables we tested for relationship with Clapper Rail density included proportion of marsh plant species, vegetation height and density, proportion of *Spartina alterniflora* hybrid (estimates generated by the ISP *Spartina* Inventory Program), channel density, ratio of various types of marsh edges to marsh area, distance to various types of marsh edges, and proportion of various types of surrounding habitat or land use (including marsh, mudflats, natural upland, salt ponds, and urban).

We found a statistically significant positive relationship between a marsh's *Spartina* hybrid cover and Clapper Rail density, i.e., there tended to be higher densities of Clapper Rails with higher proportions of hybrid *Spartina* cover. We also found that rail densities were higher at marshes with higher tidal channel densities, higher densities of tall plant stems (50-60 cm above the marsh surface), higher cover of the native cordgrass, *Spartina foliosa,* within tidal channels, longer low-elevation marsh edge relative to upland edge, and a higher proportion of low-elevation tidal mudflats in the surrounding area. The most interesting finding was a statistical interaction between *Spartina* cover and channelization. The highest rail densities were found in marshes with either a high proportion of invasive *Spartina* cover or high channel density, and if the marsh had high levels of one of these factors, the effect of the other on rail density was unimportant. For example, for sites with few channels, the more invasive *Spartina* cover, the more Clapper Rails. But for sites that were at least moderately channelized, higher invasive *Spartina* cover had no relationship with the rail numbers. These results have implications for the control of invasive *Spartina*. Because many of the most highly-invaded sites had few tidal channels and lots of tall vegetation, we predict that after *Spartina* removal, these sites will have fewer of the habitat characteristics associated with high rail densities and their rail populations are likely to decrease.

These results confirm previous studies indicating that tidal channels are a critical component of high quality Clapper Rail habitat (Albertson & Evens 2000). Other habitat features that are important include the length of low-elevation marsh edges (relative to upland edge length) and proximity to tidal mudflats. Our studies verified that areas highly invaded by non-native *Spartina* had Clapper Rail densities comparable to or greater than those found in the highest quality non-invaded marshes. Although rails show affinity for *Spartina*-invaded marshes, whether these marshes can contribute to an increase in rail populations is not known. The impact of *Spartina* removal on rail populations is also unknown. We recommend additional studies of rail reproductive success, and ongoing surveys to track changes in rail numbers associated with *Spartina* removal. We also recommend additional studies to identify factors associated with the establishment of Clapper Rail populations in young restoring marshes; these analyses could be accomplished with data collected for the studies presented here, and would be particularly valuable for ongoing restoration work in the South Bay.

For more information about the Invasive *Spartina* Project, including how to download a copy of the complete Clapper Rail habitat use report, please visit www.spartina.org.

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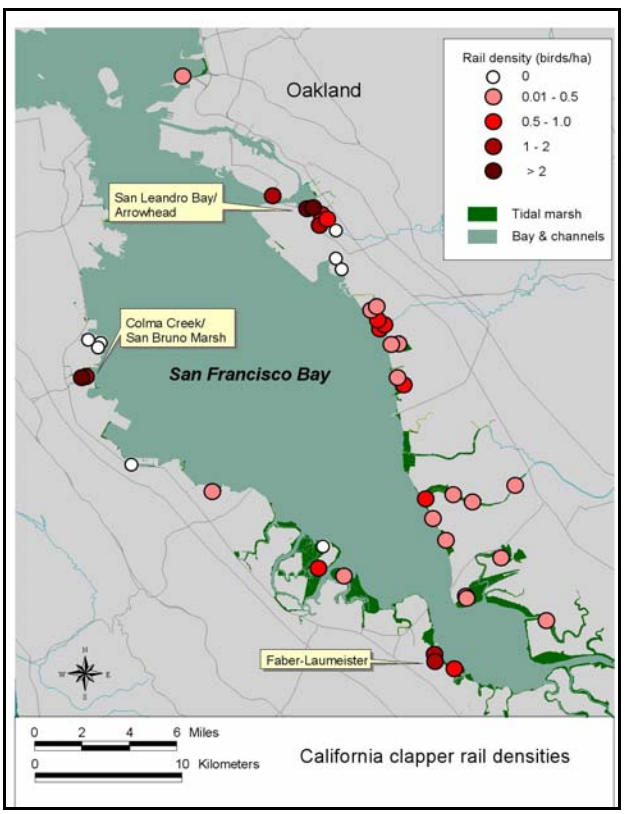

Figure 1. Map indicating study sites, color-coded by California Clapper Rail densities estimated in 2005.

Habitat-based Modeling of Wetland Bird Communities: An evaluation of potential restoration alternatives for South San Francisco Bay

Diana Stralberg (dstralberg@prbo.org), Mark Herzog, Nils Warnock, Nadav Nur, Samuel Valdez
PRBO Conservation Science, 3820 Cypress Drive #11, Petaluma, CA 94954

The 2003 acquisition of 5,471 ha of salt ponds by state and federal wildlife agencies provides an unprecedented opportunity to restore large areas of contiguous tidal wetlands in South San Francisco Bay (South Bay). From an avian conservation perspective, this could represent more than a doubling of habitat for tidal marsh-associated bird species, possibly increasing overall population viability of sensitive species such as the federally-listed California Clapper Rail (*Rallus longirostris obsoletus*) and other species of conservation concern. Meanwhile, it also presents management challenges, since the existing South Bay salt ponds support large numbers and a high diversity of waterbird species that could experience local, if not population-level, declines with the loss of this managed habitat (Stenzel et al. 2002, Warnock et al. 2002). Thus our objective was to identify habitat relationships of key avian species, and develop habitat-based models to predict avian responses to restoration and habitat change.

Based on a six-year period (1999-2004) of avian surveys conducted in tidal marsh and salt pond habitats, we developed habitat relationship models for 29 focal species and seasons, and used a model-averaging approach to generate predicted densities under various habitat alternatives comprised of restored tidal marsh and managed ponds (former salt ponds managed specifically for wildlife). Models included variables representing surrounding habitat context, as well as site-level marsh and pond characteristics. We focused on three alternatives being evaluated by the South Bay Salt Pond Restoration Project: A (“no action”), B (50% tidal restoration), and C (90% tidal restoration), as well as variations in tidal marsh pond/panne evolution and in managed pond depth within these scenarios (SBSP Restoration Project 2008). The action alternatives (B and C) included managed pond configurations designed to benefit a range of waterbird species, while alternative A was based on minimal human intervention. We evaluated changes within the restoration area itself, as well as throughout the South Bay, based on existing tidal marsh and salt pond habitats, as well as current and future projected tidal flats.

Results indicated a wide range of responses by different species, confirming that restoration will involve some trade-offs among species and habitats. However, we also found many opportunities for positive solutions through a combination of intensive management, balanced habitat configurations, and phasing of restoration activities over time. Key findings include:

- Foraging waterbird densities were generally lower in tidal marshes than in managed ponds. However, waterbird density in tidal marshes was almost always positively associated with the amount of open water, in the form of tidal channels, tidal ponds, and semi-tidal pannes. Black-necked Stilt (*Himantopus mexicanus*), Least Sandpiper (*Calidris minutilla*), Gadwall (*Anas strepera*), and Northern Shoveler (*A. clypeata*) were particularly responsive to increases in open water habitat. Thus habitat potential for waterbirds within restored tidal marshes could be increased by accelerating the development of large-scale open water features, such as high elevation salt pannes, via site engineering and construction activities. Alternatively, some restoration sites could be maintained in a state of muted tidal action, to maintain large unvegetated areas by keeping them flooded for longer periods.

