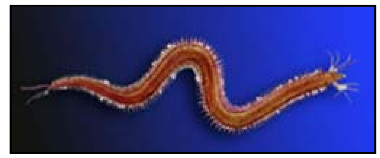
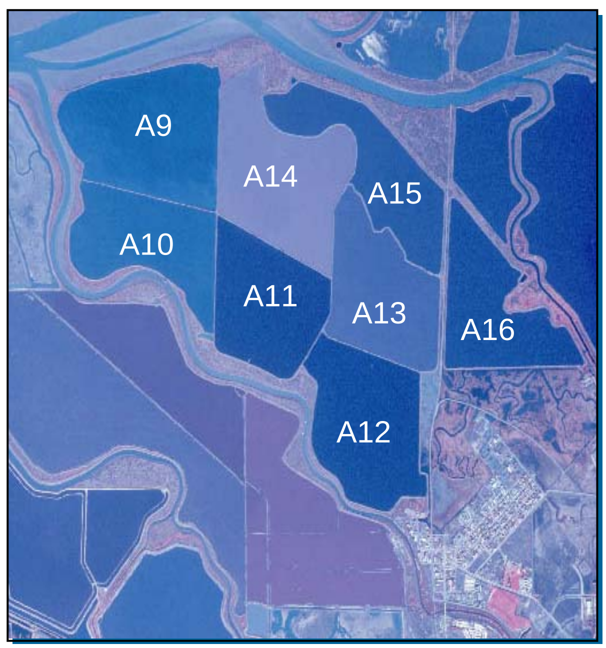
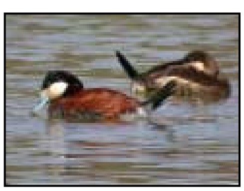
San Francisco Bay Estuary Salt Ponds
Progress Report 2001 - 2003
USGS Priority Ecosystem Science Program
USGS/USFWS (CNO) Science Support







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U. S. Geological Survey, Western Region

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San Francisco Bay Estuary Salt Ponds
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*****Preliminary Results. Do Not Cite Without Permission*****

EXECUTIVE SUMMARY

- Artificial salt evaporation ponds comprise 16,200 ha in the diked baylands of the San Francisco Bay estuary. These ponds support large numbers of waterbirds and have become an integral part of the ecosystem over the past 150 years. Recently, several proposals have recommended converting these wetlands to tidal marshes for restoration of historic resources or as mitigation. However, we lack basic information on ecological structure or physical and biological processes within these hypersaline systems and their importance in the ecosystem.

- In 1999, we initiated an interdisciplinary research study in North San Francisco Bay on the 4,000 ha Napa-Sonoma salt ponds, a former salt evaporation pond system managed by California Department of Fish and Game since 1994. In 2002, we expanded studies to include salt ponds in the southern estuary recently acquired by the U.S. Fish and Wildlife Service (USFWS) Don Edwards San Francisco Bay National Wildlife Refuge from the Cargill Salt Company. The USFWS has very limited information on the ecology and physical dynamics of these ponds. We selected eight salt ponds under USFWS management (A9, A10, A11, A12, A13, A14, A16, and A17) for intensive studies. This report provides preliminary information from the 2001-2003 field seasons regarding water quality, nutrient concentrations, the structure of pelagic and benthic invertebrate communities, and waterbird abundance and distribution.

ALVISO SALT PONDS:

- Temperature, salinity, turbidity, dissolved oxygen (D.O.) and pH were recorded monthly in Alviso salt ponds A9-A16. Temperature varied seasonally, with highest values recorded in the summer months. Pond salinity was influenced primarily by rainfall during the wet season, and evaporation and water transfers during the dry season, with highest salinities seen in the dry season. Highest salinities were typically seen in the late summer and fall, especially for the higher salinity ponds (A11-A17). The low salinity ponds, ponds A9 and A10, appeared to be heavily influenced by water transfers during the year. Turbidity, D.O., and pH did not exhibit any obvious trends throughout the year. Between-pond differences are influenced by many factors such as pond depth, wind speed, fetch, solution density, and water influx.

- Ammonium (NH_4), Nitrate (NO_3), Soluble Phosphorous (SP), Total Phosphorous (TP), and Sulfate (SO_4) levels were determined for the Alviso salt ponds from September 2002 to December 2003. SO_4 and TP were generally highest in higher salinity ponds, and NH_4 decreased with increasing salinity. No discernible patterns were found for SP or NO_3.

- The Salt Pond Box Model (SPOOM) was designed to simulate pond volume and salinity in the Napa-Sonoma salt pond complex. The model is now being reconfigured to simulate the volume and salinity for several Alviso salt ponds.

- We have identified 48 taxonomic groups of macroinvertebrates in the Alviso salt ponds. The most abundant and diverse group in benthic samples was the Crustacea with 17 different taxa. Eight Polychaete worm genera were present, mostly in ponds A9, A10, A11, and A12. There were also six species of bivalves and five insect families. Ponds with lower salinity appear to support the largest number of taxa of benthic macroinvertebrates. There was a relationship between increasing salinity and decreasing number of taxa. However, sweep samples of higher salinity ponds contained organisms tolerant of high salinity conditions. *Artemia*, in particular, resulted in greater invertebrate biomass in these ponds than in lower salinity ponds.

- We determined Chlorophyll-*a* levels using a Turner Designs submersible flurometer (SCUFA). Chlorophyll-*a* levels were generally higher in the higher salinity ponds.

- Sixty-nine species and over 228,000 birds were recorded from February 2002 to December 2003 in the Alviso salt ponds. Pond A9 contained the greatest number of birds at over 96,000 individuals (42% of the total count for the study period), whereas the remaining ponds contained substantially fewer birds, from 4% of the total in pond A17 to 12% of the total in pond A10. Gulls comprised 35% of birds overall, while diving benthivores were second in abundance at 32%. Dabblers, piscivores, shallow probers, sweepers, and deep probers made up the remainder. Ponds A9 and A10 appear important for waterfowl, A9 and A14 important for shorebirds.

- Pond use by avian foraging guilds was most strongly influenced by water depth. Diving benthivores, which require the deepest water for foraging, were well represented among all ponds. Ponds A9-A17 are usually too deep to provide substantial shallow-water foraging habitat for shorebirds, but shallow probers, deep probers, and sweepers together comprised 9% of the total count. The majority of these birds (78% of all shallow probers and 68% of all deep probers) were counted at pond A9, mostly during atypically low water level conditions in November and December 2003; smaller numbers of shorebirds were counted while roosting on islands in ponds A14, A15, and A16.

NAPA-SONOMA SALT PONDS:

- Salinity and water surface elevation data collected monthly (February 1999 – December 2003) on the Napa-Sonoma salt ponds are being used to calibrate a hydrological Salt Pond Box Model (SPOOM). SPOOM uses individual pond bathymetry and the variables rainfall, evaporation, and water transfers to calculate daily pond volume and salinity values using the conservation of mass principle.

- Biomass of invertebrates was highest on pond 1 and pond 4, and much lower in pond 3. *Heteromastus* sp. (polychaete), *Gemma* sp. (bivalve), *Corophium* sp. and *Ericthonius* sp. (amphipods) dominated taxa in ponds 1 and 2, *Polydora* sp., *Capitella* sp. (polychaetes), *Corophium* sp., and occasionally *Streblospio* sp. (polychaete) and Corixidae (waterboatman insect) dominated pond 3, and *Artemia* sp. (brine shrimp) and *Ephydra* sp. (brine flies) dominated pond 4.

- Species diversity of benthic macroinvertebrates was generally higher and similar in ponds 1 and 2 relative to ponds 3 and 4, except for a substantial change that occurred between May and September 2000. Diversity in ponds 1 and 2 was represented by 50 – 55 taxa, many of which were uncommon, and high densities of individuals from 3 – 4 taxa. Pond 3 (25 taxa) and pond 4 (12 taxa) usually had lower numbers of taxa, but higher densities (relative to ponds 1 and 2) in 2–3 taxa.

- Seventy-two species and estimates of over 456,000 birds were recorded from January 2002 to December 2003 in Napa-Sonoma ponds 1, 2, 3, 4, 2A, and 7A. Ponds 3 and 4 contained the greatest proportion of the total count (45% and 40%, respectively), whereas ponds 1, 2, 2A, and 7A contained substantially fewer birds. In contrast to Alviso salt ponds, shorebirds comprised 73% of the total count at Napa-Sonoma salt ponds (shallow probers, 55%; deep probers, 7%; and sweepers, 11%). Diving benthivores, dabblers, piscivores, and others made up the remainder.

- Bird diversity and community distribution between the ponds seem to be influenced more by water depth than by salinity. Ponds 1 and 2 were similar in salinity, but pond 1 supported more species (45) than pond 2 (31). Pond 1 was more spatially variable in water depth, which enabled it to support a wider variety of species from all foraging guilds; Pond 2 was more uniform in depth, with no islands or shallow water areas, and supported primarily diving benthivores and piscivores. Pond 2A, a revegetated pond with shallow open water areas, supported primarily dabbling ducks. Vegetation density in pond 2A (39 species) continued to increase, resulting in fewer open water areas for waterfowl, but better habitat for Virginia, black, and sora rails.

- Our initial findings of the Napa-Sonoma salt ponds indicate significant avian use and conditions that benefit migratory birds as well as unique invertebrate populations that are important forage for migratory birds. Data collected and available to date were synthesized into a manuscript, which has been accepted for publication in the peer-reviewed journal *Hydrobiologia*.

