South Bay Salt Ponds Restoration Project, Short-term Data Needs, 2003-2005 Draft Final Report

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****Preliminary Data, Please Do Not Cite or Distribute Without Permission****

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South Bay Salt Ponds Restoration Project Short-term Data Needs, 2003-2005
Draft Final Report

*****Preliminary Results. Do Not Cite or Distribute Without Permission*****

EXECUTIVE SUMMARY

- A partnership of federal, state, and non-profit agencies purchased 15,100 acres of South Bay salt evaporation ponds for management by the U. S. Fish and Wildlife Service (FWS) and California Department of Fish and Game (DFG) in 2003. These ponds represent an opportunity to restore lost tidal marsh habitat, but they also support large numbers of waterbirds and have become an integral part of the ecosystem over the past 150 years. Restoration planning and early actions are now underway to create a mixture of managed pond and tidal wetland habitat, but several data gaps have been identified that are essential to the planning and restoration process.

- The U. S. Geological Survey (USGS) began data collection efforts to fulfill priority project data needs in the spring 2003. These efforts were discussed with and funded by the State Coastal Conservancy (SCC), FWS, and DFG, supplemented by USGS science programs including the Priority Ecosystem Science (PES) Initiative, under which USGS has been studying salt pond ecosystems in the Bay since 1998. The interdisciplinary USGS science support team is providing the restoration project with a comprehensive assessment of the ecology of the San Francisco Bay salt ponds, baylands, and linked shallow water wetlands, such that optimal management strategies can be exercised that maximize benefits to wildlife. These data will provide a scientific basis for decisions supporting further research and monitoring as well as adaptive management actions. The short-term needs data provided in this report are intended to provide resource managers with critical baseline data for the restoration project.

- We developed 3 different bathymetry datasets: ponds, LIDAR, and seabed. Pond datasets were derived for 35 inundated salt ponds with a specialized shallow water sounding system created by USGS (Water Resources and Biological Resources) for the task. In 2004, point data along transect lines spaced at 50-100 m were interpolated to 25-m grid files, and converted to GIS coverages. Water depths were converted to the NAVD88 datum on the basis of staff-gage surveys from Fremont Engineers contracted by Cargill Corporation. These staff-gage surveys were distributed without metadata, so the bathymetry datasets were distributed in August 2004 with metadata files that noted the limited staff-gage information. An engineer with the consultant team found a discrepancy in the extrapolated elevations in January 2005, which was brought to our attention in May 2005. After determining that staff gages were measured differently, we sent a correction notice and revised elevation dataset for some ponds although the original water depths did not change.

- A LIght Detecting And Ranging (LIDAR) laser system (Terrapoint, Inc., managed by USGS Coastal and Marine Geology) was used to generate one of the most detailed elevation maps ever created of mud flats in an estuary. A grid of returns was created at

1-m resolution in an ASCII file, and those points were converted into 1 m and 25 m coverages, partitioned into tiles. Contours generated at 50-cm intervals were made available in AutoCAD (DWG) format. One-meter resolution hill-shaded images of both the bare earth and full feature data sets were created in GeoTIFF format. In addition, digital video imagery was collected at 2 frames per second during all flight missions and geo-referenced in AVI format with accompanying GPS files designed for viewing with Trident 3D Vision software.

❖ A seabed bathymetry survey of the South Bay was conducted by Sea Surveyors from 10 January to 5 April, 2005 under direction of Coastal and Marine Geology. The survey area was 250 km^2, extending northward from Coyote Creek in the south to San Leandro Marina on the east and Coyote Point on the west, encompassing the three purchased pond systems (Eden Landing, Alviso, and Ravenswood). A database of 450,000 seabed classification records was generated from an area of 78 km^2. Ten acoustic classes were identified representing the spatial distribution of estuary sediments segmented into tidal flat, nearshore, shelf, channel, and dredged sediments. Sediment data from 180 grab and core samples, and benthic community composition data from 10 bottom samples were collected to refine the classification scheme.

❖ Because the salt ponds were created with dredge materials, the soil types in the majority of ponds were found to have high clay, moderate silt content, and lower sand content, with the exception of West Bay ponds, which had higher sand content than the other areas. Slough sediment samples were generally lower in salinity and organic carbon content. Slough sediments were mainly silty clay loam, having higher sand and silt content than pond sediments.

❖ Organic carbon levels detected in Alviso ponds ranged from 1.15 – 4.46 mg/L, mean 2.76 mg/L; Eden Landing ponds ranged from 1.52 – 4.30 mg/L, mean 2.64 mg/L, and Ravenswood ponds ranged from 0.92 – 2.93 mg/L, mean 1.46 mg/L. As salt ponds are converted to marshlands, high organic carbon may be a determining factor for invertebrates and contaminants. Most NH4-N and NO3-N nutrient levels were relatively low, similar to those associated with unpolluted surface lake waters. Concentrations well above 10 mg/L are associated with anaerobic or polluted conditions, but only Pond B6B approached the 10 mg/L level.

❖ Water quality was collected monthly in all 53 purchased salt ponds. Temperature in the ponds follows a seasonal signal with highest temperatures in the summer. Between-pond temperature differences were typically less than 5ºC, except during the fall when the differences can exceed 6ºC. Salinity in the ponds is influenced primarily by rainfall during the wet winter season, and evaporation and water transfers during the dry season. Highest salinities are typically seen in the late summer and fall, especially for the higher salinity ponds. Water quality (salinity, temperature, pH, and dissolved oxygen) of ponds changed under the Interim Stewardship Plan are available in separate reports.

❖ Opening the salt ponds to tidal action will create multiple new sediment sinks in South Bay and will affect suspended sediment concentrations (SSCs) and net sedimentation in the Bay. In order to evaluate sediment sources, sinks, and deposition, a sediment budget for South Bay was developed using a sediment transport box model. A 10% predicted decrease in South Bay SSCs from opening additional South Bay area to tidal action will increase the likelihood that South Bay could experience a phytoplankton bloom in any given year. However, the effect of the increased likeliness of a bloom is less than the inter-annual variability in water column clearing rates caused by inter-annual variability in benthic grazing rates.

❖ A salt pond box model (SPOOM) was created to predict how water transfers will affect the salinity and depths in the ponds. Both salinity and depth are critical parameters for habitat modification and restoration. The same sediment transport box model was used to simulate the affect of adding breached ponds to the system to learn how it could change the sediment budget. These simulations allowed a landscape-scale geomorphic assessment of restoration alternatives.

❖ Distribution of wetland vegetation was studied along three slough sites (Corkscrew Marsh, Bird Island and Palo Alto Baylands) to predict evolution of wetland plants during pond restoration. Salt marsh vegetation ranged in elevation from 0.98 to 2.94 meters above MLLW. *Spartina foliosa* and *Salicornia virginica* were the most frequently observed plant species. *Atriplex patula*, *Deschampsia cespitosa* and *Limonium californicum* were each recorded at only one of the three sites.

❖ We identified 58 different taxonomic groups of macroinvertebrates in ponds. The most abundant and diverse group was the Crustacea with 17 different taxa, followed by 12 different genera of Annelids, mostly in ponds with salinity levels below 60 ppt. There were 5 different species of bivalves, and 9 insect families. Ponds with lowest salinity (27-44 ppt) had greatest taxa richness. There was a relationship between increasing salinity and decreasing richness in benthic grabs. Insecta taxa (Corixidae, Diptera and Ephydra) were positively correlated with salinity ($R^2 = 0.37$, $P<0.001$) as was Artemia ($R^2 = 0.41$, $P<0.001$); Crustacean genera Ampelisca and Corophium were negatively correlated with salinity ($R^2 = 0.56$, $P<0.001$) as were Capitella, Polydora, *Streblospio*, and Tubificoides ($R^2 = 0.50$, $P<0.001$).

❖ Samples from 8 sloughs in 2004 were dominated with *Heteromastus*, *Streblospio* and Tubeficoides. *Gemma gemma* was abundant in Mt. Eden Creek (162.6 per Ekman) and Alameda Creek (29 per Ekman) and *Macoma balthica* was present in all sloughs with largest numbers found in the Alameda Control Channel (25 per Ekman). Insecta were present in only 3 sloughs with greatest taxa richness in Mt. Eden Creek (4 species). Chironomidae was present in Mt. Eden Creek and the Alameda Flood Control Channel. Corixidae and Diptera were detected in Mt. Eden Creek and Alameda Creek. *Cumacea* were present in all sloughs and were the most abundant Crustacean in slough samples.

❖ A total of 10,258 fish representing 19 species and 16 families was caught during 2004. Of the 19 species, 13 were caught in ponds and 16 in sloughs. The greatest numbers of fish were captured with bag seines, followed by gill nets, then by minnow traps. Fish abundance was highest in June and lowest in November.

- Avian use of salt ponds varied by foraging guild, pond, and season. Alviso constituted 57% of total pond area, but supported 92% of gulls and terns and 90% of dabbling ducks counted between November 2003 and June 2005. Alviso also supported 73% of diving ducks, 72% of eared grebes, 66% of herons, and 63% of fish eaters and phalaropes. Eden Landing ponds were shallower and supported the highest proportion of shorebirds -- 52% of large shorebirds and 44% of small shorebirds between November 2003 and June 2005, despite comprising only 31% of total pond area. Eden Landing also supported 35% of fish eaters, 32% of herons, 27% of eared grebes, 24% of divers, 12% of phalaropes, 10% of dabblers, and 7% of gulls and terns. Ravenswood comprised only about 11% of total pond area and supported 31% of small shorebirds between November 2003 and June 2005. Ravenswood also supported 26% of phalaropes and 12% of medium shorebirds – counts of all other foraging guilds made up less than 5% of the total salt pond count.

- We completed Interim Stewardship Plan (ISP) analyses requested by the Project Management Team. We created extensive spreadsheets for birds, fish, and benthic data appended with physical data (temp, DO, salinity, pH, size, depth, bay distance) for each pond (available to the PMT on request). We analyzed relationships of bird use to pond conditions and provided information for estimates of richness on the spreadsheets. ISP bird survey results and subsampling questions were presented in the Bird Modeling Workshop, and results from multivariate analyses (Canonical Correspondence Analysis) of physical features of similar ponds were presented in the Pond Management Workshop. We initiated analyses that related birds to fish and invertebrate populations and refer to completed analyses in the North Bay (Takekawa et al., *in press*). Relationships of mercury, pond depth, and salinity were included in the interim mercury report, and we summarized foraging behavior of birds by pond. Finally, we are continuing analyses within grids to relate bird use to pond depths.

- The short-term needs data collected during the first two years of the SBSP Restoration Project has provided baseline information to develop a sound scientific foundation upon which management plans and actions may be based. Effective adaptive management of this complex restoration effort will require regular monitoring to detect changes and responses of the resources.

- The wetland mosaic of the entire South Bay will be changing; thus, scientific assessments should include analyses at the regional scale. For example, open bay mud flats are critical resources for migratory birds, but South Bay mud flat elevations may decrease in response to the restoration process. The SBSP Restoration Project will extend for 50 years, but the most valuable scientific investment will be in early phases of the project, since it will influence more of the major restoration decisions. We look forward to the challenge of continuing the USGS science support role for the restoration project.

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INTRODUCTION

During the past 200 years, the San Francisco Bay Estuary has undergone topographical and ecological changes resulting from human growth and development. Nearly 79% of historic salt marshes have been lost, resulting in diminished habitat for native marsh species (Goals Project 1999) and fragmentation of remaining marshlands. Commercial salt ponds were constructed around the fringes of the bay and have been a part of San Francisco Bay's landscape since 1856 (Josselyn 1983). Today, these salt ponds represent not a chance to make commercial use of unusable land but an unprecedented opportunity to reclaim and restore vital habitat for native wildlife. However, salt ponds are also important for migratory birds, and maintaining some land as managed ponds will provide refuge and foraging habitat for hundreds of thousands of wintering shorebirds and waterfowl, as well as unique assemblages of invertebrates and native fishes (Harvey *et al*. 1992, Takekawa *et al.* 2000, Takekawa *et al*., *in press*).

One of the largest wetland restoration projects in North America commenced in March 2003 with the purchase of 6,111 ha (15,100 acres) of former salt evaporation ponds in the South Bay of the San Francisco Bay estuary (Figure 1). A consortium of public and private partners acquired the wetlands, which included 3,236 ha (7,997 ac) in the Alviso complex (25 ponds), 2,206 ha (5,450 ac) in the Baumberg or Eden Landing complex (22 ponds), and 655 ha (1,618 ac) in the Redwood or Ravenswood complex (7 ponds). Alviso and Ravenswood are managed by the U. S. Fish and Wildlife Service, while Eden Landing is managed by the California Department of Fish and Game. The South Bay Salt Ponds (SBSP) Restoration Project was quickly recognized as the largest and most complex wetland restoration undertaking in the Bay; Siegel and Bachand (2002a) identified several complicated issues that could impede restoration actions or increase costs. Subsequently, Siegel and Bachand (2002b) identified short-term information needs that need to be met within the first few years for effective project planning. These needs included biophysical data collection both within the ponds and in the adjacent sloughs and were reviewed by the project management team to determine priorities.

Project objectives include maintaining current migratory bird use of salt ponds while supporting increased populations of native species that use tidal marsh habitat. Only a few descriptive studies (Carpelan 1957, Anderson 1970, Lonzarich and Smith 1997) of ecological processes of the salt ponds had reported on their value for wildlife. Although hypersaline systems such as salt ponds typically support simple assemblages of biota, the physical and biological processes affecting these assemblages may be quite complex (e.g., Rodriquez-Valera *et al*. 1985, Caumette *et al*. 1994; Pinckney and Paerl 1997). Ecological interactions and physical processes in these artificial salt ponds are poorly understood (*see* Lonzarich and Smith 1997), but the importance of lower trophic organisms and their use by migratory waterbirds has been supported by our prior research (Miles *et al.* 2000, Takekawa *et al*. 2000, Miles *et al.* 2004, Takekawa *et al. in press*) and identified in similar systems (e.g., Herbst and Bradley 1993, Elphick and Rubega 1995; Herbst and Castenholz 1995).