- Depth and salinity conditions explained much of the variation in foraging waterbird densities within managed ponds. In general, water depth had more explanatory power than salinity for individual species, except for some high-salinity specialists—Black-necked Stilt and Eared Grebe (*Podiceps nigricollis*)—and low-salinity specialists—American White Pelican (*Pelecanus erythrorhynchus*), Scaup (*Aythya* spp.) and Ruddy Duck (*Oxyura jamaicensis*). In terms of water depth, small and large shorebirds generally had much higher densities in shallow ponds (<15 cm), Eared Grebe had higher densities in deeper ponds (>1 m), and other species' responses were intermediate, with shallow ponds generally supporting more species at higher densities.
- In year 0 of any restoration alternative, soon after levees are breached and tidal action is restored, numbers of waterbirds, especially shorebirds, dabbling ducks, and some fish-eaters, are likely to increase within the restored areas, as new low-salinity, unvegetated, intertidal and subtidal foraging habitats are created. This suggests that a staggered approach to tidal marsh restoration may have the greatest opportunity to provide long-term habitat benefits for waterbirds, as newly-breached ponds may compensate for the loss of feeding opportunities in marshes that become vegetated.
- By year 50, after most restoration ponds have become vegetated, most shorebird, fish-eating, and diving duck species are expected to have higher numbers under alternatives that retain substantial areas of managed ponds (e.g., alternative B) (Figure 1). Landbirds, rails, and dabbling ducks, however, would have highest numbers under restoration scenarios with more tidal marsh area (e.g., alternative C). Weighing the needs of a broad range of species, a mixed restoration / managed pond alternative (e.g., alternative B) provides a reasonable starting point within an adaptive management framework.
- Pond management characteristics may have a greater effect on habitat capacity and overall waterbird numbers than the ratio of managed ponds to tidal marshes, to a certain point. Furthermore, intensive pond management would likely provide greater opportunities to increase waterbird numbers than the engineering of tidal marsh open

water features during restoration. Managing all ponds to be shallow (<15 cm) would have a positive effect on more species than managing all ponds to be deep (>1 m).

- Shorebird species' responses may differ by season, and, due to overall higher use of South Bay habitats during migration periods (especially spring), migration periods have the potential to become population bottlenecks without adequate managed pond habitats. Thus, for shorebirds, it may be more appropriate to focus on pond management during these periods, when ponds are more likely to exceed their carrying capacities.
- Based on observed and modeled sediment dynamics in the South Bay, combined with threats posed by invasive *Spartina* encroachment and sea level rise, tidal flats are most likely going to decrease in the South Bay, particularly north of the Dumbarton Bridge. This means that managed ponds and seasonal wetlands will become more important for the species that rely on tidal flats. While tidal marsh open water habitats may compensate for some of this loss, shorebird use of tidal marshes may be an order of magnitude lower than tidal flats.
- For two sensitive species, the tidal marsh-dependent Clapper Rail, and the dry pond-associated Snowy Plover (*Charadrius alexandrinus*), high variability in density among sites led to large ranges in predicted restoration responses. Using upper density estimates, alternatives A or B could support at least 500 individuals of each species, while using lower density estimates, no alternative could simultaneously support 500 individuals of each species. For both of these species, active predator management would be an important component of any plan for species recovery.

The principal uncertainties associated with our model predictions include current carrying capacities of South Bay habitats, the availability of alternative habitats for birds using managed ponds, the extent to which habitat quality and availability are limiting bird populations, and whether birds will indeed respond to change in availability of habitat in the manner that our habitat-based models assumed. Further research and monitoring of new and existing restoration sites will be needed to reduce these sources of uncertainty.

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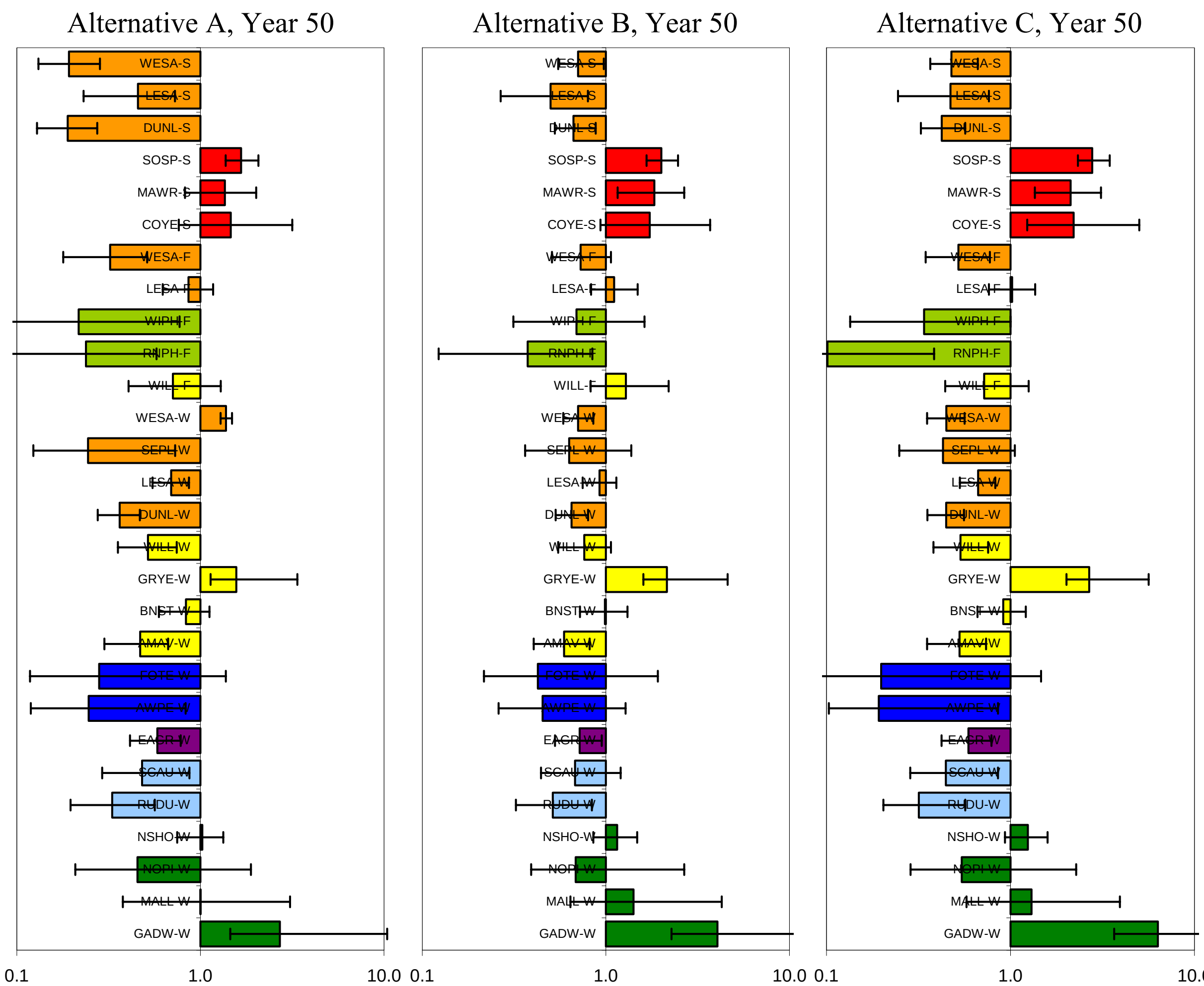