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INTRODUCTION

Background

Artificial salt pond systems have been a major component of the San Francisco Bay (Bay) ecosystem since 1856 (Josselyn 1983). A number of commercial salt ponds were acquired by the U.S. Fish and Wildlife Service (USFWS) and California Department of Fish and Game (CDFG) and are proposed for restoration to tidal marshes in South San Francisco Bay. Salt ponds in the North Bay were acquired by CDFG and at least one has been converted to tidal marsh. Such conversions or restorations are intended to reverse a severe decline in tidal marsh habitat (Josselyn 1983, Nichols *et al*. 1986). Such habitat benefits species of concern, e.g., the California clapper rail (*Rallus longirostris obsoletus*), salt marsh harvest mouse (*Reithrodontomys raviventris*), and steelhead (*Oncorhynchus mykiss*). However, salt ponds also are important for migratory birds that include listed species, e.g., snowy plover (*Charadrius alexandinus*) that nest on salt pond levees. Salt ponds 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*., *in press*). The USFWS San Francisco Bay National Wildlife Refuge manages wildlife at a number of ponds that the Cargill Corporation either currently or formerly operated for salt production. A number of these ponds have been purchased for the USFWS and CDFG to manage; these agencies will be responsible for the complex and expensive task of maintaining or restoring thousands of hectares of wetlands.

The USFWS and conservation organizations have supported conversion of salt ponds and other baylands to tidal wetlands to benefit species of concern. However, no guidelines, model, or management strategies for such conversions exist. Also, the USFWS recognizes that 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). The American Bird Conservancy designated the Napa-Sonoma Marshes State Wildlife Area inclusive of salt ponds at the northern reach of San Francisco Bay as a “Globally Important Bird Area” because a large proportion of the shorebirds and waterfowl inhabiting the estuary use this region (Accurso 1992; Anderson 1970; G. Page, unpubl. data). Projections for wetland restoration from the multi-agency San Francisco Estuary Baylands Ecosystem Goals report (Goals Project 1999) suggest that only a few hundred hectares of the more than ten thousand hectares of salt ponds throughout the estuary will likely remain during the next century. The remaining ponds probably will be converted or will return to tidal marsh once salt production is terminated. The potential implications of changes to the existing structure of ponds to the thousands of migratory birds that currently use them are unknown. Presently, we have a limited understanding of obligatory versus opportunistic use of the ponds by migratory birds.

Natural saline ponds and saltpans occurred historically at San Francisco Bay (Nichols and Wright 1971) though they comprise less acreage than today. Use of these and other similar, calm water open pond areas (e.g., vernal pools, seasonal wetlands) by migratory waterbirds was probably similar to current use of commercial salt ponds. The ponds provide roosting habitat during high winds or tides on the open Bay and invertebrate blooms that supplement the open Bay avian prey base (e.g., brine shrimp that are not found in Bay waters). Presently, natural ponds or pools have been destroyed by urban development and agriculture, including salt production. The prevailing consensus is to convert available land to tidal marsh to replace that lost to human encroachment. This consensus is driven largely by the concern for endangered species, but does not account for the possible obligatory use of salt ponds by migratory birds.

Conversion of salt ponds to tidal marsh may also affect adjacent tidal sloughs. One concern of resource managers is the effects that release of the highly saline water in the ponds may have on the ecology and physical nature of the sloughs when levees are breached. The increase in tidal prism would increase water velocity in the sloughs and perhaps cause erosion and alteration of the sloughs. Erosion may result in the re-suspension of contaminants, such as mercury, deposited during hydraulic mining in the Sierra Nevada Mountains and currently sequestered in Bay sediments (Thomas *et al*. 2002). Lack of knowledge about the hydrodynamics of the salt ponds and sloughs, however, prevents reliable prediction of these impacts.

Only a few descriptive studies (Carpelan 1957, Anderson 1970, Lonzarich and Smith 1997) of ecological processes in these ponds have 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., Pinckney and Paerl 1997; Caumette *et al*. 1994; Rodriquez-Valera *et al*. 1985). 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 identified in similar systems (e.g., Elphick and Rubega 1995; Herbst and Castenholz 1995; Herbst and Bradley 1993).

Napa-Sonoma Ponds

We are studying specific salt ponds in the Napa-Sonoma Marshes State Wildlife Area in the northern sub-region of the Bay (ponds 1, 2, 2A, 3, 4, and 7A), to develop background and guidance for restoration actions (Miles *et al*. 2000, Takekawa *et al*. 2000). Our initial findings of these ponds indicate significant avian use and conditions that benefit migratory birds (e.g., habitat quality, prey abundance) as well as unique invertebrate populations that are important forage for migratory birds. Salinity and depth seem to play an important role in invertebrate assemblage structure and subsequently avian use at different ponds. Breached levees at Pond 2A have led to colonization by tidal marsh plants. Now heavily vegetated, this pond supports far fewer migratory birds than the other ponds studied. A shortcoming of the Napa-Sonoma pond study was the inability to replicate sampling, i.e., each pond studied was physically and biologically unique. Study of salt ponds in other regions of the Bay might allow replication of North Bay research, and facilitate interpretation of results and inference derived from the Napa-Sonoma study.

Salinity and water surface elevation data collected monthly (February 1999 – present) on the Napa-Sonoma salt ponds were used to calibrate a hydrological Salt Pond Box Model (SPOOM; Lionberger *et al*. 2004). SPOOM uses individual pond bathymetry and the variables rainfall, evaporation, and water transfers to calculate daily pond volume and salinity values using the conservation of mass principle. Preliminary model output for ponds 3, 4, and 7 matched the observed data reasonably well. The other ponds in the Napa-Sonoma salt pond complex are either tidally influenced, or were not sampled for calibration.

Alviso Salt Ponds
Our continuing field efforts focus primarily on eight salt ponds in the southern sub-region of the Bay (Alviso salt ponds) that are under USFWS management (A9, A10, A11, A12, A13, A14, A16, and A17; Figure 1). The USFWS has very limited information on the ecology and physical dynamics of these ponds, and as a DOI client agency, requested assistance from USGS. PRBO Conservation Science biologists conducted bird surveys on some of these ponds, and Lonzarich and Smith (1997) studied biophysical characteristics of ponds A9 – A15. Ponds A9 and A10 appear important for waterfowl, A9 and A14 important for shorebirds, and A11 – A13 apparently not as important. Trophic, geomorphic, and hydrologic study components will be combined to develop a conceptual model to provide a foundation for management or mitigation of these ponds and future wetland restoration in lieu of commercial salt pond operations. The SPOOM model will provide water and salt budgets for the ponds that will substantially aid interpretation of the ecological data, and eventual development of the conceptual model. These models also will be useful tools for other agencies planning restoration of the Napa-Sonoma and Alviso ponds.

In addition to the study of the eight targeted salt ponds, the State Coastal Conservancy and U.S. Fish & Wildlife Service also have requested characterization of all or most South Bay salt ponds. Their added funding support will be used primarily to provide a discreet or one-time assessment of the ecology of up to 53 ponds. Sampling would be conducted in the manner defined in the following objectives, and would include bathymetry, sediment and water chemistry, avian density and use, and invertebrate and fish diversity. The added support also augments our limited USGS funding within the Priority Ecosystem Science Program.

We will use existing bird surveys and past and current data augmented with the proposed objectives to provide information needed by the USFWS to develop the best management decisions for South Bay salt ponds under the South Bay Salt Pond Restoration Program. We will help to identify those ponds and key habitat qualities that support highly diverse (abundance and species) avian communities with attention to avian species of concern, balanced with those ponds that likely might be converted to tidal marsh with the least impact of existing natural biological communities. We will continue monitoring avian use and prey dynamics in the North Bay ponds; such knowledge will increase our capability to predict changes at San Francisco Bay salt ponds. The goal of the continuing studies is to provide resource managers with a comprehensive assessment of the ecology of the San Francisco Bay salt ponds and linked shallow water systems, such that optimal management strategies can be exercised that maximize benefits to wildlife.

OBJECTIVES

The primary goal of the salt ponds study is to examine the ecological function of the salt ponds, particularly with respect to their importance for waterbirds. This includes integrated studies of primary productivity, macroinvertebrates, plants and fishes.

Objective 1. Interpret existing data and disseminate existing data on Napa-Sonoma salt ponds.

Objective 2. Determine biological structure (primary productivity and zooplankton, invertebrate diversity, nutritive quality, and biomass; avian abundance and distribution) at selected Alviso salt ponds.

Objective 3. Determine physical or water quality parameters that might influence structure of biota inhabiting Alviso salt ponds.

Objective 4. Determine relationships between the hydrologic, morphologic, and biological components of the Alviso salt ponds.

Objective 5. Continue monitoring of biological and physical parameters of Napa-Sonoma salt ponds.

METHODS

Objective 1. Interpret and disseminate existing data on Napa-Sonoma salt ponds

Data collected and available to date will be synthesized into manuscripts for publication in peer-reviewed journals.

Objective 2. Determine biological structure at Alviso salt ponds.

Study of biological structure will include measures among ponds and adjacent sloughs of chlorophyll levels as a measure of primary productivity, diversity of invertebrates and birds. The targeted ponds to be studied will include Alviso salt ponds A9, A10, A11, A12, A13, A14, A15, A16, and A17 (Figure 1).

Benthic macroinvertebrates

We characterized the taxa composition, distribution and abundance of benthic macroinvertebrate (>1.0 mm) assemblages with the goal of identifying their relation to salinity, pH, dissolved oxygen, water depth, turbidity, and biological influences. Macroinvertebrate studies are being conducted on Alviso salt ponds A9, A10, A11, A12, A14, and A16.

Benthic macroinvertebrates were sampled from a 12’ flat-bottom boat with a modified shallow-water outboard motor, using a standard Ekman grab sampler (15.2 cm x 15.2 cm x 15.2 cm) to collect invertebrates. Samples were collected by lowering the dredge into the water slowly, holding it level on the substrate and releasing the ‘jaws’. Muddy soft substrates consistently produced samples that filled the dredge, whereas on hard substrates only a small portion of the dredge was filled (dredge can’t ‘bite’ deeply into hard surface). Grab samples were washed in the field using a 1mm mesh screen and preserved in 70% ethyl alcohol and rose bengal dye. 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 collected from 5 randomly selected grids. Within each grid, we collected 3 cores from randomly selected areas. If water level in the ponds was too low and the ponds too large to navigate the boat through the middle of the ponds, we followed borrow ditches which run along the inner perimeters of these ponds. We then moved the boat away from the ditch and towards the inner part of the grid for sample collection.