Managers and conservation organizations have supported conversion of most salt ponds to tidal wetlands to benefit tidal marsh resident species of concern. Additionally, the project management team has acknowledged that some ponds should remain as managed salt ponds, as artificial salt evaporation pond systems have become integral habitat for wildlife in the estuary during the past century and currently support massive diverse and unique communities of migratory birds, invertebrates, and fishes (Ver Planck 1958). However, no guidelines, model, or management strategies exist for converting ponds to tidal wetlands, nor for maintaining salt ponds at desired depths and salinities when ponds are no longer part of a salt-making system. Because very high bird densities have been observed on a few ponds, managers hope to optimize features of the managed ponds remaining after restoration to support past numbers of migratory and wintering birds. However, avian pond selection criteria are not fully understood, and seemingly similar ponds often show high variation in bird use. More information will be needed to successfully manage habitat that will support the historic bird numbers that make San Francisco Bay an important migratory stopover site on the Pacific Flyway and a Western Hemispheric Shorebird Reserve Network area of hemispheric importance.

The restoration of subsided ponds to tidal wetlands presents many challenges as well, particularly due to a lack of detailed and reliable information on project area elevations and sediment supply. Siegel and Bachand (2002a) identified sediment supply as a key constraint to salt pond restoration. Some of the South Bay sloughs are filling with sediment according to several observations, perhaps because subsidence caused by groundwater overdraft has ceased. An evaluation of sediment sources, sinks, and deposition is necessary to understand how these processes may affect restoration timing, project costs, and potential action to minimize erosion of South Bay mud flats.

After consultation with management agencies, the U. S. Geological Survey (USGS) began a program to fulfill priority project data needs in the spring of 2003. These efforts were supported by the State Coastal Conservancy (SCC) and supplemented by the USGS Priority Ecosystem Science Initiative, under which we have been studying salt pond ecosystems in SFB since 1998. Data provided from this multidisciplinary effort are intended to provide resource managers with a comprehensive assessment of the ecology of the South Bay salt ponds and linked shallow water systems, such that optimal management strategies can be exercised that maximize benefits to wildlife. These data will provide a scientific baseline for decisions supporting further research and monitoring during the restoration, as well as for adaptive management actions. Beyond this USGS final report, we also have provided interim products including the following:

- Jan04 – Salt Pond Nutrient Report
- Feb04 – South Bay Sediment Budget (presented at American Society of Limnology and Oceanography meeting)
- Mar04 – Draft Data Gaps Summary Report
- Jun04 – South Bay Mud Flat Invertebrate Report
- Jul04 – Salt Pond and Slough Sediment Report
- Jul04 – Draft Channel Marker 17 Data Report
- Aug04 – Pond Bathymetry Data and Metadata (CDROM)
- Sep04 – Sediment Synthesis for the SBSP Restoration Project (delivered to the National Science Panel)
- Nov04 – GIS Coverages of the Pond Bathymetry (delivered to the project consultants)
- Apr05 – Coyote Creek Suspended Sediment Report
- Mar05 – Pond Bathymetry Correction Memorandum
- Aug05 – USGS Open-File Report (OFR-2005-1284) on 2004 LIDAR Survey

OBJECTIVES

The primary goals of the short-term data needs studies were to provide baseline data for the SBSP Restoration Project and to provide a scientific basis for adaptive management decisions.

Objective 1. Complete bathymetry and levee habitat mapping of ponds in the purchase agreement for interim management and hydrological modeling of restoration scenarios.

Objective 2. Characterize sediments, primary productivity, invertebrate composition, and fishes in ponds for salinity reduction and initial phases of restoration.

Objective 3a. Continue monthly monitoring of water quality concurrent with bird surveys to document baseline levels and to track changes.

Objective 3b. Complete Self-Monitoring Program (SMP) sampling and reports to document compliance with discharge requirements during the initial desalination.

Objective 4. Assess the hydrology and present morphology of the South Bay sloughs by analyzing existing data augmented with collection of new data.

Objective 5. Characterize invertebrate and fish communities in the slough systems and compare with South Bay pond communities.

Objective 6. Assist in development of a land surface elevation map for the South Bay region and map South Bay open bay and slough bathymetry.

METHODS

Objective 1. Complete bathymetry and levee habitat mapping of ponds in the purchase agreement for interim management and hydrological modeling of restoration scenarios.

Scientists from Water Resources and Biological Resources developed a shallow-water sounding system comprised of a single beam echosounder (Navisound 210, Reson), a differential global positioning system unit (DGPS, Trimble) and a laptop computer in a water-resistant case affixed to a shallow-draft, double-hulled kayak with a salt water trolling motor. This system proved effective in measuring water depths with a precision of 1 cm. Twenty depth readings and one GPS location were recorded each second; we obtained the average of twenty depth values per location during post-collection processing (SAS Institute, 1990).

Where ponds contained water of sufficient depth to use the equipment, we obtained sample transects at 100-m intervals. Because sample depths were converted to elevation based on water surface elevation, we obtained staff gage readings at 15-20 minute intervals to ensure that pond water levels did not change during the survey. We successfully sampled 35 inundated ponds, most sampled between August 2003 and March 2004. Each required 1-4 days to sample depending on pond size and sampling conditions. Prior to and following each sampling event, we checked the equipment for accuracy by performing a physical measurement of depth (with a bar check system or measuring pole) and compared it to the transducer reading. Raw data were compiled, reformatted, and converted to latitude, longitude, and depth measurements based on staff gage readings and known staff gage elevations (see individual pond metadata files for details). Data were converted to point shapefiles (ArcGIS, ESRI, Redlands, CA) and interpolated to 25-m ESRI grids (ESRI Spatial Analyst) using the inverse distance weighting method with barrier polylines to more realistically represent known topographical features.

Objective 2. Characterize sediments, primary productivity, invertebrate composition, and fishes in ponds for salinity reduction and initial phases of restoration.

Our goal was to develop a baseline characterization of the physical and biological parameters of all 53 ponds in the South Bay salt pond systems (Alviso, Eden Landing, and Ravenswood). We sampled primary productivity and nutrients in water, basic structure and chemistry of sediments, and invertebrate composition from April - June 2003. Some ponds were dry during the initial sampling period and were sampled the following spring after recent rains left standing water in the ponds.

Sediments

Sample Collection.-- Sediments were sampled from a motorized 3.7-m flat bottom boat, using a standard Ekman dredge (15.2 cm wide x 15.2 cm long x 15.2 cm high), also known as a benthic grab sampler. Samples were collected from 3 randomly selected accessible locations within each pond. Some ponds were not sampled due to inaccessibility and or dry conditions. If the water level was too low for a boat to traverse the pond, ponds were sampled from the borrow ditches which run along the inner perimeters of these ponds or by wading out to the nearest inundated areas to collect samples. In dry ponds, we traversed across the dry pond bottom until we reached the nearest inundated areas. GPS coordinates of sampling locations were recorded.

For each sample, 2 kg of sediment were collected. Samples were collected by lowering the dredge into the water, holding it level on the substrate and releasing the trigger. Soft, muddy substrates consistently produced samples that filled the Ekman, whereas on hard substrates only a portion of the sampler was filled. When substrate was deemed too hard for the Ekman, samples were collected using hand trowels or shovels. Grab samples were placed in a ziplock bag and transported to the University of California, Davis, Department of Natural Resources Laboratory (DANR) for processing.

*Soil Salinity Sample Analysis.--*The soil was saturated with water and subsequently extracted under partial vacuum of the liquid phase for the determination of dissolved salts. Soil moisture at complete saturation was estimated as the maximum amount of water held when all the soil pore space is occupied by water and when no free water has collected on the surface of the paste. The saturation percentage was twice the Field Capacity (FC) or -33kPa soil water potential and four times the Permanent Wilting Point (PWP) or –1500 kPa soil water potential for soils of loam to clay loam texture. From the saturated paste extract, estimates of Na^+ were completed with a reproducibility within 8%.

*Physio-Chemical Analyses.--*Organic Matter (OM) was quantified by potassium dichromate reduction of organic carbon and subsequent spectrophotometric measurement (modified Walkley-Black). The amount of oxidizable organic matter was quantified in which OM was oxidized with a known amount of $Cr_2O_7^{2-}$ in the presence of sulfuric acid. The remaining Cr^{3+} chromate was determined spectrophotometrically at 600nm wavelength. The calculation of organic matter is based on organic matter containing 58% carbon. The method had a detection limit of approximately 0.01% and was reproducible within 8%.

*Physio-Chemical Analyses.--*Particle size analysis (sand/silt/clay) quantified the physical proportions of three sizes of primary soil particles as determined by their settling rates in an aqueous solution using a hydrometer. The hydrometer method of estimating particle size was based on the dispersion of soil aggregates using a sodium hexametaphosphate solution and subsequent measurement based on changes in suspension density. The use of the ASTM 152 H-Type hydrometer was based on a standard temperature of 20°C and a particle density of 2.65 g cm^{-3} and units were expressed as grams of soil per liter. Corrections for temperature and for solution viscosity are made by taking a hydrometer reading of a blank solution. The method had a detection limit of 1% sand, silt, and clay (dry soil basis) and was generally reproducible within 8% (relative).

Primary Productivity and Nutrients

*Sample Collection.--*Water and most other samples were obtained using a motorized 3.7 m flat bottom boat. Water samples were collected from 3 randomly selected locations within each pond, depending on access. If the water level was too low for a boat to access, ponds were sampled by wading to wet areas or from barrow ditches found along the inner perimeters of ponds. Some ponds were not sampled initially due to inaccessibility or dry conditions. GPS coordinates of all sampling locations were recorded.

Water was collected over a 5-day period (20, 21, 28 May, and 10, 11 June). Water samples were collected in dark Nalgene bottles and kept on ice. On site or *in vivo* fluorescence was measured in samples with a Self-Contained Underwater Fluorescence Apparatus (SCUFA); these samples were then filtered and frozen for chlorophyll extraction within 8 hours usually at the U. S. Geological Survey Laboratory in Menlo Park (courtesy of Cary Lopez, Tara Schraga) and then processed at the Goldman Limnology Laboratory, University of California, Davis (UCD). Samples for water chemistry were kept cool and dark and transported to the UCD Division of Agriculture and Natural Resources Laboratory (DANR) where nitrogen as nitrate (NO_3-N) and ammonium (NH_4-N), soluble (SP) and phosphorus total (TP) in water, and sulfate (SO_4) were determined.

*Chlorophyll Analysis.--*The 53 pond complex was expected to have a high range in chemical and biological constituents, therefore fluorescence was measured with the SCUFA, and these readings were calibrated using a complete chlorophyll extraction process. Calibration of the SCUFA can usually occur periodically but because of the high variability among the 53 ponds, the SCUFA was calibrated after each pond was sampled. The SCUFA required calibration against the absolute concentration measured by the spectrophotometer due to changes in sampling environments. Temperature corrected fluorescence was determined with a SCUFA linked to a laptop in shaded conditions. The water from each pond was then filtered using a hand-pump vacuum manifold onto glass fiber filters. The water was filtered onto 25mm GF/F or GF/C filters. Filtration for each day took up to 7 hours depending on sample set, filter type, and filtration apparatus. Filters were frozen until processing. Following at least 48 hours of frozen storage, samples had 100% acetone added as extracting solution. After a 24 hour extraction period, the samples were then analyzed on a spectrophotometer to measure optical density at absorbance wavelengths of 750µm, 665µm, and 664µm before and after acidification with 0.1M HCl. The concentration of chlorophyll in each sample was then determined using the equation:

chl a =[26.7(664b-665a)*V1]/V2*L

where:

V1 = volume of extract, L
V2 = volume of sample, m^3
L = light path length or width of cuvette, cm and
664b, 665a = optical densities of acetone extract before and after acidification, respectively. These values are "corrected turbidity and are based on the spectrophotometer measurements for all 3 wavelengths (750, 665, and 664).

The value 26.7 is the absorbance correction A*K where:
A = absorbance coefficient for chlorophyll a at 664 nm = 11.0 and
K = ratio expressing correction for acidification.

The relationship between *in vivo* fluorescence recorded by the SCUFA and calculated chl *a* concentration recorded by the spectrophotometer provided a calibration coefficient.

*Nitrate and Ammonium Analysis.--*Nitrate was determined by reduction to nitrite via a copperized cadmium column. The nitrite was then determined by diazotizing with sulfanilamide followed by coupling with N-(1-naphthyl) ethlyenediaminie dihydrochloride. The absorbance of the product was measured at 520 nm. Ammonia was heated with salicylate and hypochlorite in an alkaline phosphate buffer. The presence of EDTA prevented precipitation of calcium and magnesium and sodium nitroprusside was added to enhance sensitivity. The absorbance of the reaction product was measured at 630 nm and was directly proportional to the original ammonia concentration. Samples could be stored for up to three weeks at low temperature (<4°C). For longer term storage, toluene or thymol was added to the sample to prevent microbial growth. The method used had a detection limit of approximately 0.05 mg L^{-1} and was generally reproducible within 7%.

*Soluble Phosphorus Analysis.--*The amount of soluble phosphorus in water was determined spectrophotometrically by reacting with ammonium molybdate and antimony potassium tartrate under acidic conditions to form a complex. This complex was reduced with ascorbic acid to form a blue complex which absorbs light at 880 nm. The absorbance was proportional to the concentration of phosphorus in the sample. Samples were analyzed using an automated Flow Injection Analyzer (Lachat). The method had a detection limit of 0.05 mg L^{-1} and was generally reproducible within 5%.

Total Phosphorus and Sulfur Analysis.-The concentration of P and S (*as* SO_4) and a variety of other elements were determined with nitric acid/hydrogen peroxide microwave digestion and Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) with vacuum spectrometer. The methodology used a pressure digestion/dissolution of the sample incomplete relative to the total oxidation of organic carbon. The method had detection limits ranging from 0.1 mg Kg^{-1} to 0.01% and was reproducible within 8%.