Figure 1. South Bay scenario evaluation, year 50. Model-predicted proportion of baseline (alternative A, year 0) focal species' abundance indices across South Bay tidal marsh and managed pond habitats. Error bars represent 90% confidence intervals. Model predictions are based on 1999-2004 South San Francisco Bay avian survey data. WESA = Western Sandpiper, LESA = Least Sandpiper, DUNL = Dunlin, SOSP = Song Sparrow, MAWR = Marsh Wren, COYE = Common Yellowthroat, WIPH = Wilson's Phalarope, RNPH = Red-necked Phalarope, WILL = Willet, SEPL = Semipalmated Plover, GRYE = Greater Yellowlegs, BNST = Black-necked Stilt, AMAV = American Avocet, FOTE = Forster's Tern, AWPE = American White Pelican, EAGR = Eared Grebe, SCAU = scaup spp., NSHO = Northern Shoveler, NOPI = Northern Pintail, MALL = Mallard, GADW = Gadwall. S = spring, F = fall, W = winter

Forster's Tern, Caspian Tern, and California Gull Colonies in San Francisco Bay: Habitat Use, Numbers, and Trends, 1982-2003

CHERYL M. STRONG, San Francisco Bay Bird Observatory, 524 Valley Way, Milpitas, CA 95035; 408-946-6548, current contact information: cheryl_strong@fws.gov

LARRY SPEAR, H.T. Harvey and Associates, 983 University Avenue, Building D, Los Gatos, CA 95032

TOM RYAN, ROBIN DAKIN, AND SHERRY HUDSON, San Francisco Bay Bird Observatory

We analyzed data on colonies of the Caspian Tern, Forster's Tern, and California Gull in the San Francisco Bay during 1982 to 2003. There were 13, 17, and 7 colony sites used by Caspian Terns, Forster's Terns, and California Gulls, respectively, during one or more years from 1982 to 2003. Mean number of birds at a given site was 296 Caspian Terns, 218 Forster's Terns, and 1,424 California Gulls. Mean size of gull colonies was significantly larger than that of either of the terns, and colony size differed little between the two tern species.

The number of Caspian Terns breeding within the estuary was stable from 1982 to 2003 (Figure 1) with a range of 1,002-2,636 birds. The largest Caspian Tern colony each year differed across the 22 years, but included Alameda, Bair Island, Brooks Island, Mowry, Turk, and Knight. The Brooks Island colony has been the largest since at least 1997.

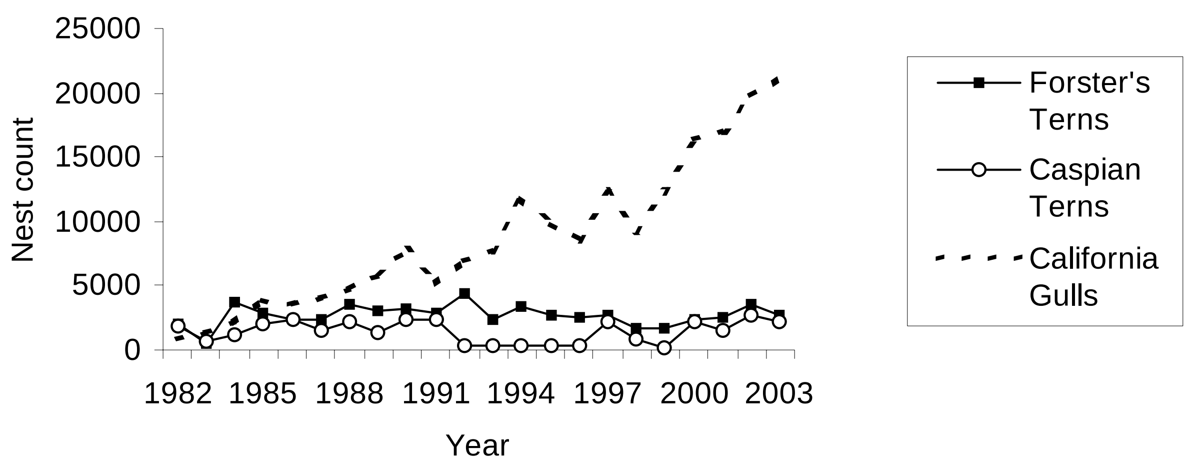
Forster's Terns ranged from 1,628-4,312 birds with a significant decline in total number of breeding Forster's Terns between 1984 and 2003. Colonies with highest numbers of Forster's Terns differed across the 22 years, and included those at Moffett, Bair Island, Baumberg, Mallard Slough, Hayward Shoreline, Turk, and Knight. The largest colony at the beginning of this study (1982) and middle (1992) was at Moffett (655-1,000 birds); however, only three colonies had >300 birds at the end of the study-- Baumberg, Belmont, and Turk

There was a range of 412 - 21,106 breeding California Gulls, however, the number increased markedly and progressively from 412 birds in 1982 to 21,106 in 2003 (Figure 1). Between 1982 and 2003, numbers of California Gulls increased significantly at each of the colony sites of this species. The largest and oldest gull colonies were at Alviso, Mowry, and Marina. The Marina, Mountain View, and Brooks Island sites were stable during approximately the first 15 years of the study followed by an increase during the later 90s and early 2000s; at the Mowry colony there was in increase in the early years, followed by stability during the latter part of the study.

All three species nested on five to six different habitat types, however, 59% and 46% of the Forster's Tern and Caspian Tern colonies, respectively, were located on salt pond islands. Four of the seven colonies of California Gulls nested on salt pond islands and salt pond levees. The largest colony (Alviso) was located on a dry salt pond not in commercial use.

An overall lack of colony site fidelity in terns and the decline among Forster's Terns is likely due to mammalian predation, human disturbance, and possibly annual variation in food availability. Flat, unvegetated islands are critical for maintaining nesting larids. Yet, the planned restoration of up to 65% (9,050 ha) of the salt pond complex of the San Francisco Bay will likely remove some of the salt pond islands and levees where 20%, 80% and 96% of the Caspian Terns, Forster's Terns, and California Gulls, respectively, were nesting in 2003. Thus, the South Bay Salt Pond Restoration Project plans must include the creation of sizeable tracts of islands specifically designed to provide nesting habitat for these larids. Severe habitat limitation would lead to competition for nesting space among the three species, likely resulting in exclusion of the terns by the gull, which nests earlier, and are larger, more abundant, and more aggressive.