Samples were sorted and invertebrates identified and enumerated with the assistance of lab technicians using appropriate keys under the guidance of the project coordinator (Usinger 1971, Merritt and Cummins 1978, Pennak 1989, Smith and Johnson 1996). Wet weight and dry weight biomass of selected groups of organisms were determined using an Ohaus, Model 3130 scale (Ohaus Corporation, Pine Brook, New Jersey). Per-organism wet and dry weight were determined for each taxonomic group.

Water quality data was collected using a multiprobe meter. We collected specific conductivity, dissolved oxygen, pH, salinity, temperature and turbidity during invertebrate sample collections. Water depth was measured with a depth recorder or meter stick. The parameters were recorded once for each grid sampled.

The substrate was visually characterized in two ways for each grid sampled. First, we estimated whether the substrate was soft, hard or medium in penetrability. Second, we estimated the predominant grain size of the substrate and also made notes of outstanding features, such as abundant shell bits, large organic debris, salt crystals, etc.

Primary productivity and Zooplankton

We determined Chlorophyll-*a* levels using a SCUFA® submersible fluorometer (Turner Designs, Sunnyvale, California), calibrated against a spectrophotometer. The SCUFA was submerged in each sample and temperature-corrected fluorescence values were recorded. Water samples were placed on ice and filtered in a laboratory within 24 hours of collection using 1.2-µm glass fiber filters (Whatman International, Maidstone, England). 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 spectrophotometer at 750, 660, and 664 nm. Chlorophyll-*a* concentration was calculated using the Monochromatic method (Wetzel and Likens 1991).

Zooplankton samples were collected using an 8-inch diameter 150-µm tow net with an attached flowmeter to measure volume sampled. Samples were preserved in Lugol’s solution and will be enumerated and identified to genus.

Avian Diversity

Abundance and Distribution

All waterbirds were counted at Alviso salt ponds A9-A17 monthly in 2003, and during January, April, June, August, October, November, and December 2002. Counts were conducted during the high tide when numbers were at peak. Species and flock size were mapped on a 250 x 250 m grid. Primary species by foraging guild included: 1) sweepers-- American avocet (*Recurvirostra* *americana*) and black-necked stilt (*Himantopus mexicanus*); 2) shallow probers-- western sandpipers (*Calidris mauri*) and dunlin (*Calidris alpina*); 3) deep probers -- marbled godwits (*Limosa fedoa*), willets (*Catoptrophorus semipalmatus*), and long-billed dowitchers (*Limnodromus scolopaceus*); 4) diving benthivores – eared grebes (*Podiceps nigricollis*) and ruddy ducks (*Oxyura jaimaicensis*); 5) dabbling ducks – northern shovelers (*Anas clypeata*) and American wigeons (*A. americana*); 6) piscivores – double-crested cormorants (*Phalacrocorax auritis*) and American white pelicans (*Pelecanus erythrorhynchos*); and 7) other – generalist species including gulls (*Larus* spp.).

Objective 3. Physical and Water Quality Parameters

Water Quality

Water quality measurements were collected monthly by WRD in Alviso salt ponds A9-A16 from April 2002 until June 2003. Four or five sampling locations were established for each salt pond 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 (Ertco, West Paterson, New Jersey) scaled for the appropriate range, in addition to the Hydrolab measurement. This is important because the Hydrolab may not accurately measure conductivity at salinities above 40 ppt. At salinities above 70 ppt, only the hydrometer was used to measure salinities. The hydrometer data were corrected for temperature and converted to salinity. The results suggest that changes in the ponds during this period mostly follow seasonal trends.

Nutrient Data

Three water samples were collected from each of the Alviso salt ponds A9, A10, A11, A12, A14, and A16. To date, water samples were collected in September and October 2002; January, April, May, June, July, August, September, October, and November 2003, and January 2004. The University of California Department of Natural Resources Analytical Laboratory analyzed these samples for total and soluble Phosphorous (TP, SP), Sulfate (SO4), Ammonium (NH_4), and Nitrate (NO_3) to derive nitrogen conditions.

Bathymetry coverages

We will develop bathymetry coverages for each pond in 50-m grids. A shallow-water sounding system attached to a shallow-draft boat was devised in previous studies (USGS, unpubl. data) and was used to measure water depths with 1-cm precision in December 2003 to February 2004. Transects were conducted across the length or width of the ponds at 100-m intervals. Depths were converted to NGVD29 by adjusting for the water elevation at staff gauges within the pond during the survey. Software such as Topogrid (ArcInfo, ESRI, Inc.) or ArcGIS Geostatistical Analyst (ESRI, Inc.) will be used to interpolate the bathymetry grid from the sample transects. The pond coverages will be created as GIS grids in Universal Transverse Mercator (UTM) coordinates based on NAD83 horizontal datum and NAVD29 vertical datum. These coverages are readily converted to other projections.

Objective 4. Relationship among hydrologic, morphologic, physical, and biological components.

Salinity and water surface elevation data were collected bi-monthly and augmented with the water quality information collected in Objective 3. These data will be used to develop and calibrate a Salt Pond Box Model (SPOOM) for the Alviso salt ponds. Also, the effect of vertical mixing by wind waves on mixing and water quality of the ponds will be evaluated. As indicated, SPOOM uses individual pond bathymetry and variables (rainfall, evaporation, and water transfers) to calculate daily pond volume and salinity values using the conservation of mass principle (Lionberger *et al*. 2004). Bathymetry (for volume surface area relationships) of the ponds were obtained as a part of Objective 3.

Also, historical charts and maps of the South Bay marsh system will be acquired from NOAA, SFEI, USGS, and Cargill Corporation, and where applicable, digitized and archived in an ARC/Info-based GIS. This GIS database will be analyzed to extract relationships between tidal channels, tidal flats, marshes, and the salt ponds. We expect to find shifts in the patterns, distributions, and relative areas of channels, tidal flats and marshes resulting from human alteration of the natural system. The distribution and aerial extent of marshes, tidal flats, tidal channels and salt ponds through time will be documented. Change in the marsh system will be related to hydrologic forcing and manmade alterations. Relationships between geomorphic components learned from the South Bay marsh system will be tested and refined using data from other areas within San Francisco Bay.

Objective 5. Continued monitoring of biological and physical parameters of Napa-Sonoma salt ponds.

Benthic macroinvertebrates

We continued to monitor macroinvertebrates at Napa-Sonoma salt ponds 1, 2, 3, and 4 in November and May 2002 and 2003. Ten locations were sampled per pond, with three benthic grabs per location, following methods stated in Objective 2. Preliminary surveys of pond 7 (1999-2000) indicated low invertebrate biomass attributed to hypersaline conditions. Consequently pond 7 was not surveyed in 2001-2003. Ponds 5 and 7 were added to our survey in November 2003 to track changes in invertebrate communities as a result of anticipated management practices (i.e., breached levees).

Primary productivity and Zooplankton

We determined Chlorophyll-*a* concentrations and collected zooplankton samples following the same methods as in Objective 2.

Avian Abundance and Distribution

We continued to monitor waterbirds at Napa-Sonoma salt ponds 1, 2, 2A, 3, 4, and 7A. High tide counts were conducted monthly in 2003, and during January, March, May, August, September, October, November, and December 2002. Ponds 1A and 7 were added in September 2002, ponds 5, 6, and 6A were added in October 2002, and ponds 8, 9, 10, and the Napa crystallizer ponds were added to the survey in March 2003.

Nutrient Data
Three water samples were collected from each of the Napa-Sonoma salt ponds 1, 2, 3, and 4. To date, water samples were collected in September, October and December 2002; February, April, May, July, August, September, October, and November 2003. The University of California Department of Natural Resources Analytical Laboratory analyzed these samples for total and soluble Phosphorous (TP, SP), Sulfate (SO4), Ammonium (NH_4), and Nitrate (NO_3) to derive nitrogen conditions.

RESULTS AND DISCUSSION

Objective 1. Interpret and disseminate existing data on Napa-Sonoma salt ponds

An initial synthesis of the Napa-Sonoma salt ponds has been completed and submitted to *Hydrobiologia* (Takekawa *et al*., *in review*) Also, an analysis of changes following the breach of Napa-Sonoma Pond 3 has been written (Shellenbarger *et al*., *in review*) and submitted to *Restoration Ecology*. A more comprehensive synthesis of the Napa-Sonoma salt ponds will be completed in early 2005.

Objective 2. Determine biological structure at Alviso salt ponds.

Benthic macroinvertebrates

Six sample collections have been completed: January, July, and October 2002 and February, June, and October 2003. Three sample collections have been sorted and identified in the laboratory: January, July, and October 2002. Preliminary results from the first three collection periods are reported.

To date, we have identified 48 macroinvertebrate taxa, most at the family and genus levels (Table 1). The most abundant and diverse group in benthic samples was Crustacea with 17 different taxa, eight Polychaete worm genera were present, mostly in ponds A9, A10, A11, and A12. There were also 6 species of bivalves and 5 insect taxa. Ponds with lower salinity appear to support the largest number of taxa of benthic macroinvertebrates (Figure 2). Ponds A9 and A10, which were less saline, had the highest numbers of taxa, 34 and 39 respectively. Number of taxa decreased in ponds A11 (19 taxa), A12 (15), A14 (6), and A16 (5). There was a relationship between increasing salinity and decreasing number of taxa. However, sweep samples of ponds A12, A14, and A16 contained organisms tolerant of high salinity conditions (i.e., *Artemia* sp., Corixidae, etc.). *Artemia* sp., in particular, resulted in greater invertebrate biomass in these ponds than ponds A9 – A11 (Table 2, Figure 3).