Benthic Macroinvertebrates

Sample Collection.--Benthic macroinvertebrates were sampled from a motorized 3.7-m flat bottom boat with a standard Ekman dredge. Samples were collected by lowering the dredge into the water slowly, holding it level on the substrate and triggering the release. Muddy or soft substrates consistently produced samples that filled the dredge, whereas only a portion of the dredge was filled on hard substrates. Sampling was conducted at four locations in each pond, each location situated within a quadrant of each pond. Four dredge samples were taken at each location; 3 of these were sieved through 1.0-mm mesh screens and the fourth through a 0.5-mm mesh screen to determine invertebrate composition and abundance. Sweep samples were collected from the slowly moving boat by placing a D-ring dip net (0.5-mm mesh) in the water column for a distance of 10m. Samples were stored in ethanol until processing. Processing entailed sorting invertebrates from debris, and then identifying and enumerating each organism to lowest practical taxon by lab technicians under the guidance of the project coordinator. The project coordinator validated identification of at least 20% of samples or 2 samples per sorter for each pond per sample period, whichever was greatest. Taxonomic identification was mostly to species, genus, or higher (family, order) classification when identification of organisms required an exorbitant amount of time (Smith and Carlton 1975, Merrit and Cummins 1996).

Fishes

We measured or sampled selected environmental variables and fish species in salt ponds during March, June, September, and November 2004. A subsample of ponds was chosen from each system to represent the salinity range across which fish would be present (i.e., <80 ppt). These ponds were A2E, A2W, A9, A10, A11 and A12 in the Alviso complex, and B1, B2, B4, B5, B6C and B7 in the Eden Landing complex. Four sampling sites or reaches were randomly established in each salt pond. Water temperature, dissolved oxygen, pH, salinity, and turbidity were measured with a Hydrolab DataSonde 3 multiprobe (Hach-Hydrolab Company, Loveland, CO). In addition, we measured water depth by using a calibrated cord attached to the multiprobe unit.

Fish were sampled with two floating monofilament gill nets fished for 2 hrs, five baited minnow traps fished for 1 h, and one bag seine hauled over a 15-m distance. The gill nets were 38-m long by 1.8-m deep, and consisted of square-mesh measuring 12.7 mm, 15.4 mm, 38.1 mm, 50.8 mm, and 63.5 mm. The minnow traps were 25.4-cm high, 25.4-cm wide, and 43.2-cm long, with 0.3-cm square mesh. Each minnow trap was baited with fish-flavored canned catfood. The bag seine was 5.5-m long and 1.8-m deep, with a mesh size of 3.2 mm. Seining was not feasible at some pond sites due to active dredging operations, an excessively soft mud bottom, extremely shallow water depths, or a combination of these situations. Sampling times in ponds were not influenced by tidal conditions.

At each site, captured fish were identified to species and measured for total length. In addition, the first 25 individuals of each species were weighed and preserved in 99% isopropyl alcohol for subsequent analysis of gut contents. Leopard sharks were exceptional because their gut contents were typically obtained by flushing the foregut with water pressure, then releasing the shark alive at the capture site (however, for any sharks near death or dead when removed from nets, gut contents were obtained by dissection). Scales from the first 25 individuals of bony fish species were removed and stored in coin envelopes for subsequent age determinations.

Objective 3a. Continue monthly monitoring of water quality concurrent with bird surveys to document baseline levels and to track changes.

Avian Diversity

Waterbirds were counted monthly at all 53 Alviso, Ravenswood, and Eden Landing salt ponds included in the March 2003 land transfer from November 2002 through June 2005. Counts were conducted during the high tide when numbers were at peak. Species and flock size were mapped on a 250 m x 250 m grid to document spatial distribution of birds and associate water depth. To increase our understanding of how birds use ponds, we documented whether birds were foraging or not foraging (but on the pond), or roosting on a levee, island, or man-made structure such as a duck blind. Data were entered for each pond according to grid number and species, and species were assigned to foraging guilds for analysis. Primary foraging guilds included: 1) dabbling ducks – e.g. northern shovelers (*Anas clypeata*) and American wigeons (*A. americana*); 2) diving ducks –e.g. ruddy ducks (*Oxyura jaimaicensis*); 3) eared grebes (*Podiceps nigricollis*) 4) fish eaters – e.g. double-crested cormorants (*Phalacrocorax auritis*) and American white pelicans (*Pelecanus erythrorhynchos*); 5) gulls and terns – e.g. ring-billed gulls (*Larus delawarensis*) and Forster's terns (*Sterna forsteri*); 6) herons – e.g. great egrets (*Ardea alba*); 7) medium shorebirds – e.g. marbled godwits (*Limosa fedoa*), willets (*Catoptrophorus semipalmatus*), and long-billed dowitchers (*Limnodromus scolopaceus*); 8) phalaropes – e.g. Wilson's phalaropes (*Phalaropus tricolor*); and 9) small shorebirds – e.g. western sandpipers (*Calidris mauri*) and dunlin (*Calidris alpina*).

Analyses were performed by season, because migratory patterns obscure trends in selection of pond characteristics. We analyzed all bird and environmental data in April (2003-2005) together to examine pond selection criteria during the spring migration period, then analyzed September and winter (December through February) data separately. We performed multiple linear regressions to determine the effects of monthly pond depth, water quality parameters, and pond size on abundance of birds in each foraging guild (Statistica 7). We then used CANOCO 4 (ter braak and Smilauer 1998) to perform forward stepwise canonical correspondence analyses (CCA; ter Braak 1986, ter Braak 1988) to reveal gradients in species composition and relate log-transformed species abundance values to environmental variables.

Pond Water Quality

Water quality measurements were collected monthly in all 53 purchased Alviso, Ravenswood, and Eden Landing salt ponds from August 2003 through June 2005. Two to five sampling locations were established for each salt pond (depending on pond size and access restrictions) with measurements typically collected near the corners of the ponds. A Hydrolab Minisonde

(Hydrolab-Hach Company, Loveland, CO) was used to measure conductivity (internally converted to salinity using the 1978 Practical Salinity Scale), pH, turbidity, temperature and dissolved oxygen at each location. The sensors on the Hydrolab were calibrated prior to each use and a calibration check was performed after sampling. Since the salt ponds are known to stratify under certain conditions, readings from the near-surface and near-bottom of the water column were collected at sampling locations where the water depth exceeded 60 cm. The specific gravity of each pond was measured with a hydrometer with a precision of 0.0005 (Ertco, West Paterson, New Jersey), scaled for the appropriate range, in addition to the Hydrolab measurement. Hydrometer readings provided an alternative salinity measurement for ponds 40-70 ppt because Hydrolab meters may not accurately measure conductivity where salinities are above 40 ppt. At salinities above 70 ppt, the Hydrolab was considered to be inaccurate (these values lie outside of the calibration curve) and only the hydrometer was used to measure salinity. The hydrometer data were corrected for temperature and converted to salinity.

Objective 3b. Complete Self-Monitoring Program (SMP) sampling and reports to document compliance with discharge requirements during the initial desalination.

In addition to monthly water quality sampling of all 53 ponds, we conducted water quality sampling required of USFWS and CDFG under the Self-Monitoring Plan administered by the Regional Water Quality Control Board (RWQCB) beginning in May 2004. Ponds open for discharge in summer 2004 were Alviso ponds A2W, A3W, and A7 and Eden Landing ponds B2 and B10. Methodology and results from sampling conducted during 2004 were detailed in annual self-monitoring reports submitted by the agencies to the RWQCB (CDFG 2005, USFWS 2005). In April 2005, Alviso ponds A14 and A16 were opened along with B2C and B8A in Eden Landing and also were sampled.

Ponds were sampled either by Initial Release Monitoring (IRM) or Continuous Circulation Monitoring (CCM) schedules according to initial pond salinity. All ponds open to discharge were monitored with a continuously logging Hydrolab Datasonde (Hydrolab-Hach Company, Loveland, CO) for salinity, pH, DO, and temperature. Receiving waters were sampled upstream and downstream of discharge points both 25 cm below the surface and at the near-bottom of the water column. IRM was required when pond salinity exceeded 44ppt at the time of discharge or when other pond conditions (e.g., dissolved oxygen or pH) did not meet required limits. Ponds sampled under IRM were required to be sampled one week before initial discharge, 1, 3, and 7 days following initial discharge, and weekly thereafter. Benthic invertebrate sampling was also required 7 days before discharge and 14 and 28 days following discharge, with another sample in the late summer.

CCM was required when pond salinity was below 44 ppt at the time of discharge. Ponds sampled under CCM were sampled for receiving water monthly from May through October, and ponds in the CCM circulation system were measured monthly during 2004 for water quality and chl *a*. Ponds were sampled annually for water column metals (total and dissolved arsenic, chromium, nickel, copper, zinc, selenium, silver, cadmium, lead, and mercury).

Management Sampling

USGS conducted water quality measurements twice monthly in Alviso salt ponds A2E, AB2, A2W, A3W, and A7, and in Eden Landing salt ponds B2 and B10, from May through July 2004 (i.e., two months prior to the initial release of ponds A2W, A3W, A7, B2, and B10). Management sampling in ponds A2E, AB2, A3N, and B4 were continued monthly during 2004 following the initial release of ponds A3W and B2, according to the CCM schedule. Twice monthly management samples were also conducted at A14, A16, B2C, and B8A beginning in February 2005. To complete management sampling, one sample location was established for each salt pond and samples were collected between 0800 and 1000 hours. A Hydrolab Minisonde (Hydrolab-Hach Company, Loveland, CO) was calibrated prior to each use and measured salinity, pH, turbidity, temperature, and dissolved oxygen. Readings were collected from the near-surface at a depth of approximately 25 cm. Because sondes may not measure salinity accurately at concentrations greater than 40 ppt, an additional method was used. USGS measured specific gravity of each pond (corrected for temperature and converted to salinity) with an appropriately-scaled hydrometer (Ertco, West Paterson, New Jersey) to a precision of 0.0005 specific gravity units. At hypersaline ponds (>70 ppt), only hydrometers were used to measure salinity.

Discharge Sampling

USGS installed continuous monitoring Datasondes (Hydrolab-Hach Company, Loveland, CO) in Alviso ponds A2W, A3W, and A7, and in Eden Landing ponds B2 and B10, prior to their initial release dates and through October (A2W, B2, and B10) or November (A3W and A7) 2004. These sondes were reinstalled before 1 May 2005 for the 2005 release year, and new sondes were installed at A14, A16, B2C, and B8A prior to their releases (beginning in April 2005). Datasondes were installed on the water control structures at the outflow of the discharge into the slough or San Francisco Bay with a PVC holder attached to a pole to allow for free water circulation around the sensors. The devices were installed at a depth of at least 25 cm to ensure that all sensors were submerged, and these depths were monitored and adjusted to maintain constant submersion as the pond water level fluctuated.

Salinity, pH, temperature, and dissolved oxygen were collected at 15-minute intervals with a sensor and circulator warm-up period of 2 minutes. Data were downloaded weekly and sondes were serviced to check battery voltage and data consistency. A recently calibrated Hydrolab Minisonde was placed next to the Datasonde in the pond at the same depth, and readings of the two instruments were compared. Any problems detected with the Datasonde were corrected through calibration or replacement of parts or instruments. The sensors on the Datasonde were calibrated prior to deployment into the salt pond and were calibrated and cleaned on a biweekly schedule unless otherwise noted in service records. During the cleaning and calibration procedure, simultaneous readings were collected with a recently calibrated Hydrolab Minisonde to confirm data consistency throughout the procedure (initial, de-fouled, post cleaned, and post calibration). The initial and de-fouled readings were also used to detect shifts in the data due to accumulation of biomaterials and sediment on the sensors.

Receiving Water Sampling

Receiving waters were measured outside pond discharge locations one week prior to discharge, one, three and seven days after initial discharge, and then weekly by USGS at sites along Guadalupe Slough adjacent to Alviso pond A3W (8 sites) and Alviso Slough adjacent to Alviso pond A7 (7 sites) from July 2004 through November 2004. Additionally, water quality measurements were collected after initial discharge and then monthly in San Francisco Bay outside the water control structure in pond A2W, B2, and B10 (3 sites each) from July 2004 until October 2004. Receiving water sampling has continued to be conducted weekly to monthly during 2005 (depending on pond conditions) outside ponds A2W, A3W, A7, A14 (Coyote Creek, San Francisco Bay), A16 (Artesian Slough), B10, B2C (Alameda Flood Control Channel), and B8A (in Old Alameda Creek outside the B8A discharge to North Creek). Sampling locations were marked using a GPS waypoint. We accessed receiving water sampling sites via boat from San Francisco Bay and used a GPS to navigate to sampling locations. When the boat was approximately 50-25 meters from the site, the engine would be cut or reduced to allow for drifting caused by current and wind to the site location. Every effort was made to ensure that the sample reading was collected from the center of the slough. A recently calibrated Hydrolab Minisonde (Hydrolab-Hach Company, Loveland, CO) was used to measure salinity, pH, turbidity, temperature, and dissolved oxygen at each location. From July 2004 through September 2004, readings were collected only from the near-surface at a depth of 25 cm. From October 2004 through November 2004, samples were collected from the near-bottom of the water column in addition to the near-surface at each sampling location. Depth readings of sample locations were collected at the completion of each Minisonde measurement to account for drift during the reading equilibration period. The specific gravity of each site was additionally measured with a hydrometer (Ertco, West Paterson, New Jersey) scaled for the appropriate range. This sample was collected concurrently with the near-surface Minisonde measurement. The majority of the samples were collected on the rising or high tide in order to gain access to the sampling sites, which were not accessible at tides less than 1.07 m (3.5 ft) MLLW. Alviso pond A2W receiving water sites could only be accessed during high tides over 1.83 m (6.0 ft) MLLW. Standard observations were collected at each site. These were:

A) Observance of floating and suspended materials of waste origin.
B) Description of water condition including discoloration and turbidity.
C) Odor – presence or absence, characterization, source and wind direction.
D) Evidence of beneficial use - presence of wildlife, fishing, and other recreational activities
E) Hydrographic conditions – time and height of tides, water column depth, sampling depths.
F) Weather conditions – air temp, wind direction and velocity, and precipitation.
Observation A, B, C, D and E were recorded at each sampling location, but F was recorded at the beginning and ending of each slough, unless weather had noticeably changed.