Figure 1. Changes in nesting populations of Forster's tern, Caspian tern, and California gull in the South San Francisco Bay, 1982-2003.



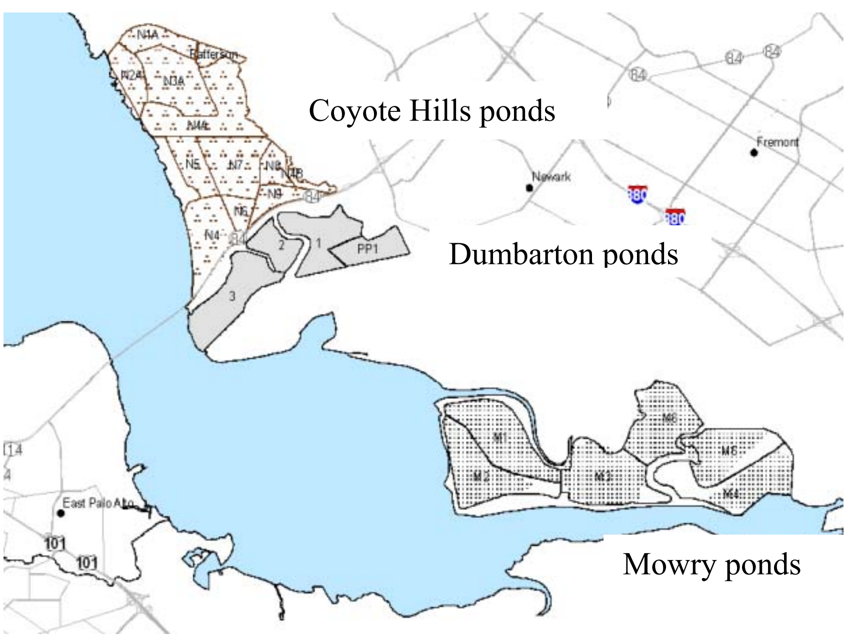
Waterbird Monitoring at the Newark Ponds, South San Francisco Bay

CHERYL M. STRONG, San Francisco Bay Bird Observatory, 524 Valley Way, Milpitas, CA 95035; 408-946-6548, current contact information: cheryl_strong@fws.gov

The South Bay Salt Pond Restoration Project will restore large tracts of tidal marsh and associated habitats to the south Bay. However, the Project Management Team is also dedicated to the preservation of open-water habitat for the more than 80 species of waterbirds that currently utilize existing salt ponds. To plan and manage the restoration so that "no net loss" of birds results, the Project Managers need to know how birds are utilizing not only the ponds located within the restoration, but also the ponds that remain in salt production.

Proponents of restoring all of the newly purchased ponds to tidal marsh argue that the ponds that remain in salt production will provide adequate open water habitat for birds. However, these areas have never been adequately surveyed to assess avian use. The San Francisco Bay Bird Observatory began monthly surveys of these salt ponds in September 2005. Here we examine preliminary results of the first eight surveys to look at pond use by shorebirds and waterfowl, as well as a salt-pond specialist, the Eared Grebe.

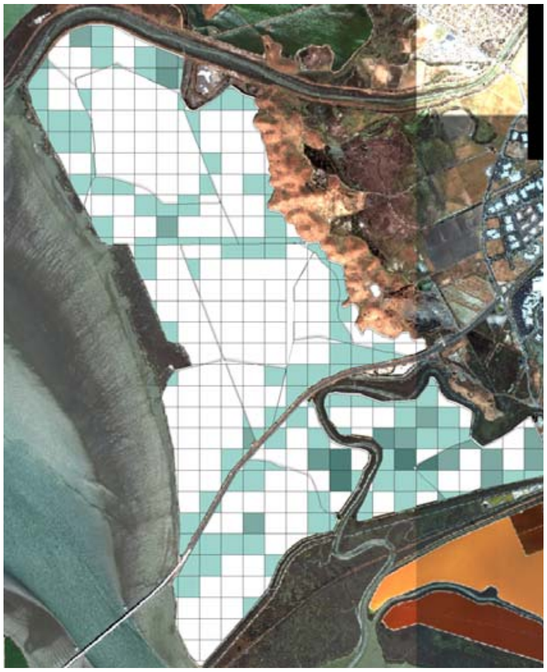
A team of two surveyers counted over 350,000 birds in approximately 16 weeks of surveys in eight months. In the three areas counted, the Dumbarton ponds accounted for 60% of birds in only 19% of the the area of ponds counted. Mowry ponds accounted for only 16% of birds in 43% of the area, and in Coyote Hills 24% of birds were counted in 38% of the area.



Area	% of total area	% of total birds	% birds foraging	Primary type of birds using area
Coyote Hills	38.35	24.09	35.38	Shorebirds and dabbling ducks
Dumbarton	18.79	60.08	34.99	Shorebirds, 75% of all Eared Grebes
Mowry	42.86	15.83	14.05	Gulls, primarily California Gulls
Totals	**100.00**	**100.00**	**31.77**	

Half of the dabbling ducks (such as Northern Shoveler) counted were counted in a single pond; a majority of diving ducks (such as Canvasback) were also counted on a single pond. While over half of the dabbling ducks were seen foraging, the diving ducks were using the site for roosting. Nearly half of the medium shorebirds (such as American Avocets) were counted on two ponds; one pond was used primarily for foraging but the second pond appears to be used primarily for roosting. Small shorebirds (such as Western Sandpipers) were the most numerous birds counted on ponds, and three ponds held the vast majority of these for roosting and foraging. Gulls (primarily California Gulls) tended to congregate for roosting in the same ponds that contain gull nesting colonies in the spring and summer. Fisheaters (including Double-crested Cormorant) were not very common in any of the ponds surveyed, but did forage in two “intake” ponds when water (and fish) was pumped in from the Bay. Eared Grebes are “salt pond specialists”, foraging on brine flies and brine shrimp that are abundant in the higher salinity ponds. Eared Grebes were concentrated into two ponds, perhaps because other higher salinity ponds were no longer available for foraging in the Alviso area due to changes in water management.

Overall, a few ponds are good for some groups of birds; a lot of the ponds were not used at all. Features such as islands within ponds are important for roosting, and the edges of levees are used for foraging in the deeper water ponds. Not all ponds are created equal: depth and salinity play an important role in determining invertebrate communities, and therefore prey abundance for many birds. Future analysis will allow us to correlate bird use and distribution to pond conditions, 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.



Map shows the average number of all small shorebirds counted between December and February. The green squares indicate numbers of small shorebirds, with darker squares representing more individuals.