<u>*Pond A9*</u>- The crustacean *Corophium* sp. was dominant in pond A9 during the three sampling periods (Table 3). *Capitella* sp., Gammaridae, and *Ericthonius* sp. were also prevalent. The

bivalve *Gemma gemma* was present during each sampling period. Of the 8 Annelids found, Tubificoides, *Capitella* sp., and *Polydora* sp. were dominant. The number and abundance of taxa increased in July and decreased in October, but were not as low as January levels. Taxa unique to pond A9 samples were *Pancolus californiensis* and Muscidae. Sweep sampling was conducted in pond A9 in January and July 2002. Two sweeps were conducted in January, which yielded 1 *Artemia* sp. total, and three sweeps in July which yielded zero *Artemia* sp. and 2 *Corophium* sp. individuals (Table 2). The substrate of pond A9 is consistently fine-grained and is mostly soft, with areas of medium to hard surface. Salinity ranged from 25 – 42 ppt with an average of 32 ppt during this period.

Pond A10- Taxa richness of pond A10 samples was similar to pond A9, although there were differences in species presence and abundance. Crustacea were abundant and dominated by *Corophium* sp., followed by *Ericthonius* sp. and Ampithoidae (Table 4). Bivalves were not present in large numbers during any sampling period. Of the 14 crustaceans found, *Corophium* sp., *Ericthonius* sp., and Ampithoidae were dominant. The number and abundance of taxa was lowest in January, increased in July and decreased slightly in October. Polychaetes were abundant and dominated by *Cirratulus* sp., *Polydora* sp., and *Capitella* sp. Tubificoides was present at all sampling times, and were most abundant in July. Taxa unique to pond A10 samples were *Nereis* sp., *Musculus senhousia, Potamocorbula amurensis, Taschadium demissum*, and *Synidotea* sp. Sweep sampling was conducted in January and July 2002. No organisms were captured in January and an average of 35 *Corophium* sp. per sweep were captured in July (Table 2). The sweep sample collected in July 2002 contained *Enteromorpha* sp. alga; *Corophium* sp. are generally non-pelagic invertebrates and were probably captured within the alga. The substrate of pond A10 is mostly of medium firmness and consistently fine-grained. Salinity ranged from 27 – 39 ppt with an average of 33 ppt during this period.

Pond A11- Pond A11 samples contained fewer taxa than ponds A9 and A10 (Table 5). Of 19 taxa found, only 2 were present in significant numbers (*Polydora* sp. and *Corophium* sp.). *Polydora* sp. was by far most abundant (mean number per grab 6.87 in July 2002, 142 per grab in January), however no *Polydora* sp. were present in October grabs. *Corophium* sp. was absent in January, present at 16 per grab in July, and decreased to 0.2 per grab in October. Taxa unique to pond A11 were *Crangon franciscorum* and *Palaemon macrodactylus*. Sweep sampling was conducted in January, July, and October 2002. *Artemia* sp. was the most abundant organism collected, and Corixidae and Hydrophilidae were also present (Table 2). The substrate on pond A11 varies between soft and medium fine-grained substrate. Salinity ranged from 67-68 ppt with an average of 67.4 ppt during this period.

Pond A12- Pond A12 samples contained fewer taxa than ponds A9 and A10 (Table 6). Of 15 taxa found, only 3 were present in significant numbers (*Polydora* sp., *Capitella* sp., and *Cirripedia* sp.). *Polydora* sp. was by far most abundant, with the greatest number occurring in January (252.67 per grab), and decreasing in July and October (10.73 and 20.13 per grab, respectively). Sweep sampling was conducted in January, July and October 2002. *Artemia* sp. was the most abundant organism captured, averaging 30.3 per sweep in January and 151 per sweep in July. Corixidae was also present in the samples, averaging 2.7 per sweep in January and 27 per sweep in July (Table 2). Pond A12 consists of a thick medium-soft substrate with fine-grained clay. Salinity ranged from 67-72 ppt with an average of 70 ppt during this period.

Pond A14- Pond A14 samples contained 6 taxa during the sampling periods (Nematoda, *Artemia* sp., *Corophium* sp., Corixidae, *Ephydra* sp., and Bryozoa; Table 7). *Artemia* sp. was the most abundant taxon, averaging 10 animals per grab in July. Other taxa were not common and often only present during one of three sampling periods. Sweep sampling was conducted in January, July, and October 2002 (Table 2). *Artemia* sp. was the most abundant taxon collected, averaging 842 individuals per sweep in January, 1083 in July, and 1126 per sweep in October. Corixidae was also present in the samples averaging 4 per sweep in January and 34 per sweep in July. Only one Corixid was found in all three sweeps combined in October. Also collected were *Ephydra* sp. larvae in July, averaging 9 per sweep. The substrate on pond A14 is generally medium to hard, and sometimes contains a brittle crusty layer and/or salt crystals over the fine-grained substrate. Salinity ranged from 71-132 ppt during this period, reaching its peak level in October 2002.

Pond A16- Pond A16 samples contained 5 taxa during the sampling periods (Table 8). *Artemia* sp. and Hydrophilidae occurred in the greatest numbers; other taxa present include Corixidae, *Ephydra* sp., and unknown Diptera. Sweep sampling was conducted in January and July 2002. Again, *Artemia* was the most abundant organism collected, averaging 213 per sweep in January and 1585 per sweep in July. Corixidae was also present in the samples averaging 4 per sweep in January and less than one per sweep in July (Table 2). The substrate of Pond A16 is mostly soft with few areas of medium to hard surface, and consistently fine-grained. Salinity ranged from 67 - 114 ppt during the sampling period.

Primary productivity and Zooplankton

We determined Chlorophyll-*a* levels using a Turner Designs submersible fluorometer. Water samples were collected in September and October 2002, January, April, May, June, July, August, September, October, and November 2003, and January 2004 from ponds A9, A10, A11, A12, A14, and A16. Data are available for September and October 2002, April 2003, and January 2004. Table 9 summarizes these results.

Zooplankton samples were collected, and will be identified and enumerated by August 2004.

Avian Diversity

Abundance and Distribution

Sixty-seven species and over 228,000 birds were recorded from February 2002 to December 2003 in Alviso salt ponds A9-A17 (Table 10). Pond A9 contained the greatest number of birds at over 96,000 individuals (42% of the total count for the study period), whereas the remaining ponds contained substantially fewer birds, from 4% of the total in pond A17 to 12% of the total in pond A10 (Table 11, Figure 4). Gulls (“other”) comprised 35% of birds overall (78,800 birds), while diving benthivores were second in abundance at 32% (73,000 birds). Dabblers (20%), piscivores (4%), shallow probers (4%), sweepers (3%), and deep probers (2%) made up the remainder.

Pond use by avian foraging guilds was most strongly influenced by water depth. Diving benthivores, which require the deepest water for foraging, were well represented among all ponds (Figure 4). Ponds A9-A17 are usually too deep to provide substantial shallow-water foraging habitat for shorebirds; shallow probers, deep probers, and sweepers together comprised 9% of the total count (Figure 4). The majority of these birds (78% of all shallow probers and 68% of all deep probers) were counted at pond A9, mostly during atypical low water level conditions in November and December 2003; smaller numbers of shorebirds were counted while roosting on islands in ponds A14, A15, and A16.

Pond A9, an intake pond adjacent to San Francisco Bay, not only contained the greatest number of birds but also supported more species (49) across the study period than any other pond. Pond A9 was the largest pond (about 34% larger than mean pond size), but guild density calculations reflect a trend similar to counts (Figure 5), indicating that factors other than pond area were responsible for the discrepancy in bird numbers between Pond A9 and the other ponds. Pond A9 was the only pond to support substantial submerged vegetation and was also lowest in salinity, which may have contributed to habitat quality for specific guilds; 90% of all dabblers were counted on pond A9. Temporal variation in water depth probably contributed to the pond's high species richness. Low water level conditions in parts of the pond in late 2003 provided habitat for probers and other shallow-water guilds, while the pond continued to support a variety of dabblers and diving benthivores (Figure 6). Pond A10, although about 7% smaller than mean pond size, supported 46 species, nearly as many as pond A9. Although pond A10 contained less than a third of the number of birds counted on pond A9, it supported many of the same species. Ponds A9 and A10, adjacent to each other and similar in salinity (about 32 ppt), supported the majority of diving benthivores and piscivores of all ponds (Figure 4). However, pond A10 was generally deeper and contained proportionately more diving benthivores (66% of birds on A10 but only 27% of birds on A9) and fewer dabblers and shorebirds (Figures 6, 7).

Pond A15 was dominated by diving benthivores, primarily eared grebes (61% of birds on A15; Figure 12), which also comprised about 32% of birds counted on ponds A11, A14, and A16 (Figures 8, 11, 13). The guild category "other" (primarily gulls) was more evenly distributed among ponds than any other guild. Because gulls were rarely seen feeding on the ponds and primarily used pond levees for roosting, they were probably influenced more by levee conditions than by water level or salinity. Gulls comprised the largest proportion of birds on ponds A11, A12, A13, A14, A16, and A17 (Figures 8, 9, 10, 11, 13, 14), but this was primarily due to low guild diversity on those ponds. Mean salinity of ponds A11-A17 ranged from 61-101 ppt, but the differences in pond salinity seemed to have little effect on guild diversity or species richness among these ponds. Pond features, especially islands, seemed to attract a greater number of species. Pond A16 (100 ppt), which contained several islands, supported more species (44) than ponds A13 (74 ppt) or A17 (101 ppt), which each had 31 species.