Sonde Calibration and Maintenance

All the instruments used for SMP sampling were calibrated and maintained according to USGS standard procedures. Datasondes were calibrated pre-deployment and maintained on a biweekly cleaning and calibration schedule unless they required additional maintenance. Dissolved oxygen sensors were particularly problematic due to the addition of self-cleaning brush attachments on the equipment which tended to damage the surface of the membrane more frequently. The problem of algae and other substances interfering with the moving parts such as on the self-cleaning brush and circulator was improved with the use of nylon sleeves. This allowed for maximum water flow past the sensor but stopped algae from wrapping around and binding the moving parts. Comparison tests indicated that the sleeves were not adversely affecting readings. Copper mesh and wire was used to inhibit growth in ponds with high concentrations of barnacles and hard algae, which could interfere with sensor function. We performed a biweekly fouling check to detect shifts in data due to the accumulation of biomaterial and sediment on the sensors. A calibration and maintenance log was maintained for each pond.

Chlorophyll *a* Sampling

USGS collected chlorophyll samples monthly in Eden Landing salt pond B4 and Alviso salt ponds A2E, AB2, and A3N in September and October 2004. Chlorophyll was not required for 2005 sampling. Two to three sampling locations were established for each salt pond and water quality measurements were collected between 0800 and 1000 hours of the same day or within one day of chlorophyll sample collection. A recently calibrated Hydrolab Minisonde (Hydrolab-Hach Company, Loveland, CO) was used to measure salinity, pH, turbidity, temperature, and dissolved oxygen at each location. Readings were collected from the near-surface at a depth of approximately 25 cm.

USGS determined Chl *a* levels using a TD700 fluorometer. Water samples were collected at 2-3 established sampling locations per pond using a water collection pole and 500ml dark Nalgene bottles. Samples were packed in ice for transport, and filtered by USGS staff within 24 hours of collection. Samples were filtered with 25 mm Whatman GF/F (glass fiber filters) (Whatman International, Maidstone, England) and filters were frozen at least 24 hours. Extraction solvent (90% acetone) was then added to the filters at least 48 hours after filtration. Absorbance of the extracts was read using a TD700 fluorometer. Chlorophyll concentration was calculated using the Fluorometric equations for extracted chlorophyll-*a* and pheopigments (Holm-Hansen et al.1965).

Benthic Invertebrate Sampling

Benthic slough samples were collected at Guadalupe and Alviso Slough receiving water sampling in 2004 locations concurrently with receiving water quality samples on three occasions. Benthic sampling was conducted in 2005 at Artesian Slough (A16), Alameda Flood Control Channel (B2C), and Old Alameda Creek (B8A). Late summer samples were also collected from established sampling locations at Guadalupe and Alviso Sloughs. Benthic macroinvertebrates were sampled from the boat using a standard Eckman grab sampler (3,512 cm^3). Samples were collected by lowering the dredge into the water slowly, holding it level on the substrate, and releasing the “jaws.” Soft substrates consistently produced samples that filled the dredge; whereas on harder substrates, only a portion of the dredge was filled (the dredge cannot as deeply penetrate a hard surface). Sampling locations with vegetative debris on the substrate produced samples with high concentrations of vegetation. Grab samples were washed in the field using a 0.5mm mesh sieve and preserved in 70% ethanol and rose bengal dye.

Samples were sorted and invertebrates enumerated using dissecting microscopes and appropriate taxonomic keys (Usinger 1971, Pennak 1989, Merritt and Cummins 1996, Smith and Johnson 1996). Sorted samples and associated sample debris were stored at USGS SFB Estuary Field Station, Vallejo, California.

Objective 4. Assess the hydrology and present morphology of the South Bay sloughs by analyzing existing data augmented with collection of new data.

Sediment Budget of the South Bay

A sediment budget was developed to evaluate sediment supply components. Sediment input was estimated from the local watersheds. Previous USGS analyses of sediment transport (Lacy *et al.* 1996, Cheng *et al.* 1998), bathymetric change (Foxgrover *et al.* 2004) in South Bay, and a daily numerical box model of sediment transport (Lionberger 2003) were used to estimate sediment flux between South Bay and the rest of San Francisco Bay at the San Mateo Bridge.

Landscape-scale Geomorphic Assessment

Phil Williams and Associates (PWA) performed a landscape-scale geomorphic assessment to assess the rate at which restored salt ponds will evolve from tidal mud flat to marsh, and how changes in sediment dynamics will impact the morphology and extent of tidal mud flat and shallow-water habitat (May *et al.* 2005). The USGS assisted PWA with this work by modifying the South Bay numerical sediment transport box model to simulate the effects of opening the ponds to tidal action under different proposed restoration scenarios. These results were combined with a zero-dimensional marsh evolution model, and empirical analyses predicted geomorphic evolution over the next 50 years.

Potential Effects on Phytoplankton Populations

The numerical model used for the sediment budget can predict suspended sediment concentrations (SSC). We used the results of two runs of the model (before and after ponds are opened to tidal action) to predict if opening ponds to tidal action will increase or decrease the SSC in South Bay. Then, using a relationship between water column sediment clearing rates and the potential for phytoplankton blooms developed by May *et al.* (2003), we predicted the effect that opening up additional area in South Bay to tidal action will have on the potential for phytoplankton blooms to occur in this basin.

Conductivity and Temperature at Channel Marker 17

Two continuously operated conductivity-temperature-depth (CTD) sensors (one mid-depth, one near bottom) were deployed at Channel Marker 17 on December 2, 2003. The lower CTD was positioned about 1 m above the bottom, while the upper CTD was positioned about 5.5 meters above bottom. The sensors were deployed during the winter wet season in 2004 and 2005. Temperature and salinity time-series were cleaned, processed, and verified and provided to the

State Coastal Conservancy in electronic format for the winter seasons of water years 2004 and 2005.

Reconfigure SPOOM for the Alviso Pond System

The salt pond box model SPOOM was originally configured to simulate pond salinity and volume for the salt ponds in the North Bay. The model was reconfigured to simulate salinity and volume of Alviso ponds for USFWS management. Several improvements were made to upgrade the model that include temperature simulation, simultaneous simulation of multiple ponds, variable unit system and vertical datum, and management controls such as screw gates. The model was tested and refined, and a user manual was written. The model and documentation will be given to the USFWS in 2005.

Sediment Synthesis

USGS hydrologist David Schoellhamer, a member of the Science Team, led the writing of the restoration Science Plan issue 2 – Sediment Synthesis. This report answered questions regarding the sediment management issues and restoration of the South Bay salt ponds in order to assist the Project Team in developing a conceptual model of sediment transport in South Bay. The synthesis was completed in February 2005.

Coyote Creek Seasonal Suspended-sediment Loads

Seasonal, daily suspended-sediment load (October – April) were measured on Coyote Creek during winters 2004 and 2005. The station was maintained and serviced by the USGS Marina field office. Suspended-sediment time-series data were cleaned, processed, and verified and made available to the State Coastal Conservancy by USGS Hydrologist Larry Freeman in electronic format after data reviews were completed.

South Bay Hydrologic Summary and Data Gaps

Existing hydrologic and sediment datasets were obtained from all available sources in the South Bay. An annotated list of data sources was compiled. Sources of the datasets included Stanford University, Santa Clara Valley Water District, USGS, City of San Jose Environmental Services Department, Hydroikos, NOAA-NOS, Cargill, H.T. Harvey and Associates, CIMIS, and Fremont Engineers Inc. The summary of the hydraulic data gaps collection effort was given to the State Coastal Conservancy.

Water Quality Sampling and Bathymetric Surveying Support

Water Resources provided a Hydraulic Engineer to assist Biological Resources staff with the design and construction of a shallow draft vessel for bathymetric surveys of the salt ponds. In addition, WRD provided a Supervisory Hydraulic Technician to train BRD in water quality sampling.

Vegetation Colonization in the Salt Ponds

Little was known about how vegetation distributed along the sloughs of the South Bay salt ponds has changed through time. Such changes are a function of factors such as sediment load, salinity, and hydrodynamics in the South Bay, and may be an indication of how restoration will proceed subsequent to the conversion of salt ponds to salt marshes. For this reason, an analysis of wetland vegetation cover through time was collected as a complement to the current research concerning hydrologic flows, sediment load, and sedimentation processes.

Vegetation and elevation data were collected in 1983 by the California State Lands Commission at Corkscrew Marsh, Bird Island and Palo Alto Baylands in South San Francisco Bay. Marsh surface and tidal channel elevations were determined at a total of 962 stations by three-wire leveling to established tidal benchmark stations at each site and referenced to Mean Lower Low Water (MLLW) relative to the National Tidal Datum Epoch (1960-78). In addition, presence or absence of nine salt marsh species, percent plant cover, and percent bare soil were recorded for 1-m^2 quadrats at 648 stations. These data were used to determine historic patterns of vegetation colonization relative to elevation at these South Bay sites.

Objective 5. Characterize invertebrate and fish communities in the slough systems and compare with South Bay pond communities.

The current diversity of birds in the South Bay is strongly linked to the invertebrate resources in ponds, sloughs, and mud flats. Similarly, the abundance of fish is related to salinity conditions, cover, and available food-forage fishes. Pond restoration requires colonization from adjacent sloughs and bay mud flats. Thus, we conducted surveys to document existing invertebrates and fishes in salt ponds and in adjacent sloughs. Surveys were conducted in the major sloughs of the Alviso (Stevens Creek, Guadalupe Slough, Alviso Slough, Coyote Creek, and Mud Slough), and Eden Landing (Mt. Eden Creek, Alameda Creek, Alameda Flood Control Channel) systems.

Sediments

*Sample Collection.--*Sediments were sampled from a motorized boat, using a standard Ekman dredge (3,512 cm^3). Samples were collected from 3 locations within each slough (at mouth of slough, adjacent to salt ponds, and upriver from salt ponds). GPS coordinates of sampling locations were recorded. Each sample contained 2 kg of sediment. Samples were collected by lowering the dredge into the water, holding it level on the substrate and releasing the trigger. Soft, muddy substrates consistently produced samples that filled the Ekman, whereas on hard substrates only a portion of the sampler was filled. When substrate was deemed too hard for the Ekman, samples were collected using hand trowels or shovels. Grab samples were placed in a ziplock bag and transported to the University of California, Davis, Department of Natural Resources Laboratory (DANR) for processing.

*Sample Analysis.—*Procedures were defined in Obj. 2.

Benthic Macroinvertebrates

Invertebrate surveys were conducted in the major sloughs of the Alviso and Eden Landing systems. Three invertebrate sweep and three benthic samples were collected in the main sloughs in 3 locations (below, adjacent, above) relative to the ponds following methods outlined for invertebrate collections in the ponds. Invertebrate communities within ponds were determined following procedures in Obj. 2.

In the sloughs, sediment samples were collected from 3 locations below the ponds or at the mouth of the sloughs, adjacent or next to the ponds, and above or upstream of the ponds in Guadalupe, Alviso, Mallard, and Mud sloughs. At each location samples were taken at the edge of the mud flats for a total of 12 samples.

Sample Collection- Benthic macroinvertebrates were sampled from a motorized 3.7-m flat bottom boat, using a standard Ekman dredge. Samples were collected by lowering the dredge into the water slowly, holding it level on the substrate and triggering the release. Muddy or soft substrates consistently produced samples that filled the dredge, whereas only a portion of the dredge was filled on hard substrates. Sampling was conducted at four locations in each pond, each location situated within a quadrant of each pond. Four dredge samples were taken at each location; 3 of these were sieved through 1.0 mm mesh screens and the fourth through a 0.5 mm mesh screen to determine invertebrate composition and abundance. Sweep samples were collected from the slowly moving boat by placing a D-ring dip net (0.5mm mesh) in the water column for a 10 m distance. Samples were stored in ethanol until processing. Processing entailed sorting invertebrates from debris, and then identification and enumeration of each organism by lab technicians under the guidance of the project coordinator.

Fishes

During 2004, we measured or sampled selected environmental variables and fish species in sloughs on three occasions (June, September, and November). The sloughs consisted of Alviso Slough, Coyote Creek, Stevens Creek, Old Alameda Flood Control Channel, and Coyote Hills Slough. Four sampling sites or reaches were randomly established in each slough. Water temperature, dissolved oxygen, pH, salinity, and turbidity were measured with a Hydrolab DataSonde 3 multiprobe. In addition, we measured water depth by using a calibrated cord attached to the multiprobe unit.

Fish were sampled with two floating monofilament gill nets fished for 2 h, five baited minnow traps fished for 1 h, and one bag seine hauled over a 15-m distance. The gill nets were 38-m long by 1.8-m deep, and consisted of square-mesh measuring 12.7 mm, 15.4 mm, 38.1 mm, 50.8 mm, and 63. 5 mm. The minnow traps were 25.4-cm high, 25.4-cm wide, and 43.2-cm long, with 0.3-cm square mesh. Each minnow trap was baited with fish-flavored canned catfood. Seining was not feasible in sloughs due to excessively soft mud bottoms. Sampling times in sloughs were restricted to periods of slack tide (little or no current).

At each site, captured fish were identified to species and measured for total length. In addition, the first 25 individuals of each species were weighed and preserved in 99% isopropyl alcohol for subsequent analysis of gut contents. Leopard sharks were exceptional because their gut contents were typically obtained by flushing the foregut with water pressure, then releasing the shark alive at the capture site (however, if sharks were near death or dead when removed from nets, gut contents were obtained by dissection). Scales from the first 25 individuals of bony fish species were removed and stored in coin envelopes for subsequent age determinations.

Objective 6. Assist in development of a land surface elevation map for the South Bay region and map South Bay open bay and slough bathymetry.