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

John Takekawa[1], Josh Ackerman[1], Collin Eagles-Smith[2], Susan Wainwright-De La Cruz[1], Terry Adelsbach[2], A. Keith Miles[1], Gary Heinz[3], Dave Hoffman[3], Steve Schwarzbach[1], Tom Suchanek[1], Tom Maurer[2], Cheryl Strong[4], Nils Warnock[5]

[1]USGS Western Ecological Research Center, Vallejo, Davis, and Sacramento, CA
[2]FWS Ecological Services, Sacramento, CA
[3]USGS Patuxent Wildlife Research Center, Laurel, MD
[4]San Francisco Bay Bird Observatory, Alviso, CA
[5]PRBO Conservation Science, Petaluma, CA

The San Francisco Bay Estuary (SFBE) has a legacy of mercury (Hg) contamination from former local mining operations and gold extraction. This mercury contamination threatens both human health and ecosystem function. Mercury bioavailability within subregions of the watershed, and even the watershed as a whole, ultimately may be increased by certain restoration approaches. Wetland restoration efforts may remobilize mercury, potentially increasing waterbird exposure to methylmercury (MeHg). Avian reproduction is a sensitive endpoint to evaluate MeHg toxicity (Wiener et al. 2003); however, assessing toxic risks are hampered by inadequate understanding of exposure among different foraging guilds of birds and lack of field and laboratory integration.

In 2005, a research team led by the U.S. Geological Survey and U.S. Fish and Wildlife Service, and cooperators including the San Francisco Bay Bird Observatory and Point Reyes Bird Observatory's Conservation Science, initiated a CalFed-supported study to quantify dietary exposure in three foraging guilds, examine mercury effects, and determine interspecies variation in sensitivity. Waterbirds may be grouped in foraging guilds distinguished by their feeding method, diet preferences, and habitat use. These guilds include (1) surface feeding American Avocet (*Recurvirostra Americana)* and Black-necked Stilt (*Himantopus mexicanus)*, (2) diving Surf Scoter (*Melanitta perspicillata)*, and (3) fish-eating Forster's Tern (*Sterna forsteri).* Here, we provide a summary of preliminary results and early study implications from the first field season (Schwarzbach *et al.* 2005).

Avocets and Stilts. We captured 141 recurves and radio-marked 93 birds to examine their movements from more than 3,400 locations. Invertebrates sampled at 3-4 randomly selected locations included *Corixidae* (Water Boatmen), *Artemia* (Brine Shrimp), *Mysis* (Shrimp) and occasionally *Corophium* (Amphipod), while recurve diets included *Corixidae*, *Corophium*, Gastropods, Bivalves, *Chrionomidae*, Tiger Beetles, and Polychaetes.

Forster'sTerns. Fifty Forster's Tern adults were radio-marked to obtain nearly 1,400 locations. Fish were sampled from 136 locations including Topsmelt, Jacksmelt, Shiner Perch, Inland Silverside, Longjaw Mudsucker, Yellowfin Goby, Bay Goby, Staghorn Sculpin, Pacific Sardine, Northern Anchovy, Pacific Herring, Striped Bass, Sacramento Splittail, Speckled Sandab, and Starry Flounder. Mean Hg in Forster's Tern muscle was 1.35 ppm wet weight (N=42) with no sex difference ($F_{1,18}$=0.05, P=0.83) during pre-breeding, but sex differences ($F_{1,22}$=7.33, P=0.01) during breeding. Breeding Hg levels were greater than pre-breeding levels ($F_{1,41}$=22.87, P=0.01) indicating rapid bioaccumulation, but females had lower levels because they likely deposited mercury into eggs.

Surf Scoters. We also sampled and radio-marked 160 Surf Scoters and obtained more than 3,100 locations during the winter. We sampled their invertebrate prey and documented bioaccumulation from 159 scoters from early (Nov-Dec), mid (Jan-Feb), and late (Mar-Apr) winter. Scoters had increased Hg in livers from early to late winter (t_{38}=-3.62, P=0.01), with larger differences in the North Bay (t_{14}=2.33, P=0.01). Most birds departed San Francisco Bay by April 15, 2005, and we followed satellite-marked birds to breeding areas in boreal forest of Canada near Yellowknife (http://www.werc.usgs.gov/sattrack/scoter).

Nesting studies on recurves and terns. Nests were monitored weekly for 419 Avocets, 168 Stilts, and 581 Forster's Terns. Recurve nest success was highest for Avocets in Alviso's Pond A16 (86%) where land predators had limited access. Nest success was lower in Pond A8 (35%) where California Gulls depredated nests, but Stilts had success in New Chicago Marsh (48%) where vegetation protected nests from aerial, but not land predators. Forster's Terns nesting on island colonies had higher success than recurves (range: 57%-94%).

Recurve chick studies. We captured 107 recurve chicks soon after hatching and attached transmitters with temperature sensors. We obtained 760 locations and identified cause-of-death for chicks that died. Only 13.9% (±4.2% SE) of Avocet and 31.7% (±10.1% SE) of Stilt chicks survived 21 days. Mortality was 2.52 (1.45-4.39) times greater for Avocet than Stilt chicks (N=107, X^2=10.67, P=0.001) and decreased for lighter chicks (N=107, X^2=6.18, P=0.01), but was not related to hatching date (N=107, X^2=1.81, P=0.18). Fifteen transmitters from Avocets were found at the Pond A6 California Gull colony (>17,000 gulls), but no Stilts were taken by Gulls.

Tern chick studies. We captured 1,290 Forster's Terns and found differences in Hg levels among colonies ($F_{2,10}$=8.04, P=0.01) and hatching dates ($F_{3,1280}$=509.0, P<0.001), but not growth rates (λ=0.92, $F_{9,253}$=1.0, P=0.40; date: λ=0.94, $F_{3,104}$=2.4, P=0.07). Wing growth rates declined with increasing muscle Hg (R^2=0.71, N=6, P=0.12).

Laboratory studies on species sensitivity. For decades, Mallards have been used to assess Hg toxicity in laboratory trials. Recently, egg injection studies have been used to examine species differences in embryo sensitivity. We are testing embryo survival through 90% of incubation in 23 species of birds. For example, survival decreased in Ibis at 0.1 ppm Hg compared with 1.6 ppm Hg in Mallards.

Management implications. Our studies of bird movements, diet, and sensitivity are providing a much clearer understanding of bioaccumulation in birds. Habitat restoration will benefit from these studies to allow for analysis of the potential for bioaccumulation, including the potential to carry contaminants to northern breeding areas. With greater understanding of these processes, we should be able to better predict likely mercury risks to biota in many regions of the estuary.

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Snowy Plover Nesting in Salt Ponds around the San Francisco Bay: Water Levels, Predators, and Management

LESLIE TUCCI and CHERYL M. STRONG, San Francisco Bay Bird Observatory, 524 Valley Way, Milpitas, CA 95035; 95002; 408-946-6548, current contact information: cheryl_strong@fws.gov

JOY ALBERTSON, Don Edwards San Francisco Bay National Wildlife Refuge, P.O. Box 524, Newark, CA 94560; 510-792-0222

Since 2003, the San Francisco Bay Bird Observatory and the Don Edwards San Francisco Bay National Wildlife Refuge (Refuge) have coordinated monitoring efforts for the Pacific Coast Western Snowy Plover (*Charadrius alexandrinus nivosus*) breeding population in the San Francisco Bay Area. We estimated plover and avian predator numbers and, in 2004, began tracking the success of plover nests.