Objective 3. Physical and Water Quality Parameters

Water Quality

Figures 15-24 detail the monthly temperature, salinity, turbidity, dissolved oxygen (D.O.) and pH (and associated variability) in Alviso salt ponds A9-A16. Temperature in the ponds follows a seasonal signal with highest temperatures in the summer. Between-pond temperature differences were typically less than 3ºC, except during the fall when the differences can exceed 5ºC. 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, ponds A9 and A10, 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. Figures 25 and 26 depict D.O. and pH versus salinity for all ponds. These data suggest that D.O. concentration and pH are not dramatically affected by salinity until salinities top 80 ppt. Beyond this point, both pH and D.O. appear to generally decrease with increasing salinity.

Nutrient Data

Tables 12-18 summarize Ammonium (NH_4), Nitrate (NO_3), Soluble Phosphorous (SP), Total Phosphorous (TP), and Sulfate (SO_4) levels for Alviso salt ponds from September 2002 to December 2003. SO_4 values were generally highest in higher salinity ponds. NH_4 decreased with increasing salinity. Over time, TP and NH_4 peaked in the fall and dropped to their lowest values in winter, rising again in the summer and fall. No discernible patterns were found for SP, TP, or NO_3.

Bathymetry coverages

Bathymetry surveys were conducted for 38 ponds in December 2003 through February 2004. Analyses are underway to create GIS coverages of the pond bathymetry.

Objective 4. Relationship among hydrologic, morphologic, physical, and biological components.

The Salt Pond Box Model (SPOOM) was designed to simulate pond volume and salinity in the Napa-Sonoma salt pond complex (Lionberger *et al*. 2004). The model is now being reconfigured to simulate the volume and salinity for several Alviso salt ponds, and it will also include a new pond temperature subroutine (temperature is an important habitat variable). Reconfiguration will be completed upon conclusion of the bathymetric pond surveys. The collection of bathymetry data by BRD should be completed by the end of April 2004. Pond volume and surface area as a function of depth are required for calibrating salinity in the model. The temperature subroutine has been coded and is currently being tested on Napa-Sonoma salt pond simulations previously calibrated to pond volume and salinity. Napa-Sonoma salt pond temperatures were measured monthly during regular water quality sampling between February 1999 and October 2001 and allow calibration of the temperature routine. Initial modeling results correlate well with measured data.

Objective 5. Continued semi-annual monitoring of biological and physical parameters of Napa-Sonoma ponds.

Benthic macroinvertebrates

We continued to monitor macroinvertebrates at Napa-Sonoma Ponds 1, 2, 3, and 4 in November and May 2002 and 2003 (Figure 27). Ponds 5 and 7 were added to our survey in November 2003. Table 19 reports species presence in ponds 1-4. Tables 20-23 report mean number of individuals per Ekman grab for February 2001 to June 2002.

Species diversity of benthic macroinvertebrates was generally higher and similar in ponds 1 and 2 relative to ponds 3 and 4, except for a substantial change that occurred between May and September 2000. Diversity in ponds 1 and 2 was represented by 42 taxa, many of which were uncommon, and high densities of individuals from 3 – 4 taxa. Pond 3 (21 taxa) and pond 4 (7 taxa) usually had lower numbers of taxa, but higher densities (relative to ponds 1 and 2) in 2–3 taxa. *Heteromastus* sp. and *Polydora* sp. (polychaetes) dominated taxa in ponds 1 and 2. *Polydora* sp., Nematoda, and occasionally Corixidae (waterboatman insect) and *Artemia* sp. (brine shrimp) dominated pond 3, and *Artemia* sp. and *Ephydra* sp. (brine flies) dominated pond 4.

Primary Productivity and Zooplankton

To date, water samples were collected in September and October 2002; January, April, May, June, July, August, September, October, and November 2003, and January 2004. Data are available for September and October 2002, April 2003, and January 2004. Table 24 summarizes these results for ponds 1-4.

Eight zooplankton taxa were recorded in lower salinity ponds (ponds 1 and 2), seven were recorded in pond 3 and only four taxa were recorded in pond 4. Seasonally, more taxa were recorded during May–June and fewest during September–March. Two taxa comprised 94.3% of the zooplankton counted: copepods comprised 66.1 % and *Artemia* sp. 28.2 %. Copepods were more abundant in ponds 1 and 3 than in ponds 2 or 4. *Artemia* sp. appeared infrequently in samples from ponds 1–3, but was the most abundant taxa in pond 4.

Avian Abundance and Distribution

Seventy-two species and estimates of over 456,000 birds were recorded from January 2002 to December 2003 in Napa-Sonoma salt ponds 1, 2, 3, 4, 2A, and 7A (Table 25). Ponds 3 and 4 contained the greatest proportion of the total count (45% and 40%, respectively), whereas ponds 1, 2, 2A, and 7A contained substantially fewer birds (Table 26, Figure 28). In contrast to the generally deeper Alviso salt ponds, shorebirds comprised 73% of the total count at Napa-Sonoma salt ponds (shallow probers, 55%; deep probers, 7%; and sweepers, 11%). Diving benthivores (12%), dabblers (11%), piscivores (2%), and other (2%) made up the remainder.

Avian diversity (species and abundance) and distribution between the ponds seem to be influenced more by water depth than by salinity. Ponds 1 and 2 were similar in salinity, but pond

1 supported more species (45) than pond 2 (31). Pond 1 was more spatially variable in water depth, which enabled it to support a wider variety of species from all foraging guilds (Figure 29); pond 2 was more uniform in depth, with no islands or shallow water areas, and supported primarily diving benthivores (88% of the total count on pond 2) and piscivores (primarily terns, 10%; Figure 30). Ponds 3 and 4 also supported diving benthivores (Figures 31, 32), while pond 2A, a revegetated pond with shallow open water areas, supported primarily dabbling ducks (74% of the pond total; Figure 33). Vegetation density in pond 2A (39 species) continued to increase, resulting in fewer open water areas for waterfowl, but better habitat for Virginia, black, and sora rails. Birds counted on pond 7A (41 species), which contains a few islands, comprised only 3% of the total count, but 78% of these were shorebirds (Figure 34).

The ponds with the highest diversity were pond 3 (53 species and 45% of the total birds; Figure 31), which was breached in August 2002, and pond 4 (52 species and 40% of the total birds; Figure 32), a highly saline mid system pond that was connected to pond 3 via a siphon. These ponds contained varying water depths, with both shallow areas for shorebirds and deeper areas for waterfowl. Prior to an unauthorized breach on the northern pond 3 levee at South Slough, pond 3 had begun to dry. Water was not flowing through the siphon system into pond 4 because of concentrated dense salt water in the pipes, resulting in increased salinity and dry conditions, especially during summer months. After the breach at South Slough, salinity in pond 3 declined from about 70 ppt to slough levels by January 2002, and increased tidal flow in the pond removed the blockage in the siphon. As a result, pond 4 water level increased and salinity declined, while muted tidal action in pond 3 provided a greater variety of habitats for waterbirds and resulted in vegetation colonization by August 2003. As vegetation and sedimentation replace open water areas in the pond, pond 3 may begin to more closely resemble a restored tidal marsh similar to pond 2A and support fewer shorebirds and waterfowl.

Nutrient Data

Tables 27-30 summarize Ammonium (NH_4), Nitrate (NO_3), Soluble Phosphorous (SP), Total Phosphorous (TP), and Sulfate (SO_4) levels for ponds 1-4 from September 2002 to November 2003.

LOGISTICAL ISSUES

In winter and spring, rainfall caused muddy levees, preventing access to many ponds. We were unable to conduct invertebrate sampling or bird surveys during these times.

FUTURE RESEARCH: CHANGING LANDSCAPE

SOUTH BAY

Large-scale water management changes are imminent at South Bay salt ponds under U.S. Fish & Wildlife Service (FWS) and also California Fish & Game jurisdiction. These changes will involve hydrological changes aimed primarily at increasing water circulation within groups of ponds and water exchange between ponds and sloughs. We will formulate additional hypotheses of anticipated physical and biological alterations as a result of the water management changes. Surveys of biological and physical parameters will continue on the FWS south bay ponds to document potential changes in structure of bird communities and their prey base communities and also basic (e.g., feeding, foraging) avian use of the ponds. Studies also will be initiated that focusing on habitat elements and food webs in the ponds and their comparative value for natural resources. For example, we will determine biomass and caloric value ratios of common invertebrate species to assess avian prey quality compared to the bay proper. Future studies also will determine the composition of existing salt pond communities in the South Bay (and North Bay) in comparison to adjacent seasonal wetlands, tidal salt marshes, mudflats, or shallow bays. Bathymetry data and monthly salinity readings will continue and be used to correlate water depth and salinity with bird use on the salt ponds; fish surveys were initiated in April 2004 and will continue in FY 05.

WRD currently has funding from the SCC for work on the South Bay salt ponds for the following four tasks: 1) initiate installation of a sediment gauge on Coyote Creek (Larry Freeman, Marina Field Office), 2) develop a sediment budget specifically for South San Francisco Bay, 3) deploy shallow and deep Conductivity/Temperature/Depth Sensors (CTD's) at Channel Marker 17 during winter FY2004 and 4) collect and compile research and data sets dealing with San Francisco Bay (data gaps). In addition, the U.S. Fish and Wildlife Service has provided funding to reconfigure our Salt Pond Box Model (SPOOM) for use in management of the flow through the Alviso pond system. Partially funded by SCC in support of South Bay salt pond work, WRD is developing a sediment budget specific to South San Francisco Bay, and will apply this budget to an analysis of potential effects of opening salt ponds to tidal action that in turn could alter the suspended sediment concentration and change phytoplankton bloom dynamics.

NORTH BAY

Research will focus on biophysical interactions between ponds and surrounding sloughs and effects of breaches. We will continue to monitor changes in Napa-Sonoma salt ponds 3, 4, and 5 due to breaches and compare these changes to other ponds. With support from the State Coastal Conservancy (SCC), we will continue bimonthly bird surveys and seasonal invertebrate and water sampling in the Napa-Sonoma salt ponds to examine interannual variation in these communities.