Land surface elevation and bay bathymetry are critical data for the tidal wetland restoration project. The USGS assisted in contracting airborne topographic LIDAR and bathymetry surveys to collect this data. Contracting took considerably more effort than anticipated because of the complexity of the surveys and the need for extremely accurate data. The USGS evaluated the data collected, and when necessary, directed additional efforts to remedy quality control or other data issues. We initiated the process of creating a grid (digital terrain model; DTM) of present-day land and bay. By comparing this grid with our 1983 grid (Jaffe *et al.*, unpublished data), we can determine whether the erosion rate in South San Francisco Bay has changed from the 1956-1983 period. This is essential information for developing a sediment budget and for landscape scale analysis of restoration alternatives.

A complete sediment budget includes sediment grain size as well as quantity. Bottom sediment grain size information allows evaluating whether sediment of the proper size is available from the natural system in the volumes needed for successful tidal wetland restoration. Sediment size at the surface and within the bed is used in sediment transport models to predict the geomorphic impact of restoration of the salt ponds on other parts of the Bay. Bed sediment size samples were recently taken to complement existing sediment samples. An acoustic seabed classification system was mounted the bathymetric survey vessel to map the bottom sediment size. We initiated work to create a sediment size map for South San Francisco Bay from data from this system and grain size analysis of bed sediment. Details on the data collection efforts and data evaluation are presented in sections on LIDAR, Bathymetry, Bed Sediment Size, and Sediment Budget.

LIDAR Mapping

The USGS was responsible for many aspects of LIDAR data collection and analysis including:

- Developing the LIDAR contract
- Aiding in definition of the survey area
- Setting parameters for flight times to ensure data collection at low tides
- Evaluating data collection schedule during survey
- Collecting ground-truth data (with TerraPoint)
- Organizing additional ground-truth efforts by other agencies
- Evaluating data quality
- Reviewing TerraPoint QA/QC report and suggested revisions
- Preparing LIDAR data for merging with bathymetry survey to create DTM

Foxgrover and Jaffe (2005) presented an overview of the LIDAR survey and a preliminary quality assessment.

LIDAR Survey.--The 2004 South San Francisco Bay LIDAR survey was conducted by TerraPoint from 5-21 May 2004. The time of the survey was chosen during a period of extreme low tides during daylight hours so that tidal flats would be exposed during data acquisition and video could be collected during the survey. Nominal flight line spacing was 99 meters, providing an overlap of 102% between flight lines. Data were collected over approximately 6,800 km on approximately 350 flight lines (Figure 2). Base stations and ground-truth sites were established to calibrate the survey (Figure 3), and satellite imagery was used in conjunction with the LIDAR surveys to eliminate overwater returns (Figure 4).

Bay Bathymetry

The USGS was responsible for many aspects of bathymetry data collection and analysis including:

- Developing the bathymetry contract
- Aiding in definition of the survey area
- Contacting NOAA for technical assistance with tidal reduction, tide gauge selection, and datum conversions
- Collaborating with NOAA on tide and datum issues

Pending funding for work to complete the study, the USGS will be responsible for:

- Evaluating data quality
- Reviewing Sea Surveyors QA/QC report and suggested revisions
- Preparing USGS report that presents bathymetry data overview and a preliminary quality assessment
- Preparing bathymetry data for merging with LIDAR survey to create DTM

Bathymetry Survey.--The 2005 South San Francisco Bay bathymetry survey was conducted by Sea Surveyors from 10 January to 5 April, 2005. The start of the survey was delayed until high accuracy tide gauges were installed and sending data to a NOAA data center using a GOES satellite to allow real-time monitoring of instrument performance. The survey area was approximately 250 km^2, extending from tidal sloughs and Coyote Creek in the south to approximately San Leandro Marina on the east shore and to Coyote Point on the west shore (Figure 5). Sounding data was collected every 0.3 m along track lines. Track line spacing was 100 m in the Bay and less in Coyote Creek and the sloughs.

Tidal Reduction and Datum Conversion.--NOAA played a key role in the bathymetric survey by selecting tide gauge type, loaning accurate acoustic tide gauges, determining optimum locations for tide gauges, aiding in installation of tide gauges, and developing tidal zoning to correct soundings to the 1983-2001 tidal epoch MLLW tidal datum. Referencing soundings to MLLW for the 1983-2001 tidal epoch allows comparison to earlier surveys to determine geomorphic change and whether the bay and mudflats are sinks or sources of sediment—a key question in restoration. NOAA also developed the conversion from MLLW datum to NAVD88, the LIDAR datum. This conversion makes it possible to merge the bathymetry and LIDAR survey to create continuous coverage of elevation and depth.

The soundings collected in South San Francisco Bay were corrected for vertical changes in the water surface elevation caused by tide. Corrections were done in 30 zones defined by NOAA (Figure 8), with each zone having a time correction and scale correction to apply to tides measured at one of three locations with high accuracy acoustic tide gauges. At each location, an AQUATRAK air acoustic tide gauge was housed in a 9.14-m (30 ft) long stilling well mounted to a vertical structure (Figures 6-9). Tide data was recorded using a SUTRON data logger and also transmitted it to the NOAA data center to allow real-time evaluation of data quality. These locations were:

- San Leandro Marina (NOAA Station 9414688)
- West Fishing Pier at San Mateo Bridge (NOAA Station 9414458)
- East Fishing Pier at Dumbarton Bridge (NOAA Station 9414509)

The original plan called for correction using five locations; however, the acoustic tide gauge at Coyote Creek did not work properly and the correction using the permanent NOAA tide gauge at Redwood City resulted in unacceptable errors. The malfunction of the acoustic tide gauge at Coyote Creek required Sea Surveyors to install less accurate gauges in Coyote Creek and the tidal sloughs. These gauges were used to correct soundings to NAVD88. The datum conversion from NAVD88 to MLLW, which is being done by NOAA has proven to be difficult and is taking more time than expected. It is possible that additional geodetic or tide data will need to be collected for this conversion.

<u>Bed Sediment Size.--</u>The USGS was responsible for determining baseline conditions for bed sediment size. Activities included:

- Developing the seabed acoustic classification system contract
- Bed surface sediment sampling
- Analysis of existing USGS sediment cores to determine sub-bottom sediment size
- Analysis of grain size of surficial and sub-bottom sediments
- Interpretation of seabed acoustic classification data
- Preparation of sediment size map for South San Francisco

<u>Bed Surface and Sub-bottom Sediment Sampling.--</u>The USGS collected 153 grab samples south of San Mateo Bridge from August to December, 2004 to determine the distribution of surface sediment grain size (Figure 10). During the December sampling cruise, the USGS tested new collection equipment for taking gravity and short box cores from a small boat. These tests resulted in successful collection of two short box cores and a short gravity core in the study area. In a companion study (not funded by the Conservancy, but that will benefit restoration planning), the USGS contracted SeaEngineering to collect short box cores and determine sediment erosion rates on the mud flats in front of the three restoration areas (core locations shown as red triangles in Figure 10).

Additional research on sub-bottom sediment size was done using sediment gravity cores the USGS collected in the 1990s (Figure 11). These cores were stored in USGS core refrigerator and are in good condition. As of early summer, nine cores had been logged. Information from these logs indicates that the sub-bottom sediment in the region of the cores primarily clays and contained little sand. Sand in the sub-bottom may not be available as natural fill because it may not be transported to restoration sites by tidal currents and wind waves. These cores are also useful for determining the long-term sediment history of South Bay. This history may be used to determine if the sediment dynamics of South Bay were different when there were large tidal wetlands along its shores.

Acoustic Seabed Classification

As part of the bathymetry survey of South San Francisco Bay, Quester Tangent was subcontracted to collect acoustic seabed classification data. These data were collected to improve the understanding of the distribution of seabed sediment types and their erodibility. This information is critical for planning the restoration of South San Francisco Bay salt ponds.

Acoustic seabed classification is the organization of the sea floor into discrete units based on the characteristics of its acoustic response. The acoustic response can be captured as an echo time series using a single beam echosounder with stand-alone or integrated digital acquisition hardware. A map of sea floor acoustic diversity can be generated using unsupervised classification techniques applied to time series or image data. Acoustic diversity is considered a proxy for geoacoustical parameters including acoustic impedance contrast, scatter and volume reverberation which all vary with sediment type. In addition biological and anthropogenic features can influence the acoustic response.

A QTC VIEW seabed classification system recorded echoes from a single beam 50 kHz echosounder. Approximately 450,000 seabed classification records were generated from an area of about 30 sq. miles. Ten distinct acoustic classes were identified (Figure 12). The ten classes represented the spatial distribution of estuary sediments broadly segmented into tidal flat, nearshore, shelf, channel, and dredged sediments. The classification scheme will be further refined using sediment data from more than 180 grab and core samples and benthic community composition data from 10 bottom samples collected in the study area.

Sediment Budget

A sediment budget is essential information for developing a plan for successful pond restoration. A sediment budget for the period 1956 to 1983 indicated that South Bay is losing large quantities of sediment. By calculating a budget for dynamically similar regions, sediment transport pathways and processes of sediment transport can be inferred, including cells during the 1956-1983 period (Figure 13). We created a grid (DTM) of the present-day bay. By comparing this grid with our 1983 grid (Jaffe et al., unpublished data), we plan to determine whether the erosion rate in South San Francisco Bay has changed from the 1956-1983 period.

RESULTS AND DISCUSSION

Objective 1: Complete bathymetry and levee habitat mapping of ponds in the purchase agreement for interim management and hydrological modeling of restoration scenarios.

Bathymetry datasets from 35 ponds (Table 1a-b, Figure 14) were distributed on CD in August 2004 and included detailed metadata files. Although the sounding system was effective at pond depth measurement, accurate conversion of those data to NAVD88 elevation values required that pond staff gages be present and recently surveyed to a vertical datum. We surveyed staff gages at ponds A9-A16 with a laser level and rod from benchmark H555 (1.137 m or 3.729 ft, surveyed by USGS with Bestor Engineers in 9/25/1996; Takekawa, unpubl. data) during August 2002, and used the resulting elevation values to convert the bathymetric surveys to NAVD88. For two ponds (A2W and A3W) for which we could not locate staff gages at the time of the bathymetric survey, we measured water height from temporary levee benchmarks that were later surveyed by Moffatt-Nichol (D. Trivedi). Conversion of these ponds to NAVD88 was accurate.

In most of the other ponds, Cargill, Inc. provided survey data for staff gages contracted through Fremont Engineers in 1999. Because we were unable to obtain metadata for this survey, we assumed that the staff gage values provided represented the top height measurement of the gage (the standard set for staff gage surveys of the North Bay salt ponds) and converted water depths to elevations as noted in the original pond metadata files, including the three conversion methods (Appendix A). Our surveys of the water depths were accurate; however in May 2005, we learned from K. Wheeler (Schaaf & Wheeler) through E. Gross that had they determined in January 2005 that the staff gage heights provided from Cargill represented the physical top of the gage rather than the top height mark. We released a correction memo (with adjustment values) later that same month, and the adjusted point data, GIS grid files, and metadata were made available.

We used pond outline shapefiles (digitized on-screen from georeferenced aerial photos) to overlap bathymetric grids (Figure 14) and derive pond elevation statistics (ESRI Spatial Analyst; Table 1a-b). We converted monthly staff gage readings to monthly water depth statistics by applying an adjustment calculated from staff gage surveys (see above) and subtracting pond bottom elevation statistics. These values were essential for association with water quality measurements and bird species and guild abundance measurements for use in multiple regression and canonical correspondence analyses, described in Objective 3. Additionally, we used pond grid shapefiles to overlap bathymetric grids and derive elevation statistics for individual 250-m grid cells.

Objective 2. Characterize sediments, primary productivity, invertebrate composition, and fishes in ponds for salinity reduction and initial phases of restoration.

Sediments

In an estuarine environment, soil particle size can be a major driver for invertebrate habitat selection. Texture classes of soils were interpreted via particle size analysis through the use of a soil texture triangle (Figure 15, USDA 2001). Because the salt ponds were created with dredge materials, the soil types in the majority of ponds tended to have high clay, moderate silt content, and lower sand content (Figures 16-18). Soil type at Ravenswood ponds had higher sand content than the other areas; with the exception of pond R3 (Figure 18), all ponds were sandy loam (Table 2a-b, Figure 15).

Increased organic carbon content in sediments is often associated with reduced invertebrate abundances as it accompanies low dissolved oxygen and elevated sulfide, ammonia, and contaminant levels (Thompson and Lowe 2004). Organic carbon levels were high relative to reference areas reported by Thomson and Lowe 2004 (0.86 – 0.91), but under salt pond conditions, these levels probably were not associated with affecting invertebrate abundance. However, higher organic carbon could be associated with an increased possibility of higher contamination (USFWS, unpublished report). As salt ponds are converted to marshlands, high organic carbon may be an impacting factor for invertebrates and contaminants. Organic carbon levels detected in Alviso ponds ranged from 1.15 – 4.46 mg/L, mean 2.76 mg/L (Table 2a). Organic carbon levels detected in Eden Landing ponds ranged from 1.52 – 4.30 mg/L, mean 2.64 mg/L (Table 2b). Organic carbon levels detected in Ravenswood ponds ranged from 0.92 – 2.93 mg/L, mean 1.46 mg/L (Table 2b).

Primary Productivity and Nutrients

The process to estimate primary productivity (chlorophyll *a*) was repeated twice for each pond and mean results were presented (Table 3). Nitrogen as nitrate and ammonium, and total and soluble phosphorus were determined by the DANR lab facility at UC Davis (Table 4a-c). Most NH_4-N and NO_3-N levels were low, similar to levels associated with unpolluted surface lake waters. Concentrations well above 10 mg/L are associated with anaerobic, polluted, or related conditions. Only Pond B6B was approaching the 10 mg/L level.