Snowy Plovers nest on a number of ponds in the South Bay; however, the vast majority of plovers are found on a very few ponds. Eden Landing, near the San Mateo Bridge, houses the majority of the Bay's plovers. Within the ponds, plovers nest on large, isolated playas with little or no connection to surrounding levees. Most nests are located near high-salinity foraging areas that have large swarms of brine flies for plover adults and chicks.

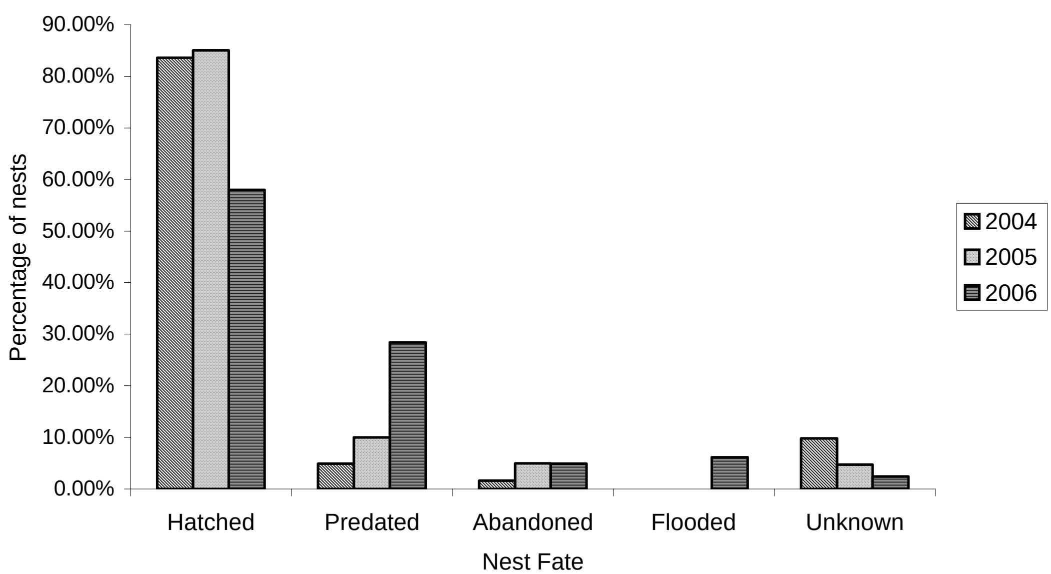
In 2006, we found 81 nests in the South Bay. Out of these nests, 23 of them were predated, four were abandoned, five were flooded, and 47 hatched (Figure 1). One hundred thirty-three chicks hatched from known nests, but we have no information on chick survival. We estimate that approximately 100 plovers are nesting in the San Francisco Bay overall, all on salt ponds in the South Bay. The biggest concerns we have identified that limit Snowy Plover numbers in the Bay include avian predators and water level management.

The timing of lowering water levels plays an important role in nest site selection; late rains as well as pond water management can limit nesting sites. Various ponds are now managed for plover nesting habitat, and actively lowering the water levels early in the nesting season in 2006 increased the surface area available for nests. Water management allows us to provide better nesting habitat, but we are still learning how best to balance water intake with tidal fluctuations to maintain isolated playas while avoiding nest flooding.

Nest success for the Bay decreased from 83.6% in 2004 and 85% in 2005 to 58% this year due to high levels of predation. Primary predators of concern include California Gulls, Northern Harriers, raccoons, skunks, foxes, and cats. Northern Harriers were of particular concern in 2006, since a number of pairs nested in the marsh adjacent to the plover nesting areas and harriers hunted low over the salt pannes. Harriers will probably be of greater concern as restoration increases the amount of marsh in the landscape. California Gulls are of concern due to their sheer numbers in the South Bay; they are increasingly seen roosting and foraging in the area with the highest concentration of plovers (Robinson et al. 2006, Strong et al. 2004).

Since nearly all of the Snowy Plover nesting and foraging habitat is located within the footprint of the South Bay Salt Pond Restoration Project, special efforts should be made to retain sufficient habitat for Snowy Plovers in the future. Our management recommendations include providing drying salt ponds for nesting along with adjacent high salinity foraging ponds for adults with broods. While nesting islands within forage ponds could provide plovers with necessary habitat for their eggs and broods, it remains to be seen whether or not Bay plovers will successfully nest on island habitat. To reduce predation, we recommend removing perches and modifying power towers to limit use by nesting predators. Predator removal will likely be required in order to increase plover nesting success in the South Bay.

Figure 1. Western Snowy Plover nest fates in the South Bay, 2004-2006.



Citations

Robinson, C., C. Strong, L. Tucci and J. Albertson. 2006. Western Snowy Plover Numbers, Nesting Success, and Avian Predator Surveys in the San Francisco Bay, 2006. Unpub. report to the USFWS and CDFG. San Francisco Bay Bird Observatory, Alviso California.

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MANAGEMENT

AND

POLICY

Habitat Restoration in an Urban Setting: Uncovering Opportunities, Creating Partnerships and Mobilizing Volunteers to Restore the South Bay Salt Ponds

Marilyn Latta, Save The Bay, 350 Frank Ogawa Plaza, Suite 900, Oakland, CA

Save The Bay is one of many partners supporting the South Bay Salt Pond Restoration Project, assisting in many ways from advocacy to planning to providing some of the first opportunities for the public to be involved at the Eden Landing Ecological Reserve in partnership with the California Department of Fish and Game. Our work provides:

- A model for responsible public access/ restoration stewardship
- Low-cost techniques for how to move forward beyond levee breaching, including eradicating invasives and establishing natives
- Site monitoring appropriate for volunteers- small low-cost pilot experiments that may be applied to larger breaches

Save The Bay's Community-Based Restoration Program

In 2000, Save The Bay founded its Community-Based Restoration Program to create diverse partnerships between local schools, community groups, businesses, and resource agencies to involve the public in wetland habitat restoration projects. Save The Bay has used a variety of innovative techniques to build support and participation within the community, focusing especially on schools and community groups.

In the six years since it was created, the Community-Based Restoration Program has engaged over 35,000 student and adult volunteers in restoring habitat at ten regional wetland, island, creek, eelgrass, and oyster sites around the Bay. This translates to over 140,000 hours of volunteer labor at these sites. Volunteers have removed more than 220,000 pounds of non-native invasive plants in wetland restoration areas, and planted over 85,000 wetland native species, all grown from seed collected by volunteers at each site. Volunteer participation in wetland habitat restoration has contributed substantially to wetland restoration sites in the San Francisco Bay Estuary, and our successful model is already being replicated in other areas of California.

Key partners in Save The Bay's Community-based Restoration Program include East Bay Regional Park District, the City of Palo Alto, the U.S. Fish and Wildlife Service (at San Pablo Bay National Wildlife Refuge, Marin Islands National Wildlife Refuge and State Ecological Reserve, and Don Edwards National Wildlife Refuge), California Department of Fish and Game, Marin County Open Space District, the California Coastal Conservancy, National Fish and

Wildlife Foundation, and the national partnership between Restore America's Estuaries and NOAA Fisheries Community-Based Restoration Program.