PES Salt Pond funds will be used to continue support of the temperature, salinity and suspended sediment recording station at Mare Island Causeway near the Napa-Sonoma salt ponds, as well as monthly water quality sampling in Napa-Sonoma salt ponds 3-5 to provide data regarding physical habitat conditions to the biologists sampling in the area.The SCC also funded an initial survey of the scour hole forming in South Slough in front of the pond 3 breach. This hole will be re-surveyed later in FY2004 to explore breach-related habitat changes in South Slough.

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TABLES AND FIGURES

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Table 1. Macroinvertebrate species presence, Alviso salt ponds, San Francisco Bay, CA. 2002.

	Taxonomic Group	**A9**	**A10**	**A11**	**A12**	**A14**	**A16**
Nematoda	Nematoda	x	x		x	x	
Oligochaeta	*Tubificoides* sp.	x	x	x	x		
Polychaeta	*Capitella* sp.	x	x	x	x		
	Cirritulus sp.	x	x	x			
	Eteone sp.	x	x				
	Heteromastus sp.	x	x		x		
	Nereis sp.		x				
	Polydora sp.	x	x	x	x		
	Pseudopolydora sp.	x	x	x	x		
	Streblospio sp.	x	x	x			
Bivalvia	*Gemma gemma*	x	x				
	Macoma balthica	x	x				
	Musculus senhousia		x				
	Potamacorbula amurensis		x				
	Solen sicarius	x	x				
	Tschadium demissum		x				
Crustacea	*Ampelisca* sp.	x	x				
	Ampithoidae	x	x				
	Artemia sp.	x	x	x	x	x	x
	Cirripedia			x	x		
	Copepoda	x	x	x			
	Corophium sp.	x	x	x	x	x	
	Crangon franciscorum			x			
	Cumacea	x	x				
	Ericthonius sp.	x	x	x	x		
	Gammaridae	x	x	x			
	Mysis sp.	x	x				
	Ostracoda	x	x	x	x		
	Palaemon macrodactylus			x			
	Pancolus californiensis	x					
	Paranthura elegans	x	x				
	Sphaeromatidae	x	x				
	Synidotea sp.		x				
Insecta	Corixidae			x	x	x	x
	unknown Diptera						x
	Ephydra sp.			x		x	x
	Hydrophilidae		x	x	x		x
	Muscidae	x					
Other	Turbellaria		x	x			
	Lineidae	x	x				
	Assiminea californica	x	x				
	Acarina	x	x				
	Diadumene sp.	x	x				
	Edwardsia sp.		x		x		
	Hydrozoa	x	x				
	Obelia sp.	x	x		x		
	Bryozoa	x				x	
	Enteromorpha alga (g)	x	x				
TOTAL # TAXA		34	39	19	15	6	5

Table 2. Macroinvertebrate presence in sweep samples, reported in mean number per sweep, Alviso salt ponds, San Francisco Bay, CA. Samples collected January – October 2002.

Date	**SALINITY** ppt	***Artemia***	**Corixidae**	***Corophium***	**Gammaridae**	***Ephydra***	**Hydrophilidae**	***N***
Pond A9								
January	32.46	0.5						2
July	25.80			0.67	0.67			3
Pond A10								
January *	35.03							3
July	27.48			34.6667				3
Pond A11								
January	61.41	577	1.67					3
July	42.10	7	12.66				0.33	3
October	62.16	488.7	7.33					3
Pond A12								
January	55.62	30.33	2.67					3
July	57.16	150.7	26.67					3
Pond A14								
January	71.85	842	3.67					3
July	103.97	1083	35			8.67		3
October	132.20	1126	0.33					3
Pond A16								
January	67.60	213.3	4					3
July	93.47	1585	0.67					3

* No invertebrates were captured in January sweeps at Pond A10.

Table 3. Pond A9 benthic macroinvertebrates, Alviso salt ponds, San Francisco Bay, CA. Reported as mean number per grab, *N*=15.

	Taxonomic Group	**January 2002**	**July 2002**	**October 2002**
Nematoda	Nematoda		25.40	2.20
Oligochaeta	*Tubificoides* sp.	4.53	100.67	52.60
Polychaeta	*Capitella* sp.	21.20	7.80	225.73
	Cirratulus sp.			0.07
	Eteone sp.	0.53	10.13	3.00
	Heteromastus sp.	1.13	0.67	
	Polydora sp.	10.20	39.20	5.60
	Pseudopolydora sp.	0.07	0.93	0.67
	Streblospio sp.	0.27	4.13	0.20
Bivalvia	*Gemma gemma*	3.47	9.13	1.67
	Macoma balthica			0.07
	Solen sicarius		0.13	
Crustacea	*Ampelisca* sp.	0.20	0.07	
	Ampithoidae	8.27	0.07	
	Artemia sp.		0.13	
	Copepoda		29.07	
	Corophium sp.	135.87	517.20	481.27
	Cumacea	0.80	9.33	
	Ericthonius sp.	23.00	111.73	1.73
	Gammaridae		334.73	
	Mysis sp.	0.13		
	Ostracoda		8.24	0.40
	Pancolus californiensis	1.47	17.13	0.07
	Paranthura elegans	4.33	10.27	
	Sphaeromatidae	0.07	0.07	0.13
Insecta	Muscidae		0.80	
Other	Lineidae	9.73	0.73	4.93
	Assiminea californica	0.07		
	Acarina		0.40	
	Diadumene sp.	0.07	0.13	
	Hydrozoa		0.07	
	Obelia sp.	0.27		
	Bryozoa	0.47		
	Enteromorpha alga (g)		64.02	4.20

Table 4. Pond A10 benthic macroinvertebrates, Alviso salt ponds, San Francisco Bay, CA. Reported as mean number per grab, *N*=15.

	Taxonomic Group	January 2002	July 2002	October 2002
Nematoda	Nematoda		1.87	0.27
Oligochaeta	*Tubificoides* sp.	8.33	62.80	4.33
Polychaeta	*Capitella* sp.	30.47	1.00	60.80
	Cirraitulus sp.	47.13	124.87	118.53
	Eteone sp.	4.00	1.27	0.27
	Heteromastus sp.	0.20	0.07	0.53
	Nereis sp.			5.80
	Polydora sp.	54.53	36.87	9.40
	Pseudopolydora sp.		0.53	
	Streblospio sp.	0.07	0.20	2.20
Bivalvia	*Gemma gemma*		0.27	0.07
	Macoma balthica			0.73
	Musculus senhousia		0.13	
	Potamacorbula amurensis		0.13	
	Solen sicarius		0.27	
	Tschadium demissum			0.07
Crustacea	*Ampelisca* sp.	0.13	0.33	0.07
	Ampithoidae	0.73	36.40	60.67
	Artemia sp.		0.20	0.07
	Copepoda		4.47	
	Corophium sp.	6.27	292.67	510.60
	Cumacea		0.13	
	Ericthonius sp.	64.67	75.60	116.87
	Gammaridae	0.27		0.47
	Mysis sp.		0.93	
	Ostracoda		0.27	0.07
	Paranthura elegans		0.07	0.53
	Sphaeromatidae		0.13	0.13
	Synidotea sp.		0.13	
Insecta	Hydrophilidae			0.07
Other	Turbellaria		0.53	
	Lineidae	0.33	1.07	
	Assiminea californica		0.07	0.20
	Acarina		0.13	
	Diadumene sp.	0.27	0.13	1.27
	Edwardsia sp.	0.13	0.20	
	Hydrozoa	0.07		0.40
	Obelia sp.	0.27		
	Enteromorpha alga (g)			9.65

Table 5. Pond A11 benthic macroinvertebrates, Alviso salt ponds, San Francisco Bay, CA. Reported as mean number per grab, *N*=15.

	Taxonomic Group	**January 2002**	**July 2002**	**October 2002**
Oligochaeta	*Tubificoides* sp.			0.13
Polychaeta	*Capitella* sp.	0.07	3.67	
	Cirratulus sp.	0.07		0.07
	Polydora sp.	6.87	142.00	
	Pseudopolydora sp.		0.53	
	Streblospio sp.		0.07	
Crustacea	*Artemia* sp.	6.27	0.80	
	Cirripedia		3.33	0.07
	Copepoda		0.07	
	Corophium sp.		16.00	0.20
	Crangon franciscorum		0.07	
	Ericthonius sp.		1.27	
	Gammaridae		0.07	
	Ostracoda		0.07	
	Palaemon macrodactylus		0.87	
Insecta	Corixidae (adult)	0.79	0.40	0.20
	Corixidae (larvae)		8.87	
	Ephydra sp. (larvae)		0.07	
	Hydrophilidae (adult)		0.13	
	Hydrophilidae (larvae)		3.73	
Other	Turbellaria		0.13	

Table 6. Pond A12 benthic macroinvertebrates, Alviso salt ponds, San Francisco Bay, CA. Reported as mean number per grab, *N*=15.

	Taxonomic Group	**January 2002**	**July 2002**	**October 2002**
Nematoda	Nematoda		0.13	
Oligochaeta	*Tubificoides* sp.	0.20		0.07
Polychaeta	*Capitella* sp.	17.20	3.33	2.13
	Heteromastus sp.		0.47	
	Polydora sp.	252.67	10.73	20.13
	Pseudopolydora sp.		0.20	
Crustacea	*Artemia* sp.	0.20	0.13	0.07
	Cirripedia	13.87	2.33	17.00
	Corophium sp.	0.60		
	Ericthonius sp.	0.07		
	Ostracoda			0.07
Insecta	Corixidae (adult)	0.53	0.07	
	Corixidae (larvae)		0.07	
	Hydrophilidae (larvae)	0.27		
Other	*Edwardsia* sp.	6.60		
	Obelia sp.	0.53		0.13

Table 7. Pond A14 benthic macroinvertebrates, Alviso salt ponds, San Francisco Bay, CA. Reported as mean number per grab, *N*=15.