Benthic Macroinvertebrates

We identified 58 different taxonomic groups of macroinvertebrates, most at the family and genus levels. The most abundant and diverse group was the Crustacea with 17 different taxa, followed by 12 different genera of Annelids, mostly in ponds with salinity levels below 60 ppt. There were 5 different species of bivalves, and 9 insect families. Ponds with lower salinity (27-44 ppt) had greater richness, i.e., greater number of different taxa (Table 5). There was a relationship between increasing salinity and decreasing richness in benthic grabs (Figure 19). The most common species in the salt pond benthic samples were lumped into general groups and correlations between salinity and invertebrate abundance were calculated (Figure 20). Insecta taxa (Corixidae, Diptera and *Ephydra*) were positively correlated with salinity ($R^2 = 0.37$, $P<0.001$) as was *Artemia* ($R^2 = 0.41$, $P<0.001$); Crustacean genera *Ampelisca* and *Corophium* were negatively correlated with salinity ($R^2 = 0.56$, $P<0.001$) as were Annelida taxa *Capitella*, *Polydora*, *Streblospio*, and Tubificoides ($R^2 = 0.50$, $P<0.001$) (Figure 20).

Alviso.--We sampled 25 ponds in the Alviso complex, 21 between March and June of 2003 and 4 ponds (A20, 21, 22, and A6) in April 2004 that were dry in 2003. Salinity in Alviso ranged from 27 – 252 ppt. Nine of the ponds were characterized by relatively low salinity (<50 ppt), 10 medium (51 – 106 ppt), and 6 high salinity (180 – 252 ppt). Annelids, mainly *Polydora*, followed by *Capitella* and some Tubificoides and *Streblospio* were prevalent in low salinity ponds (Table 6, Figure 21). *Polydora* was present in large numbers in ponds less than 80 ppt and absent from all ponds above 80 ppt (Table 7). Other Annelids diminished in numbers when pond salinity was above 56 ppt. The 3 most common taxa of Insecta in Alviso ponds were Corixidae, Diptera, and *Ephydra* (Table 8). Diptera and *Ephydra* were present in substantial numbers in Pond A22, otherwise, all three species were not abundant in Ekman grab samples. The bivalve *Gemma gemma* was present in 4 Alviso ponds and most common in Ponds A10 and A2W (Table 7). *Tryonia* was present in Pond A2E with average 41.6 per benthic grab and AB2 with 17.1 per benthic grab (Table 9). The Crustacea, mainly *Ampelisca* and *Corophium*, were abundant in ponds of <40 ppt salinity (Table 10). *Ampelisca* was not present in any pond with salinity ≥ 56 ppt. Except for an individual *Corophium* present in one Ekman grab, this genus was absent from ponds ≥ 56 ppt as well. Average abundance of all taxa detected in Ekman grab samples from Alviso ponds were summarized (Tables 6, 8, 10, and 11). *Artemia* dominated sweep samples in medium to high salinity Alviso ponds, with an average of 900 – 3700 individuals per sweep (Table 12). Corixidae was present in medium salinity ponds ranging from a mean of 0.67 – 200 individuals per sweep.

<u>Eden Landing.--</u>We sampled 21 Eden Landing ponds in June 2003, except ponds B8A and B6A (dry) that were sampled March 2004. Eden Landing ponds ranged in salinity from 41 – 175 ppt, with the majority of the ponds averaging around 80 ppt salinity: 6 ponds averaged 40 ppt, 12 ponds averaged 60-100 ppt, and 3 ponds were greater than 115 ppt. Annelids were only detected in ponds lower than 67 ppt salinity (Table 13, Figure 22). The most abundant Annelids were Tubificoides and *Streblospio*, followed by *Polydora* and *Capitella* (Table 14). *Corophium* dominated 5 of the 6 ponds with less than 52 ppt and *Ampelisca* was also present, in lesser quantity (Table 13). *Artemia* was present in large numbers in ponds with higher salinity, generally if *Artemia* was present, *Coropium* and *Ampelisca* were absent and vice versa (Table 13). Ephydra was the most common insect species in Eden Landing ponds and was present in high salinity as well as moderate salinity ponds (Table 13). Average abundance of all taxa detected in Ekman grab samples from Eden Landing were summarized (Tables 15–18). *Artemia* and Corixids were the most common species noted in sweep samples and were absent from ponds with salinity lower than 44 ppt (Table 19).

<u>Ravenswood.--</u>With exception of Pond R1 (sampled June 2003), all Ravenswood ponds were dry in 2003 and were subsequently sampled March 2004. In general, salinity was highest in Ravenswood compared to the other South Bay complexes, with 6 of the 5 ponds between 265 and 327 ppt, and only 1 Ravenswood pond, R1, below 100 ppt (Table 20, Figure 23). Consequently, taxa richness was lowest in the Ravenswood's system compared to Alviso and Eden Landing (Table 5). Ravenswood ponds were dominated with *Artemia* which generally increase in numbers in the higher salinity ponds (Table 20). The Insecta Corixidae was present in highest numbers in Pond R1 and decrease considerably in the remaining ponds (Table 21). In general *Ephydra* was higher in all ponds than Diptera (Table 22). No Gastropoda or Bivalvia were detected in the Ravenswood ponds. Crustacea species detected in benthic samples were *Artemia* and Gammaridae (Table 23). Except for Pond R1, *Artemia* was present in high numbers in all sweep samples in Ravenswood ponds. Corixidae was most abundant in Pond R1 (Table 24). Other taxa present in sweep samples included Diptera, *Ephydra*, and Muscidae (Table 25).

Ponds in the 53 pond set that had salinities similar to Alviso Ponds A9 – A15 (sampled multiple seasons) characteristically had similar invertebrate assemblages and relative abundances. The late spring – early summer seasons, when the 53 ponds were sampled, was usually associated with higher abundances of most taxa (Table 26, Figure 24).

Fishes

A total of 10,258 fish represented by 19 species and 16 families was caught during 2004 (Table 27). Of the 19 species, 13 were caught in ponds and 16 in sloughs. Although we failed to capture bat rays (*Myliobatis californica*), several individuals were observed swimming within the Alviso ponds. Overall, the highest numbers of fish were captured with bag seines, followed by gill nets, then by minnow traps (Table 28). Fish abundance was highest in June and lowest in November. Gill nets, bag seines, and minnow traps targeted different portions of fish communities in the ponds and sloughs (Table 27). In the Alviso and Eden Landing ponds, topsmelt accounted for most of the gillnet catch (>81%). Seining captured mostly rainwater killifish (72.4%) in the Alviso ponds. By comparison, seining in the Eden Landing ponds yielded mostly yellowfin goby (40%) and topsmelt (28.8%). Although minnow traps yielded few fish, most captured individuals consisted of rainwater killifish or yellowfin goby.

Generally, water quality conditions varied significantly among ponds (Table 29). Water temperature and dissolved oxygen fluctuated seasonally, with higher temperatures and lower dissolved oxygen concentrations occurring during June and September (Table 30). Overall, mean temperatures in Alviso were higher than in Eden Landing, and Alviso and Eden Landing sloughs. Mean pH values in Alviso differed significantly from values measured in Eden Landing (Table 29). Overall, however, pH values did not exhibit much temporal variation over the four sampling periods.

Objective 3a. Continue monthly monitoring of water quality concurrent with bird surveys to document baseline levels and to track changes.

Avian Diversity

Alviso.--Avian use of salt ponds varied by foraging guild, pond, and season (Tables 31-41). Alviso salt ponds constituted 57% of total pond area, but supported 92% of gulls and terns and 90% of dabbling ducks counted on all ponds between November 2003 and June 2005. Alviso ponds also supported 73% of diving ducks, 72% of eared grebes, 66% of herons, and 63% of fish eaters and phalaropes.

Alviso ponds can be separated into geographical groupings of ponds in close proximity to one another that also share a circulation pattern and tend to share similar water quality characteristics. Ponds A1, A2W, A2E, AB1, AB2, A3N, and A3W together comprised 26% of all birds counted (Table 31, Figure 25), and supported similar foraging guilds. Ponds A1 and A2W, for example, both supported primarily ducks and fish eaters. Sixteen percent of all dabbling ducks counted in Alviso were counted on ponds A2W and A1, while these two ponds together supported 31% of the diving ducks and 20% of the fish eaters. Ponds A2E, AB1, AB2, A3N, and A3W supported 35% of herons, 29% of fish eaters and divers, and 25% of dabbling ducks. Seasonally, diving ducks comprise the largest proportion of birds on these ponds during winter months, when bird numbers on this system peak, and are replaced by gulls and terns during the summer (Table 31, Figure 26). Foraging rates were relatively consistent among ponds (Figure 27). Nineteen to forty-one percent of dabbling ducks were foraging when they were counted, whereas 3.5-7% of diving ducks were foraging. Eared grebes had high foraging rates (21-66%), as did herons (37-81%) and small shorebirds (40-86%). The foraging rate for fish eaters was 19-47%, and for gulls and terns was typically less than 10%.

Thirty-eight percent of all birds counted in Alviso were found on ponds A5-A8, and nearly half of these were counted on pond A5 alone (Table 31, Figure 28). Alviso pond A5, the largest pond and one of the most variable in water depth, supported the largest number of birds overall, including 53% of Alviso's small shorebirds, 39% of phalaropes, 36% of medium shorebirds, 26% of herons, and 18% of dabbling ducks. Pond A7, which is adjacent to pond A5 but much smaller, supported 38% of Alviso's phalaropes. California gulls comprised the majority of birds counted at pond A6, which has supported a breeding colony that has accounted for 24% of all gulls and terns counted on the Alviso system (many gulls counted elsewhere may have also belonged to this colony). Seasonally, gulls and small shorebirds make up the largest proportion of birds on this system during the summer months, when bird numbers on this system peak, while dabbling ducks made up a larger proportion of the much smaller total during the winter (Figure 29). Fifteen to 58% of dabbling ducks were foraging at the time they were counted, while the foraging rate for diving ducks was 4-36%. Although pond A6 supported a large number of breeding gulls, nearly none were observed foraging on A6 and foraging rates in this system were less than 15%. However, 28-63% of eared grebes and 82-96% of phalaropes were observed feeding, and 28-78% of small shorebirds and 26-49% of herons were feeding (Figure 30).

Ponds A9-A17 were the most variable in water quality parameters (particularly salinity, Figure 66a) and also in bird guild distribution, with the lowest salinity ponds (A9-A10) supporting the largest number of birds. These nine ponds together supported 24% of the total bird counts on Alviso ponds (Figure 31); by foraging guild, these ponds supported 33% of dabbling ducks (23% on pond A9), 29% of diving ducks (26% on A9-A10), 72% of eared grebes (60% on A13-A17), 36% of fish eaters (24% on A9-A10), and 23% of herons (15% on A9-A10). The ponds supported 29% of gulls and terns, which were evenly distributed across ponds, and less than 15% of shorebirds. This pond system showed clear seasonal trends (Figure 32). Overall numbers peaked during the winter months, when eared grebes, dabbling and diving ducks generally comprised well over 50% of the count. Gulls were present year-round, but comprised the largest proportion of the total count during the summer months when few ducks were present (Table 32, Figure 32). Foraging rates were consistent in these ponds, and generally higher than other ponds (Figure 33). Dabbling ducks were foraging 6-78% of the time and diving ducks foraged 3-39% of the time. Eared grebes had consistently high foraging rates from 38 to 72%, and phalaropes were feeding nearly 100% of the time.

The "island ponds," A19-A21, along with A22 and A23, were the most saline and often have the lowest water levels in Alviso. Thirteen percent of all birds counted in Alviso were counted at these ponds (Figure 34), but this was primarily due to very large numbers of gulls. Gulls were the primary bird guild seen at these ponds, which lie in close proximity to a landfill. More gulls (35% of all gulls counted in Alviso despite the large breeding colony at A6) have been found on this system than on any other Alviso ponds (Table 32). Fourteen percent of Alviso's eared grebes have also been counted on this system, along with 8% of medium shorebirds and 4% of small shorebirds. Seasonally, numbers were highest during the winter months (Tables 33-34), but gulls generally make up the largest proportion of birds regardless of season (Table 32, Figure 35). Foraging rates on this pond system were highly variable and in most cases were based on few birds (Figure 36). Foraging rates for gulls was less than 5% except on pond A20 (23%), suggesting that gulls use these ponds primarily for roosting and not for feeding. Gulls were frequently observed flying to and from the nearby landfill, which may provide a significant proportion of their diet.

Eden Landing.--Although Alviso supported the majority of dabbling and diving ducks, Eden Landing was shallower overall and supported the highest proportion of shorebirds - 52% of medium shorebirds and 44% of small shorebirds counted between November 2003 and June 2005, despite comprising only 31% of total pond area. Eden Landing also supported 35% of fish eaters, 32% of herons, 27% of eared grebes, 24% of divers, 12% of phalaropes, 10% of dabblers, and 7% of gulls and terns.

Ponds 1C-6C were shallow ponds of varying water level and supported 16% of all birds counted in Eden Landing (Figure 37). Despite the relatively low numbers of birds counted overall, these ponds were relatively important for some groups, especially dabbling ducks. Thirty-eight percent of Eden Landing's dabbling ducks (29% at B3C and B4C), 28% of gulls and terns, 24% of medium shorebirds, 16% of small shorebirds, 10% of herons and phalaropes, 6% of diving ducks, and less than 5% of eared grebes and fish eaters were counted at these ponds. Small and medium shorebirds comprised the largest proportion of birds counted at these ponds, with the highest numbers on ponds B3C and B4C (Table 35, Figure 37). Seasonally, numbers peak during winter and during spring migration periods, but small and medium shorebirds consistently comprise the majority of birds seen on this system (Figure 38). Pond foraging rates were variable but high relative to other ponds (Figure 39), with dabblers foraging 24-76% of the time and small shorebirds foraging 44-86% of the time. Foraging rates for medium shorebirds ranged from 20-70%.