Clockwise from top left: Students help grow native plants; a native oyster—the focus of one of Save The Bay's restoration programs; volunteers work at Bair Island; children get involved too—after all, they're inheriting this planet!

Salt Pond Restoration in the San Francisco Estuary: Management Options for Reducing Mercury Methylation

Phillip A. Lebednik, John Grattan, Pablo R. Martos, and Peter T. Zawislanski
LFR Inc., 1900 Powell St., 12th Flr., Emeryville, CA 94608
Contact for further information: phillip.lebednik@lfr.com

<u>Project Team Members</u>
LFR Inc, San Francisco Bay Regional Water Quality Control Board, Association of Bay Area Governments, University of California at Santa Cruz, San Francisco Estuary Institute, San Francisco Bay Area Wetlands Restoration Program, San Francisco Estuary Project, San Francisco Bay Conservation and Development Commission, Bay Planning Coalition, Young Community Developers, Inc.

Methylmercury, the most toxic form of mercury, is a cancer-causing substance and also a potent neurotoxin. Based in part on high levels of methylmercury in fish tissue and the resulting fish consumption advisories, San Francisco Bay (Bay) has been listed by the State as a water body impaired by mercury. Concern over human consumption of Bay fish has led to a state grant that is funding this project, with the ultimate goal of lower the levels of methylmercury in fish and other biota in the Bay. To accomplish this goal, this project is focusing on reducing the uptake of methylmercury in Bay tidal wetlands. Wetlands are important because it is thought that most of the methylmercury found in fish is produced in these locations. The three-year project was initiated in late 2005. It will generate recommendations for managing marsh ecosystems to minimize methylmercury uptake in wetlands and reduce mercury concentrations in Bay fish. The project will also recommend approaches for minimizing methylmercury exposure in restored marshes, such as those in the South Bay Salt Pond Restoration Project.

The project team (LFR and UC Santa Cruz) is collaborating with the South Bay Salt Pond Restoration Project (SBSP) to conduct studies in SBSP salt ponds, and will ultimately provide recommendations for control options to minimize methylmercury production in salt ponds that are being restored to tidal marsh habitat. Restoration projects around the Bay that expand the amount of tidal wetlands could hypothetically result in higher levels of mercury in Bay fish. Current literature indicates that areas newly flooded as a result of levee breaching could generate higher levels of methylmercury when compared with existing tidal wetlands. Under this hypothetical scenario, methylmercury initially accelerates to a higher level over a period of years (intermediate phase) and then decelerates to some lower equilibrium level as the restored marsh matures (climax phase). This project will take such a trajectory into account when developing control options. For each phase we will estimate the potential for methylmercury production, identify potential control strategies for managing and/or restoring the ponds, and determine the degree to which such strategies are expected to reduce methylmercury production.

The primary questions being addressed in the project are: 1) What are the environmental parameters controlling the production of methylmercury in Bay wetlands? and 2) How can these parameters be feasibly manipulated to reduce the amount of methylmercury taken up into Bay food webs? The environmental parameters controlling methylmercury production are being assessed through: 1) review of scientific literature on mercury biogeochemistry and, 2) field studies measuring levels methylmercury alongside the various parameters thought to control it. The means of manipulating methylmercury, or "control options", are being developed primarily with existing tools and techniques for controlling the water, sediment, and biological composition of wetlands. Promising control options will then be tested in pilot studies to determine how well they control methylmercury production.

This project will result in a number of products that will be submitted to the San Francisco Bay Regional Water Quality Control Board, including recommendations for: 1) methylmercury control options, 2) monitoring protocols to document reduction in methylation of mercury in tidal wetlands and, 3) future studies based on data gaps. Recommendations generated by the project could ultimately be adopted and implemented on a regulatory basis by the state. Figure 1 illustrates two potential control options and their theoretical effect on methylmercury (MeHg) production.

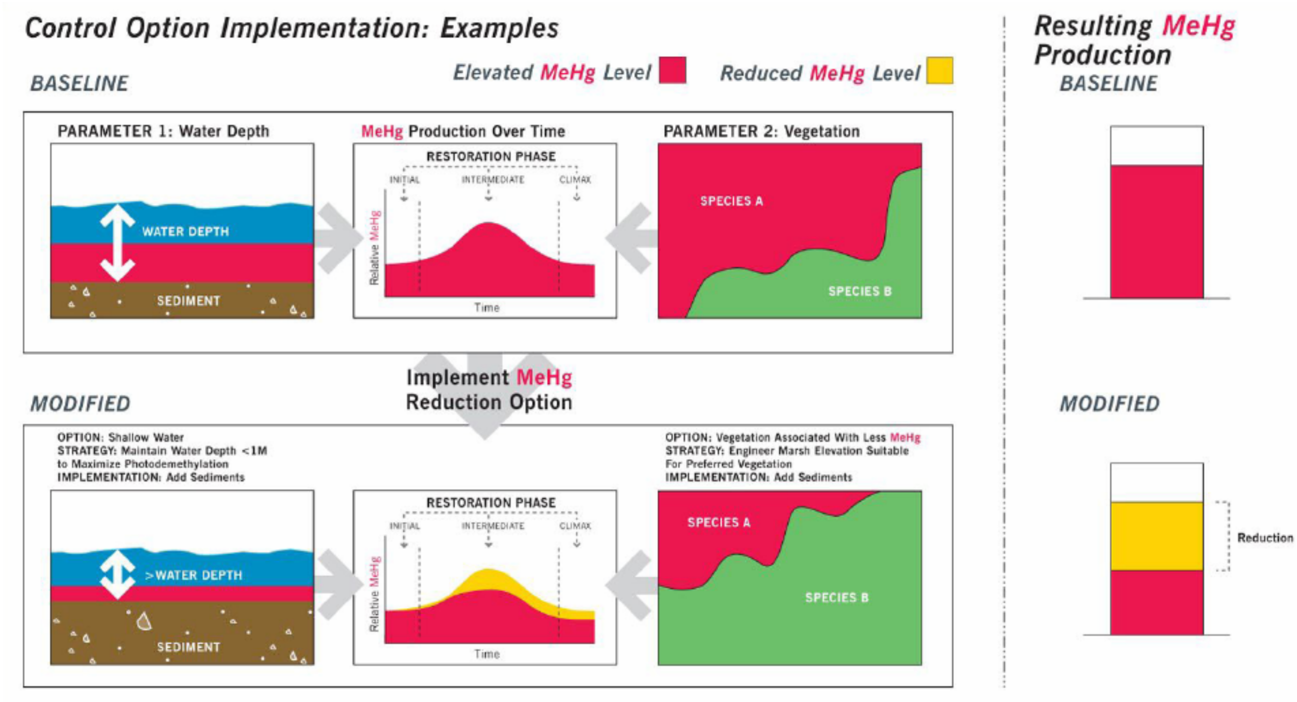

Figure 1. Conceptualization of how management options may reduce methylmercury in marsh systems.