	Taxonomic Group	**January 2002**	**July 2002**	**October 2002**
Nematoda	Nematoda			0.07
Crustacea	*Artemia* sp.	7.87	10.00	3.93
	Corophium	0.07		
Insecta	Corixidae	0.27		
	Ephydra sp. (adult)			0.13
	Ephydra sp. (larvae)	0.13		
	Ephydra sp. (pupae)	0.93	1.07	0.13
Other	Bryozoa			0.07

Table 8. Pond A16 benthic macroinvertebrates, Alviso salt ponds, San Francisco Bay, CA. Reported as mean number per grab, *N*=15.

	Taxonomic Group	**January 2002**	**July 2002**	**October 2002**
Crustacea	*Artemia* sp.	0.93	16.67	6.13
Insecta	Corixidae (adult)	2.53	0.07	0.13
	unknown Diptera		0.07	
	Ephydra sp. (pupae)	0.13		
	Hydrophilidae (adult)	0.20		0.40
	Hydrophilidae (larvae)	13.67	2.73	2.67

Table 9. Chlorophyll-*a* concentrations (mg/m^3), Alviso salt ponds, San Francisco Bay, CA. Samples collected September and October 2002, April 2003, and January 2004.

	Chl-*a* (mg/m^3)			
Pond	**Sep-02**	**Oct-02**	**Apr-03**	**Jan-04**
A9	9.08		5.61	7.01
A10	20.43		84.11	0.71
A11	83.97		86.91	82.30
A12	340.43	79.10	277.55	285.36
A14	301.84	88.44	233.49	311.79
A15		51.40		
A16	256.32	224.68	327.21	161.00

Table 10. Monthly counts of waterbird species in major foraging guilds, Alviso salt ponds A9-A17, San Francisco Bay, CA. Sample dates January 2002 – December 2003.

				2002									**2003**						
Species	Jan	Apr	Jun	Aug	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dabblers																			
American coot	12				2			228	219	383			1				10	25	150
American wigeon	35	7				379	220	2861	4190	3412						23	8	2609	4355
blue-winged teal																		4	
cinnamon teal							4									1		3	
gadwall		16	2	1		5		88	188	136	5	18	22		13	25	3	108	496
green-winged teal					2	44											2	18	1127
mallard	6	21	20	3	13	18	6	2	17	4	4	12	19	4	77	61	21	60	15
northern pintail	72	24			186	196	53	4	422	87	1	1				291	593	2054	1267
northern shoveler	1045	453			88	2691	1967	827	1112	992			1		21	1328	2209	3233	3347
Divers																			
bufflehead	239					375	50	62	874	311								200	199
ruddy duck	1307	306		2	2079	1983	1897	2712	8530	3164	593	38				5	795	1944	2033
canvasback	1126	19			11	673	1370	285	744	94								1	837
redhead	31					114		62	16										
scaup (lesser, greater)	111	332			34	450	142	740	4114	1364	477	593				3	47	588	536
surf scoter									2										
common goldeneye	16	10				11	3	5	7	3	3							10	21
Clark's grebe		3	1	4	1	13		3		17		4	3	1	2	6	1	3	7
Eared grebe	984	611	1		834	4011	3221	1356	2896	4110	3021	948	18	1	132	550	727	1322	2041
horned grebe					1														
pied-billed grebe	2			29	13	62	15	3	5			1	1	15	84	97	222	98	20
western grebe	165	133	10		6	74	46	19	101	64	19	17	4			3	30	42	62
Piscivores																			
American white pelican	3		154	117	125	12	21	17			10	43	56	247	405	560	865	554	38

Table 10 Continued.

				2002									**2003**						
Species	Jan	Apr	Jun	Aug	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
brown pelican				24	18	6	5	2					2		79	81	48	9	
black skimmer				4							1	2	5	2					
Caspian tern			5	6	1								1		4	1			
Forster's tern		34	166	48	60		10		7		14	135	228	214	73	102	1	6	10
least tern	1																		
double-crested cormorant	6	72	49	108	248	24	19	18	10	15	182	121	169	160	500	859	937	115	9
black-crowned night heron			4	1									1	1					
great blue heron	3	2	7	7	2	1	1	2				1		1	2	7	15	5	1
great egret	9	22	22	50	13	1	7	3	2	2	3	4	7	1	4	47	161	53	5
snowy egret	7	23	49	10	52	23	7	4	4	7	1	2	19	9	13	87	188	162	22
common merganser										1									
hooded merganser						4													
red-breasted merganser	43	16				18	7	1	32	19		1						28	5
Shallow Probers																			
black-bellied plover														9		69		176	739
semipalmated plover				7															
killdeer	6			3	1						5		4	10		1			
dunlin	2	8				12					1	11							2249
sanderling									1										1
least sandpiper	52			187	14	34	30	16			36			254	187	180	181	84	108
western sandpiper	48			63	28			16				27		21	42	3	154	187	2685
‘peeps’		9			30				1		200								
Deep Probers																			
dowitcher (long, short-billed)				151										45				115	1607
greater yellowlegs		1			6				1						1			2	2
lesser yellowlegs				1			1											3	
long-billed curlew				22		87		40	19					412	5	116	154		4

Table 10. Continued.

Species	2002 Jan	Apr	Jun	Aug	Oct	Nov	Dec	2003 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
marbled godwit				5		27		20	35					64	37	2	55	774	697
whimbrel								1											
willet	18	36		49	37	67	6	13		1	39			90	101	60	138	190	85
Sweepers																			
American avocet	1	453	225	177	7	127		2	2	23	171	208	362	1035	695	2	635	359	807
black-necked stilt		3	15	164	16	22					8	25	25	41	81	11	9	10	30
red-necked phalarope				2				4							288	3	1	25	
Wilson's phalarope			7											746	15				
Other																			
Bonaparte's gull	66	44				77	16								15	9		21	46
California gull	14528	1638	1891	248	2461				53	1971	1706	1338	1620	1772	3263	2211	3936	112	2
glaucous-winged gull									118										1
herring gull	7835	35					1184	2022	641	2174	5							2358	2141
mew gull	1	1																	
ring-billed gull	17	26			331	68	847	271	19	101					8	4	63	133	129
Thayer's gull	369	9							3	1							2	2	
western gull	6689	83	29	1811	298				1		2				211	151	94	36	4
gull (unidentified)		15	67		268	1967	428	455	4766	376	664	1			3		129	1	45
turkey vulture		1				4	3	2								4	2		
Canada goose	190	3						5	14	21	8	2	2						1
common raven	1					2		2			6								2
merlin																			1
peregrine falcon						1			1										
white-tailed kite	1																		
Total	**35047**	**4469**	**2724**	**3304**	**7286**	**13683**	**11586**	**12173**	**29167**	**18853**	**7185**	**3553**	**2570**	**5155**	**6361**	**6963**	**12436**	**17842**	**27989**

Table 11. Total counts of waterbird species in major foraging guilds, Alviso salt ponds, San Francisco Bay, CA. Sample dates February 2002 – December 2003.

Species		Pond								
		A9	A10	A11	A12	A13	A14	A15	A16	A17
Dabblers										
American coot	*Fulica americana*	843	185	2						
American wigeon	*Anas americana*	17621	453	14		9			2	
blue-winged teal	*Anas discors*	4								
cinnamon teal	*Anas cyanoptera*	8								
green-winged teal	*Anas crecca*	1189	4							
gadwall	*Anas strepera*	1039	12	27	12	6	2	9	7	12
mallard	*Anas platyrhynchos*	220	81	15	10	3	1	22	14	17
northern pintail	*Anas acuta*	5106	134	4	2		5			
northern shoveler	*Anas clypeata*	15801	345	398	12	38	698	970	862	190
Divers										
bufflehead	*Bucephala albeola*	998	1076	215	3		4	10	2	2
ruddy duck	*Oxyura jamaicensis*	15207	11064	341	66	144	251	105	170	40
canvasback	*Aythya valisineria*	4091	1022	14		1			4	28
redhead	*Aythya americana*	14	205				4			
scaup (lesser, greater)	*Aythya affinis, A. marila*	5372	3050	588	53	0	442	18	6	2
surf scoter	*Melanitta perspicillata*		2							
common goldeneye	*Bucephala clangula*	46	40						3	
eared grebe	*Podiceps nigricollis*	201	268	3834	1900	1864	4559	8095	4225	1838
horned grebe	*Podiceps auritus*								1	
pied-billed grebe	*Podilymbus podiceps*	295	327		2				38	5
Clark's grebe	*Aechmophorus clarkii*	9	23	14		16		3	3	1
western grebe	*Aechmophorus occidentalis*	48	479	159	32	68	4	5		
Piscivores										
American white pelican	*Pelecanus erythrorhynchos*	2286	396	33	14	33	358	4	50	53
brown pelican	*Pelecanus occidentalis*	57	126	32	15		44			
black skimmer	*Rynchops niger*								14	
Caspian tern	*Sterna caspia*		8	2	1	2	3		2	
Forster's tern	*Sterna forsteri*	228	43	59	54	17	80	6	620	1
least tern	*Sterna antillarum*	1								
double-crested cormorant	*Phalacrocorax auritis*	1549	1568	214	65	29	155	2	16	23
black-crowned night heron	*Nycticorax nycticorax*	1	1					1	3	1
great blue heron	*Ardea herodias*	30	8	5	2	5	2	1	4	
great egret	*Casmerodius albus*	305	25	33	15	23	4	1	7	3
snowy egret	*Egretta thula*	451	81	36	60	28	14	7	10	2
common merganser	*Mergus merganser*	1								
hooded merganser	*Lophodytes cucullatus*		4							
red-breasted merganser	*Mergus serrator*	40	73	1		10		2		44

Table 11. Continued.