Although ponds B1-B7 accounted for only about 15% of total Eden Landing bird numbers (Figure 40), the majority of diving ducks and fish eating birds at Eden Landing were found in deeper ponds with more consistent water levels. These ponds supported 86% of fish eaters, 59% of diving ducks (45% in B1-B2), 55% of herons, 37% of gulls and terns, 26% of eared grebes, 20% of dabbling ducks, and less than 5% of shorebirds counted in the Eden Landing complex. Diving ducks and fish eaters comprised the largest proportion of the count overall (Table 35, Figure 40) and during winter months (Tables 37-38, Figure 41), but fish eaters, shorebirds, and gulls and terns comprised a larger proportion of the total count when bird numbers were low in summer and as they increased in the fall. Fourteen to 64% of dabbling ducks counted were foraging, compared to 6-25% of diving ducks and 14-29% of fish eaters (Figure 42).

B6A, B6B, B8, B8A, and B9 are north of Old Alameda Creek and were generally very shallow, seasonally inundated, and highly saline. These ponds accounted for a high proportion of Eden Landing's total bird count (37%, Figure 43), primarily due to their attractiveness to saline specialists and shorebirds. These ponds supported 77% of Eden Landing's phalaropes and 60% of its eared grebes. Both species preferred waters in the salinity range that supported *Artemia* spp., and pond B9 had the highest counts of *Artemia* spp. in pelagic sweep samples (Table 19), more than any other pond. Although some southern ponds had high counts of *Artemia* spp. and *Ephydra* spp., (Tables 13, 19), invertebrates were sampled on only one occasion, and pond conditions favorable to these species in some shallower ponds may be more ephemeral than in the B6A-B9 system. Some ponds in the B1C-B6C and B1-B7 systems increased in salinity seasonally, but B6A-B9 were higher in salinity year-round and probably also provided *Ephydra* spp. and *Artemia* spp. habitat for a greater portion of the year. Pond B9 also had the highest counts of *Ephydra* spp. in benthic samples (Table 13), which provided food for many shorebird species. In addition to grebes and phalaropes, 48% of small and 29% of medium shorebirds in the complex were counted in these ponds, along with 20% of gulls and terns, 10% of diving ducks, 7% of dabbling ducks, and 2% of fish-eating birds. Pond numbers were highest during winter and spring migration, with shorebirds comprising the majority of the birds counted (Tables 37-38, Figure 44). Eared grebes and diving ducks were also counted during the winter and occurred primarily on pond B9 (Table 36, Figure 43), where they foraged at a rate of 39-86% (grebes) and 52-80% (diving ducks) around the deeper west end of the pond and along the deep borrow ditches around the perimeter. Sixty-six to nearly 100% of observed phalaropes were foraging when they were counted (Figure 45).

The northern ponds, B10-B14, supported 32% of Eden Landing birds. These were primarily small and medium shorebirds (Table 36, Figure 46), and, seasonally, diving ducks and terns (Tables 37-38, Figure 47). Although 35% (29% in B10-B11) of dabbling ducks and 25% of diving ducks in Eden Landing were counted on these ponds, ponds B10-B14 supported 41% of medium and 34% of small shorebirds in the Eden Landing complex. Recent water level changes in pond B10, which was temporarily and periodically opened to tidal action beginning in June 2004, have encouraged this trend as shorebirds have been attracted to exposed mud during low tide. In pond B10, 59.4% of small shorebirds counted in the pond were actively foraging (Figure 48).

Ravenswood.--Ravenswood comprised only about 11% of the total area of salt ponds included in these bird surveys. However, 31% of small shorebirds counted on all ponds between November 2003 and June 2005 were counted in Ravenswood. Ravenswood also supported 26% of phalaropes and 12% of medium shorebirds – counts of all other foraging guilds made up less than 5% of the total salt pond count. Ravenswood ponds were among the shallowest of the salt ponds and were only shallowly inundated during winter months. Accordingly, small shorebirds made up the majority of counts during most months (Tables 40-41, Figure 49). Numbers were higher during winter and peaked around spring migration during April with most birds counted on pond R1 (lowest salinity) and RSF2 (Table 39, Figure 50), where 34-56% of small shorebirds were observed foraging (Figure 51).

Multivariate Analyses

Multiple linear regressions for birds counted during spring migration (April) explained 13.2-54.3% of the variation in species richness (Adj R^2 = 0.132 – 0.543; Table 42), and all regression models were significant (P < 0.05). The winter (Adj R^2 = 0.050 – 0.385; Table 43) and the fall (September: Adj R^2 = 0.111 – 0.320; Table 44) relationships were somewhat weaker, but trends were similar. For total birds in April, stepwise regression selected 4 independent variables driving bird numbers: pond size, mean depth, maximum depth, and salinity, but pond size (P = 0.12) and salinity (P = 0.09) were not significant. All four variables were significant in the winter model, but in the fall, mean depth, temperature, and pond size were significant. Pond size was expected to be significant wherever more birds congregated on a larger area, because analyses were performed on transformed count values rather than density. Because pond management decisions are made on a pond-by-pond basis, size was considered as a characteristic of each pond rather than a confounding factor. However, analyzing for total birds was problematic because lumping bird species with opposing selection criteria may confound the analysis. Accordingly, the analysis was performed separately on each foraging guild.

Because dabbling ducks were counted at peak numbers in the salt ponds during the winter months, the winter analysis should provide the most appropriate information about pond selection for this guild. Dabbling ducks were associated with mean pond depth, maximum pond depth, salinity, and pond size. Shallow water and aquatic vegetation (not present in highly saline ponds) provided optimal foraging conditions for this guild.

Diving ducks, also present in highest numbers during the winter, were also associated with mean pond depth, salinity, and pond size. Additionally, they were significantly associated with pH, not just during the winter, but also during April ($P < 0.001$) but not significantly in September ($P = 0.056$). Pond depth was important for diving ducks because they need deeper pond water to dive for benthic invertebrates. Salinity was a factor because prey species may be sensitive to salinity (Bivalves such as *Macoma balthica*, for example, were present only in lower salinity ponds; Tables 9, 17, 26), and pH may have a similar limiting effect on prey species.

Eared grebes were present primarily in the winter and were associated with minimum pond depth, variability in pond depth, pond size, and salinity. Because eared grebes dive for food, primarily *Artemia* spp., while foraging in salt ponds, depth and salinity were important variables for pond selection.

Fish eaters were associated with pond size (although not in April) and with salinity during the winter and in the spring, but not in the fall. Pond salinity cycles seasonally and reaches its peak in fall, so September is a time when pond salinity differences were most pronounced. Fish were not tolerant of salinities greater than 80 ppt, so birds that eat fish were strongly associated with ponds of lower salinity and perhaps higher dissolved oxygen. Because herons and Forster's terns also feed on fish, they showed similar associations with salinity. Herons are sit-and-wait predators that stand in shallow water or along banks and wait for their prey, so they were associated with water depth as well. Terns were associated with salinity and herons with salinity and variability in water depth during the spring. During the winter, terns were only associated with temperature, but counts were low during winter months and we lacked sufficient data to determine trends. Herons were associated with depth and pond size but not salinity in the winter, but in the fall, they were associated with both depth and salinity.

Small shorebirds need very shallow water to forage and were consistently associated with mean pond depth. Medium shorebirds were associated with mean pond depth except in September, when they were associated with temperature and pond size. Phalaropes were associated with pond size, pH, and salinity in the fall.

During the spring, the ratio of canonical to unconstrained eigenvalues was 0.38, suggesting that the analysis explained 38% of the explainable variance in the data (Figure 52). The length of the arrows showed the relative importance of the environmental variables to species composition, and the perpendicular distance of the guild points from the arrows revealed the strength and direction of that variable's influence on that foraging guild. In April, salinity and pond depth were the most important factors overall, with eared grebes related to increased salinity and shorebirds related to decreased pond depth. In September, the analysis explained 44% of the explainable variance in the data (Figure 53). Pond size and temperature were relatively more important in the fall compared with the spring, perhaps because smaller ponds were warming up and drying more quickly. Eared grebes and phalaropes were associated with increased salinity and depth, while diving ducks were associated with decreased salinity and increased depth. Shorebirds were again associated with lower depth, and herons and fish eaters with lower salinity. During the winter months, the analysis explained 35% of the variance in the data (Figure 54). Pond size was relatively less important in the winter. Shorebirds were associated with lower pond depth, herons and fish eaters with lower salinity, and grebes with higher salinity.

Pond Water Quality

Pond water quality graphs are presented in geographic groupings, with nearby ponds often sharing water quality patterns when they are on the same circulatory pathway (Figures 56-95). Temperature in the ponds follows a seasonal signal with highest temperatures in the summer. Between-pond temperature differences were typically less than 5ºC, except during the fall when the differences can exceed 6ºC. Salinity in the ponds is influenced primarily by rainfall during the wet winter season, and evaporation and water transfers during the dry season. Highest salinities are typically seen in the late summer and fall, especially for the higher salinity ponds. The low salinity ponds appear to be heavily influenced by water transfers during the year. Trends in turbidity, D.O. and pH between ponds and seasons are much less obvious. The between-pond differences appear to be greater during the summer dry season. Between-pond differences are influenced by a number of physical factors including pond depth, wind speed, fetch, solution density and amount of water influx (rainfall or water transfers), so these differences are not surprising.

Objective 3b. Complete Self-Monitoring Program (SMP) sampling and reports to document compliance with discharge requirements during the initial desalination.

USGS completed data collection of the water quality parameters for the SMP. Results from 2004 water quality monitoring activities can be found in annual self-monitoring reports (USFWS 2005 and CDFG 2005). Data from 2005 are posted at the project webpage (http://www.southbayrestoration.org), where the reports are available for download.

Objective 4. Assess the hydrology and present morphology of the South Bay sloughs by analyzing existing data augmented with collection of new data.

Sediment budget of the South Bay

Siegel and Bachand (2002) identified sediment supply as a key constraint to salt pond restoration. In order to evaluate sediment sources, sinks, and deposition, a sediment budget for South Bay was developed using a sediment transport box model. Opening the salt ponds to tidal action will create multiple new sediment sinks in South Bay and will affect SSC and net sedimentation in the Bay. The same sediment transport box model was used to simulate the affect of adding breached ponds to the system to learn how it could change the sediment budget (Figure 95). These simulations allowed PWA to perform a landscape-scale geomorphic assessment of restoration alternatives. We used the model runs to analyze the potential effects of changing SSC on the potential for phytoplankton blooms. In general, the decrease in South Bay

SSC (roughly 10% decrease) that results from opening additional South Bay area to tidal action will increase the likelihood that South Bay could experience a phytoplankton bloom in any given year. However, the effect of the increased likeliness of a bloom is less than the inter-annual variability in water column clearing rates caused by inter-annual variability in benthic grazing rates. These results were presented at the American Society of Limnology and Oceanography meeting in February 2004 (Shellenbarger *et al.* 2004) and will be formalized in a written report with a draft due 30 Sept. 2005.

Conductivity and temperature data at Channel Marker 17

Conductivity and temperature data were collected continuously every 15 minutes at Channel Marker 17 in South Bay during the winters of water years 2004 and 2005 (Figure 96). The instruments successfully collected data during wet-weather periods. Cleaned and processed data were provided to the State Coastal Conservancy and Phillip Williams & Associates (at the request of the SCC) after each data collection effort.

Reconfigure SPOOM for the Alviso pond system

Management of water movement through the existing pond system will be a primary concern for managing the short-term future to maintain resource values, and for long-term restoration alternatives. Minimizing the expense of pumping and examining scenarios for water flows would be greatly enhanced through use of model simulations. The salt pond box model (SPOOM) was developed to track water and salinity budgets for the Napa-Sonoma salt pond complex (Lionberger *et al.* 2004). The SPOOM model can be used to predict how water transfers will affect the salinity and depths in the ponds. Both salinity and depth are critical parameters for habitat modification and restoration. SPOOM is being reconfigured to simulate ponds in the Alviso pond complex. The SPOOM model can be used as a valuable management tool by the FWS for predicting how to control the pond systems to maintain existing habitat and prevent an accumulation of salt. The model will be provided to USFWS during the summer 2005.

Sediment Synthesis

The purpose of the synthesis answered six questions regarding the sediment management issue and restoration of the South Bay salt ponds (report completed 2005):

- What is the importance of the issue as it relates to the Project Objectives?
- What do we know about this issue as it relates to the Project?
- What is the level of certainty of our knowledge?
- What predictive tools exist for gaining an understanding of this issue and what tools are needed to reduce uncertainty to an acceptable level?
- What are potential restoration targets and performance measures, linked to the Objectives, for evaluating the progress of the restoration project and what management measures might be used to reduce negative impacts?

- What key questions essential to the success of the restoration need to be addressed through further studies, monitoring, or research?

The report has undergone review of the Science Team and will be published in a future outlet.

Coyote Creek Seasonal Suspended-sediment Loads

Daily seasonal suspended-sediment load was collected at an existing flow gaging station on Coyote Creek and the site was maintained by the USGS Marina Field Office. Data were successfully collected during wet-weather periods of water years 2004 and 2005. The addition of a sediment station at the Coyote Creek flow station provided more accurate assessments of the sediment inflow to South Bay and boundary condition data for numerical models of sediment dynamics in South Bay. The three largest sources of freshwater to South Bay (Friebel *et al.* 2002) (Alameda Creek, Coyote Creek, and Guadalupe River) were measured for both water discharge and sediment load.

South Bay Hydrologic Summary and Data Gaps

The purpose of collecting existing hydrologic data was to identify data gaps and to compile existing data for future reference. Identified data gaps, such as suspended-sediment load from Coyote Creek were targeted for future data collection activities. At the request of the Coastal Conservancy, the list was passed on to Amy Stewart at Phillip Williams and Associates in the spring of 2004. A data summary was provided to the State Coastal Conservancy in July 2004 by PWA. PWA's Data Summary Report can be found at http://www.southbayrestoration.org/pdf_files/Final_SBSP_Data_Summary.pdf.

Vegetation Colonization in the Salt Ponds

Collectively over the three sites (Corkscrew Marsh, Bird Island and Palo Alto Baylands), salt marsh vegetation ranged in elevation from 0.98 to 2.94 meters above MLLW (Table 45). *Spartina foliosa* and *Salicornia virginica* were the most frequently observed plant species. *Atriplex patula, Deschampsia cespitosa* and *Limonium californicum* were each only recorded at one of the three sites. Funded with state matching funds as a separate project by USGS, results for this study will be available as Orlando *et al.* (*in prep*).