Adaptively Managing Public Access and Wildlife: Shorebirds and Trails

Lynne Trulio[1] and Jana Sokale[2]

1 Department of Environmental Studies, One Washington Square, San Jose State University, San Jose, CA 95192-0115; ltrulio@earthlink.net
2 Sokale Environmental Consulting, 7788 Hazelnut Drive, Newark, CA 94560

This presentation was delivered before publication was complete. Please see the published work:
Trulio, L. and J. Sokale. 2008. Shorebird Foraging in Response to Trail Use around San Francisco Bay. Journal of Wildlife Management 72(8):1775-1780.

The mission of the 15,100-acre South Bay Salt Pond Restoration Project is the restoration and enhancement of wetlands in the South San Francisco Bay while providing for flood management and wildlife-oriented public access and recreation. To meet public assess goals, a range of public access features, including trails, overlooks, and kayak launches, will be integrated into the Project's habitat management actions. However, there is significant uncertainty about the effects of public access on sensitive species. To address these uncertainties, adaptive management--a directed approach to achieving the Project's objectives through learning from management actions—will be used to determine how best to meet these two, potentially competing, goals. Information from monitoring and applied studies will be used to adaptively manage public access based on: 1) public access effects on wildlife, and 2) public demand for access/recreation features.

The Project is planning to add a large number of new trails in the area and the effect of trails on waterbirds is a key management question. Researchers agree that breeding waterbirds are very sensitive to human disturbance, whether the disturbance is from trail use, boats, or research (Carney and Sydeman 1999). Hunting is widely recognized as a major for species, causing death and changing behavior (Madsen 1998a,b). Research can also cause serious impacts to species such as nest abandonment and stress (Carney and Sydeman 1999). Studies also show that directly approaching birds is significant source of disturbance (Thomas, et al. 2003, Klein, 1993, Burger & Gochfeld, 1981). However, the effects of trail use on migratory shorebirds in foraging habitat have not been well studied and information specific to the San Francisco Bay is needed.

To provide some information on this question, we studied the effect of trail use on waterbird numbers, species richness and foraging behavior at three locations around the San Francisco Bay for 24 months, from July 1, 1999 to September 30, 2001. We collected data at

100 ft x 100 ft trail and non-trail sites at each location. Each site was tidal and mudflats were fully exposed at low tide. We counted birds in the quadrats and the number of trail users going by the quadrats for 4-hour periods, on 2 weekdays and 2 weekend days per month.

Eighty-five percent of the birds we observed during the study were shorebirds and the majority of these were western and least sandpipers. Human trail use varied greatly between trail and non-trail sites and between paired high use (typically weekend days) and lower use days (typically weekdays) (Figure 1).

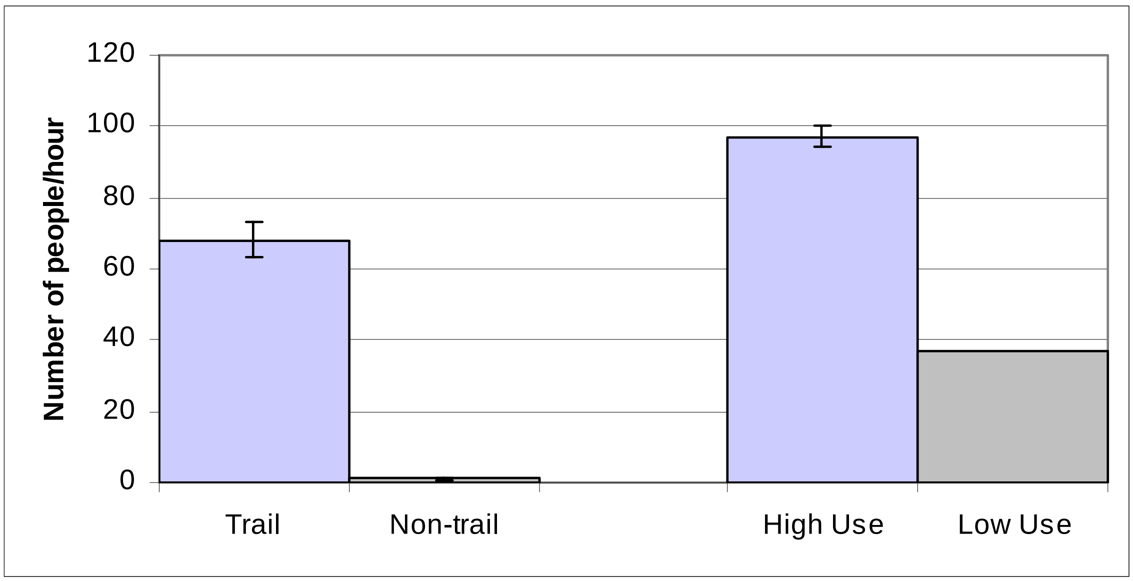

Figure 1. Human trail use per hour (means and standard errors) at Trail and Non-Trail sites and on high use days versus paired lower use days at the trail sites.

Preliminary analyses were conducted using General Linear Models and analyzed only shorebirds as they dominated our sites. For trail versus non-trail sites, we found no relationship between the number of trail users and the number of shorebirds ($F_{2,239} = 0.289$; $P = 0.593$). Nor was there a relationship between the percent of birds foraging and trail use ($F_{1,239} = 0.003$; $P = 0.955$). The number of species was related to trail use ($F_{1,239} = 7.509$; $P = 0.007$), but this was due to an increase in species number with trail user number.

For paired higher use versus lower use days (typically, weekends versus weekdays), preliminary analyses indicated that human trail use had an effect on the number of birds ($F_{1, 119} = 3.848$; $P = 0.052$) and this effect was due to a gradual decrease in the number of birds as trail use rose. Average species richness per 4-hour observation day did not differ between high and lower use days ($F_{2,119} = 0.903$; $P = 0.344$), nor did the average proportion of birds foraging ($F_{2,104} = 0.247$; $P = 0.781$).

These analyses indicate that human trail use at the trail versus non-trail sites had no negative effects on bird response as measured by the number of birds using the sites, the number species, and the percent of birds foraging. This low response may be due to these factors:

- Tangential approach, such as at our sites, disturbs shorebirds less than direct approach.
- Rapid movement and loud noises are significant disturbance factors, but did not occur at our site.s
- Large waterbirds respond sooner than small ones, and the birds we studied were small.
- Dogs are a big source of disturbance, but were uncommon at our sites.
- Birds at our sites may be habituated to human presence.

We did find bird numbers decreased with increasing trail use numbers at trail sites, which indicates that high use, such as occurs on weekends, may negatively affect bird presence.

Given the range of human use we saw at our sites, these findings suggest that managers may responsibly locate trails next to shorebird foraging habitat, especially if conditions listed above occur. However, it is essential that shorebirds have significant areas where no trails or other public access exist, to provide them undisturbed habitat for nesting, foraging, and loafing. Final results of this research will appear in *Journal of Wildlife Management*, 72 (8):1775-1780.

These findings on shorebirds can be used to help adaptively manage trail siting, development, and use. On-going research will provide information on managing other wildlife-public access interactions, including recreational boating in harbor seal and foraging waterfowl habitat as well as trail use in nesting snowy plover and foraging waterfowl habitat.

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