Objective 5. Characterize invertebrate and fish communities in the slough systems and compare with South Bay pond communities.

Sediments

Slough sediment samples in sloughs were generally lower in salinity and organic carbon content (Table 46). Slough sediments were mainly silty clay loam, having higher sand and silt content than pond sediments (Figure 97).

Benthic macroinvertebrates

We completed a summary of the available existing invertebrate surveys from South Bay mud flats (Thompson and Shouse 2004, Appendix B), which was made available in June 2004 as background for examining the ecological linkage of the shallow-water habitats in restoration planning studies at a landscape level.

Eight sloughs were sampled for invertebrates in April 2004. Samples were dominated with *Heteromastus*, *Streblospio* and Tubeficoides. *Gemma gemma* was abundant in Mt. Eden Creek (162.6 per Ekman) and Alameda Creek (29 per Ekman) and *Macoma balthica* was present in all sloughs with largest numbers found in the Alameda Control Channel (25 per Ekman; Table 47). Insecta was present in only 3 sloughs with greatest taxa richness in Mt. Eden Creek (4 species; Table 48). Chironomidae was present in Mt. Eden Creek and Alameda control Channel (Table 48). Corixidae and Diptera were detected in Mt. Eden Creek and Alameda Creek. (Table 48). *Cumacea* was present in all sloughs and was the most abundant Crustacean detected in slough samples (Table 49). Average abundance of Annelida taxa and other taxa are summarized (Tables 50-51, Figure 99). In general, benthic Ekman grabs in Sloughs contained lower invertebrate populations than pond samples. Mt. Eden Creek had highest taxa richness (24) and Mud Slough lowest (11) (Table 52). The pattern of invertebrate assemblages in slough samples is similar to that found by Thompson and Shouse (2004) in south bay mud flat samples. Thompson and Shouse (2004) demonstrated that there could be high amount of variability in these species depending on year.

Fishes

Sixteen fish species were captured in sloughs. Overall, the highest numbers of fish were captured with bag seines, followed by gill nets, then by minnow traps (Table 28). Fish abundance was highest in June and lowest in November. Due to federal permitting restrictions, fish were not sampled in sloughs during March.

Gill nets, bag seines, and minnow traps targeted different portions of fish communities in the ponds and sloughs (Table 27). In the Alviso sloughs, topsmelt accounted for most of the gillnet catch (>81%). By comparison, gill net catches in the Eden Landing sloughs were not dominated by a single species; instead, three species--topsmelt (31.4%), northern anchovy (27.5%), and leopard shark (24.2%)--collectively dominated the gill net catch. Seining was not used in sloughs. By comparison, seining in the Eden Landing ponds yielded mostly yellowfin goby (40%) and topsmelt (28.8%). Although minnow traps yielded few fish in both ponds and sloughs, most captured individuals consisted of rainwater killifish or yellowfin goby.

Generally, water quality conditions varied significantly among ponds and sloughs (Table 29). Water temperature and dissolved oxygen fluctuated seasonally in both ponds and sloughs, with higher temperatures and lower dissolved oxygen concentrations occurring during June and September (Table 30). Overall, mean temperatures in the Alviso sloughs were higher than in the Eden Landing ponds and the Alviso and Eden Landing sloughs. In addition, mean concentrations of dissolved oxygen were significantly higher in the Eden Landing sloughs (6.77 mg/l) than in other waters. Mean pH values in the Alviso ponds and sloughs differed significantly from values measured in the Eden Landing ponds and sloughs (Table 29). Overall, however, pH values did not exhibit much temporal variation over the four sampling periods. Mean salinities varied between ponds and sloughs (Table 29), with higher concentrations typically occurring in ponds (salinities in the Eden Landing ponds exceeded 90 ppt in March; Table 30).

Objective 6. Assist in development of a land surface elevation map for the South Bay region and map South Bay open bay and slough bathymetry.

LIDAR

More than 250 million returns were collected resulting in a data density greater than one point per square meter over the extent of the LIDAR data (Figure 99). The detail captured by the LIDAR survey is remarkable. For example, a shaded-relief map of the Coyote Creek region (Figure 100) shows many small-scale features not detectable in other elevation data sets. Foxgrover and Jaffe (2005) present additional LIDAR images from the survey.

To make this enormous data set manageable for various end users, all of the deliverables (except hill-shaded images) were partitioned into both 1 x 1 km and 2 x 2 km tiles with 25-meters of overlap between adjacent tiles (Table 53). The bare earth and full feature (all return) point data were made available as ASCII comma delimited text files. TerraPoint also generated a bare earth grid of last returns at 1 m resolution, in ASCII format. The gridded bare earth data was also made available at 1 m and 25 m resolution in an ArcInfo ASCII format for easy import into GIS coverages. Contours generated at a 50 cm nominal contour interval were created in AutoCAD (DWG) format. One-meter resolution hill-shaded images of both the bare earth and full feature data sets were produced in GeoTIFF format. In addition to the elevation data, digital video imagery was collected at 2 frames per second during all flight missions. The geo-referenced video files were in AVI format with accompanying *.GPS files designed for viewing with Trident 3D Vision software. The San Francisco Estuary Institute was given the responsibility for distributing this data (contact: Eric Zhang, ericz@sfei.org, 510-746-7361).

<u>LIDAR Accuracy.--</u>LIDAR accuracy is a function of errors in position and orientation of the laser and the characteristics of the surface being illuminated. Uncertainty in the orientation of the laser is the primary factory influencing horizontal accuracy. Errors in differential GPS solutions and uncertainty in elevations of the ground surface on steep terrain also degrade horizontal accuracy. Absolute positional (horizontal) accuracy at the 2σ level is 20 to 60 cm on all but extremely hilly terrain (Table 54).

Uncertainty in orientation of the laser and differences in elevation of the illuminated surface, which was a distorted circle with a diameter of approximately 0.75 m, are the primary factors determining vertical accuracy. Ground elevations of steep slopes, such as the sides of levees, are less accurate than elevations on flat surfaces (Table 54). The vertical accuracy of this system on low sloping, hard surfaces is 10 to 15 cm at the 95% (2σ) confidence level.

<u>LIDAR ground-truthing.--</u>Over 650 ground-truth measurements were taken in seven areas to evaluate LIDAR performance (Figure 3). Ground-truth locations were selected to include the variety of surface types within the study area and included tidal flats, levees, and marshes. Ground-truthing included static GPS measurements throughout the study area and kinematic GPS surveys on paved roads. Elevations of the static and kinematic GPS ground-truthing points have accuracy relative to the GPS control network of 2 cm in three dimensions, at the 95% confidence interval. A total of 165 static ground-truth points were collected in a variety of

terrain to evaluate how well LIDAR was estimating bare earth elevations in differing vegetations, slopes, and on soft surfaces (tidal flats). Along with each GPS measurement, notes were collected on the description of the terrain, and if present, the type, density, and height of vegetation.

For static ground-truth points, the average difference between the LIDAR and ground-truth elevations was 3.6 cm and 95% (2σ) of the LIDAR elevations were within 28 cm of ground-truth elevations (see appendix). However, accuracy varied with surface types (Table 55). LIDAR estimates of the bare earth surface in areas of pickleweed (*Salicornia virginica*) marsh were good with a 2σ error of 18 cm while in the bulrush (*Scirpus californicus* or *Scirpus maritimus*), LIDAR performed poorly with a 2σ error of 192 cm. Based upon our limited number of bulrush ground-truth locations, we believe the high error is the result of the very dense vegetation that was impenetrable by the LIDAR. Gently sloping areas such as those sampled containing pickleweed, tidal flats, or the center of the levees performed relatively well, while the edges of the levees did not. The higher error of measurements at either the top edges of the levees or at the base of the levee banks is a result of the size of the laser footprint and the steep slope of the levees. The laser footprint is approximately 0.75 m in diameter and with typical levee slopes of 10 to 20 degrees; the LIDAR is unable to resolve the steep slopes with the same accuracy of gently sloping terrain.

In addition to the 165 static ground-truth points, 593 check points were collected using a kinematic surveying method in which the GPS is mounted to an automobile and set to collect data every second. The kinematic ground-truth points were collected along two separate stretches of paved roads totaling 10 km in length and compared to the bare earth LIDAR surface to evaluate absolute accuracy. For the entire set of these points, the average difference between LIDAR and ground-truth elevations was -1.9 cm and 95% of the LIDAR elevations were within 13.2 cm of ground-truth elevations.

<u>Limitations of the 2004 LIDAR survey.--</u>The 2004 South San Francisco Bay LIDAR survey collected elevation data from a variety of surfaces including bare earth, vegetation, structures, and water. The primary limitation to using the data set is the uncertainty in the type of surface the return is from. The three most common problems are: (1) discriminating tidal flats from water returns, (2) discriminating bare earth from vegetation, and (3) discriminating dry ponds from water.

The problem of discriminating tidal flats from water was addressed using the intensity and pattern of LIDAR returns. When LIDAR is collected over water or very dark surfaces, rather than receiving the typical full-swath return, the laser beam is only reflected back to the receiver in a in a very narrow range close to nadir. This reflection pattern results in a limited swath return approximately 30-50 m wide as opposed to the anticipated full swath return of 245 m over a solid surface. Without the full swath return, data from adjacent flight lines do not overlap, resulting in striped pattern of narrow bands of data alternating with bands of no data (Figure 6).

Unfortunately, there is not a simple automated way of identifying these over-water returns and manually delineating them as such can be quite laborious. This data set was collected over a time span of three weeks and due to the complex nature of tides in South Bay, it is impossible to determine a single elevation under which all returns would be classified as over-water returns. Although geo-referenced video was collected at the time of the flights, it has proven difficult to distinguish tidally influenced areas of shallow water from the mudflats, which in the video both appear brown. Therefore, the video, does not independently serve as a reliable source for identifying over-water returns.

The technique that was most reliable for discriminating water and tidal flat was using a combination of high-resolution satellite imagery, exaggerated hill shaded images of the LIDAR, and LIDAR return intensity to manually delineate and remove over-water returns. The IKONOS imagery proved useful in determining areas of standing water that remained relatively constant from the time the imagery was collected and throughout the collection of the LIDAR. Areas such as levied ponds could be delineated using the IKONOS but the imagery could not be used to identify continually changing tidal inundation levels such as those in the tidal flats. To determine the bay-ward extent of the tide or to identify small puddles of water within the tidal flats, LIDAR intensity in conjunction with exaggerated hill-shades of the full feature return data set is best suited for distinguished these false returns from valid surface elevation returns. Areas of water tend to give a strong LIDAR return directly at nadir relative to surrounding tidal flats and marsh (Figure 6). Although a subjective technique, the results appear to be promising.

<u>Logistical constraints.--</u>In winter and spring, some sampling was rescheduled because rainfall caused muddy levees, preventing or restricting access to many ponds. Bathymetric sampling on ponds was further complicated because recent rains were often needed to ensure sufficient depth for sampling. Fish sampling was complicated in many ponds by early ISP activities, which resulted in fluctuating water levels. LIDAR flights were delayed due to problems with airport airspace restrictions.

SUMMARY AND RECOMMENDATIONS

Data collected during the first two years of the SBSP Restoration Project provide baseline information on project area elevation and bathymetry, historic plant species elevation, sedimentation processes, sediment chemistry and character, water quality, nutrients, primary productivity, benthic and pelagic macroinvertebrates, fishes, and birds. These data provide a scientific foundation upon which habitat response to management actions can be evaluated that has already proven useful at this early stage of the project; continued monitoring will provide necessary feedback as restoration continues.

Initial Stewardship Plan (ISP) actions were initiated in July 2004 when five project ponds were opened to circulation with Bay waters (followed by four additional ponds in April 2005). Our monthly monitoring of pond water quality and bird use enabled us to document that winter bird use was substantially higher in the salt pond complexes following pond circulation (for salinity reduction) than in the previous two winters, and that the primary increase in bird numbers was found on ponds that had been affected by the action (Figure 101). Additionally, we identified shorebirds and dabbling ducks as the primary affected foraging guilds (Figure 102) and documented that changing water levels were the likely cause. Although some birds responded quickly to pond changes, these early conditions will not continue indefinitely, and improved understanding of habitat needs will be key to maintaining target populations.

Newark and Mowry salt pond complexes remain in salt production; it is expected that they will supplement much of the lost salt pond habitat during restoration processes to maintain bird abundances in the South Bay. However, these ponds have been little studied, and it is unknown whether they can support large numbers of migratory shorebirds. Supplemental surveys of these salt ponds by San Francisco Bird Observatory in 2005-2006, coordinated with USGS project pond surveys, will provide valuable information on how all five major salt pond systems in the South Bay interact with respect to bird use and distribution.

South Bay mud flats are an important foraging resource for shorebirds, which use the salt ponds primarily during low tide when mud flats are not available. The salt pond beds are now lower than the floor of the adjacent baylands because of groundwater pumping and subsidence. As a result, a large amount of sediment will be required for restoration of salt ponds to tidal marsh (Siegel and Bachand 2002). Sediment may come from adding dredge material, capturing downstream sediments from nearby creeks, and from redistribution in the South Bay that may result in erosion of South Bay mud flats. In addition, invasive *Spartina alterniflora* may spread into the mud flats and vegetate farther onto the intertidal shoals, thereby decreasing available habitat for waterbirds (Stralberg *et al.* 2004). Monitoring of mud flat use by shorebirds will document the importance of mud flat habitat to shorebirds and provide guidance for management action.

The SBSP Restoration Project may extend for 50 years, but the most valuable scientific investment will be in early phases of the project since it will influence more of the future decisions. Consistent project monitoring is a key component of adaptive management and has been called "the environmental counterpart to financial accounting and reporting" (Lee 1993), a tool that can either support management actions or provide the information needed to guide them back in the right direction. Although not all datagaps can be identified and addressed prior to implementing management action (Trulio *et al.* 2005), filling these key datagaps early in the project provides a scientific basis on which to move forward.

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