Species		A9	A10	A11	A12	A13	A14	A15	A16	A17
Shallow Probers										
black-bellied plover	*Pluvialis squatarola*	915		9				69		
semipalmated plover	*Charadrius semipalmatus*							2	3	2
killdeer	*Charadrius vociferous*				5			4	21	
dunlin	*Calidris alpina*	2244					8	14	17	
sanderling	*Calidris alba*	2								
least sandpiper	*Calidris minutilla*	78	38	3	3	169	128	322	520	102
western sandpiper	*Calidris mauri*	2985	34	27	43	38	18	94	35	
‘peeps’	*Calidris* spp.	200	8	0	4	10	9	9	0	0
Deep Probers										
dowitcher (long, short-billed)	*Limnodromus scolopaceus, L. griseus*	1722		45				144	7	
greater yellowlegs	*Tringa melanoleuca*	3	1	1	5		2		1	
lesser yellowlegs	*Tringa flavipes*	1					1		3	
long-billed curlew	*Numenius americanus*	19	9	6			459	366		
marbled godwit	*Limosa fedoa*	1526	10	27			74	78	1	
whimbrel	*Numenius phaeopus*						1			
willet	*Catoptrophorus semipalmatus*	412	24	15	11	14	200	192	60	2
Sweepers										
American avocet	*Recurvirostra americana*	2145		30	121	390	1111	193	1042	259
black-necked stilt	*Himantopus mexicanus*	53		27	22	52	6	21	156	123
red-necked phalarope	*Phalaropus lobatus*		4	25	221	45	7	21		
Wilson's phalarope	*Phalaropus tricolor*				13	2	2		751	
Other										
Bonaparte's gull	*Larus philadephia*	22	13	53	114	7	39	44	2	
California gull	*Larus californicus*	8204	4003	2834	13254	4871	2983	547	448	1606
glaucous-winged gull	*Larus glaucescens*						1			118
herring gull	*Larus argentatus*	126	139	4143	230	3933	2524	979	3264	3057
mew gull	*Larus canus*				0		1		1	
ring-billed gull	*Larus delawarensis*	114	161	119	252	170	4	817	185	195
Thayer's gull	*Larus thayeri*		9					1	272	104
western gull	*Larus occidentalis*	882	396	2164	1625	1937	1445		174	786
gull (unidentified)	*Larus* spp.	1590	617	724	1464	1483	1562	225	679	841
turkey vulture	*Cathartes aura*			3		4		2	3	4
Canada goose	*Branta canadensis*	12	194	6	1		2	2	2	27
common raven	*Corvus corax*					3	7	2		1
merlin	*Falco columbarius*		1							
peregrine falcon	*Falco peregrinus*		1		1					
white-tailed kite	*Elanus leucurus*			1						
Total		**96316**	**26765**	**16302**	**19707**	**15422**	**17219**	**13407**	**13710**	**9488**

Table 12. Pond A9 average dissolved nutrient concentrations (mg/l), Alviso salt ponds, San Francisco Bay, CA.

Date	Ammonium (NH_4)	Nitrate (NO_3)	Phosphorous (P Soluble)	Phosphorous (P Total)	Sulfate (SO_4)
Sep-02	<0.05	0.06	0.56		689.3
Nov-02	0.78	0.74	0.54	0.4	800.1
Jan-03	<0.05	0.74	0.46	<0.1	
Apr-03	0.06	0.40	0.41	0.5	
May-03	0.17	<0.05	0.94	0.8	931.0
Jul-03	0.52	0.08		0.7	
Aug-03	0.46	<0.05	0.78		1065.3
Sep-03	0.34	<0.05	0.78		793.3
Oct-03	0.19	<0.05	0.75	0.7	
Nov-03	0.34	<0.05	0.33	0.4	
Dec-03	0.24	0.12	0.39	0.4	

Table13. Pond A10 average dissolved nutrient concentrations (mg/l), Alviso salt ponds, San Francisco Bay, CA.

Date	Ammonium (NH_4)	Nitrate (NO_3)	Phosphorous (P Soluble)	Phosphorous (P Total)	Sulfate (SO_4)
Sep-02	0.22	0.10	0.81		2792.5
Nov-02	0.37	0.58	0.62	0.4	804.7
Jan-03	<0.05	0.22	0.28	<0.1	
Apr-03	0.27	0.79	0.53	0.5	
May-03	0.70	<0.05	0.71	0.6	927.0
Jul-03	0.30	<0.05		0.9	
Aug-03	0.31	<0.05	0.76		1946.5
Sep-03	0.16	<0.05	0.92		780.0
Oct-03	0.16	<0.05	1.05	1.0	
Nov-03	0.23	0.08	0.69	0.7	
Dec-03	0.23	<0.05	0.58	0.6	

Table 14. Pond A11 average dissolved nutrient concentrations (mg/l), Alviso salt ponds, San Francisco Bay, CA.

Date	Ammonium (NH_4)	Nitrate (NO_3)	Phosphorous (P Soluble)	Phosphorous (P Total)	Sulfate (SO_4)
Sep-02	0.20	<0.05	0.98		1750.6
Nov-02	0.62	0.05	0.79	0.9	1778.6
Jan-03	0.42	<0.05	0.69	0.5	
Apr-03	0.16	0.07	0.77	1.1	
May-03	0.12	0.07	0.81	1.0	1969.0
Jul-03	0.84	<0.05		0.9	
Aug-03	0.47	0.03	0.81		2239.7
Sep-03	0.17	0.04	0.82		1375.0
Oct-03	0.09	0.04	0.77	1.0	
Nov-03	0.05	<0.05	0.51	0.7	
Dec-03	0.07	<0.05	0.38	0.5	

Table 15. Pond A12 average dissolved nutrient concentrations (mg/l), Alviso salt ponds, San Francisco Bay, CA.

Date	Ammonium (NH_4)	Nitrate (NO_3)	Phosphorous (P Soluble)	Phosphorous (P Total)	Sulfate (SO_4)
Sep-02	0.06	<0.05	0.86		1501.0
Nov-02	0.73	<0.05	0.95	1.1	1629.1
Jan-03	0.58	0.07	0.98	0.7	
Apr-03	0.17	0.08	0.88	1.2	
May-03	0.11	0.07	0.89	1.2	2044.5
Jul-03	1.03	0.06		1.0	
Aug-03	0.4	0.04	0.84		1704.0
Sep-03	0.24	0.06	0.85		1545.0
Oct-03	0.11	0.04	0.94	1.2	
Nov-03	0.07	<0.05	0.85	1.1	
Dec-03	0.12	<0.05	0.71	1.2	

Table 16. Pond A14 average dissolved nutrient concentrations (mg/l), Alviso salt ponds, San Francisco Bay, CA.

Date	Ammonium (NH_4)	Nitrate (NO_3)	Phosphorous (P Soluble)	Phosphorous (P Total)	Sulfate (SO_4)
Sep-02	0.33	0.16	0.92		3538.9
Nov-02	0.21	0.07	0.98	1.5	2542.1
Jan-03	0.17	0.07	0.88	1.0	
Apr-03	0.21	0.11	0.88	1.4	
May-03	0.13	0.07	0.78	1.1	2311.0
Jul-03	0.26	0.08		1.3	
Aug-03	0.09	0.03	0.80		1918.0
Sep-03	0.42	0.07	0.83		2153.3
Oct-03	0.14	0.04	0.89	1.3	
Nov-03	0.12	0.06	0.79	1.2	
Dec-03	0.12	<0.05	0.77	1.1	

Table 17. Pond A15 average dissolved nutrient concentrations (mg/l), Alviso salt ponds, San Francisco Bay, CA.

Date	Ammonium (NH_4)	Nitrate (NO_3)	Phosphorous (P Soluble)	Phosphorous (P Total)	Sulfate (SO_4)
Sep-02					
Nov-02	0.14	0.07	0.97	1.2	2133.8
Jan-03	0.19	0.07	0.98	0.9	
Apr-03	0.18	0.08	0.84	1.3	
May-03	0.11	0.06	0.87	1.3	2214.0
Jul-03	0.12	0.06		1.3	
Aug-03	0.12	0.04	0.74		2152.0
Sep-03	0.11	0.08	0.84		2360.0
Oct-03	0.15	<0.05	0.83	1.3	
Nov-03	0.12	0.06	0.90	1.3	
Dec-03	0.14	<0.05	0.71	1.1	

Table 18. Pond A16 average dissolved nutrient concentrations (mg/l), Alviso salt ponds, San Francisco Bay, CA.

Date	Ammonium (NH_4)	Nitrate (NO_3)	Phosphorous (P Soluble)	Phosphorous (P Total)	Sulfate (SO_4)
Sep-02					
Nov-02	0.18	0.07	0.93	1.3	2479.4
Jan-03					
Apr-03	0.20	0.10	0.74	1.3	
May-03	0.11	0.06	0.64	0.9	2440.0
Jul-03	0.12	0.06		1.2	
Aug-03	0.14	0.03	0.72		2587.0
Sep-03	0.13	0.07	0.70		2710.0
Oct-03	0.18	<0.05	0.62	1.2	
Nov-03	0.14	0.06	0.78	1.2	
Dec-03	0.49	3.45	0.32	0.3	

Table 19. Macroinvertebrate species presence, Napa-Sonoma salt ponds, San Francisco Bay, CA.

	Taxonomic Group	**Pond 1**	**Pond 2**	**Pond 3**	**Pond 4**
Nematoda	Nematoda	x	x	x	
Oligochaeta	Oligochaeta	x			
	Tubificoides sp.	x	x	x	
Polychatea	*Capitella* sp.	x	x	x	
	Cirratulus sp.	x	x		
	Eteone sp.	x	x		
	Heteromastus sp.	x	x	x	
	Nereis sp.	x	x		
	Pancolus sp.			x	
	Polydora sp.	x	x	x	
	Pseudopolydora sp.	x	x	x	
	Spionidae	x	x		
	Streblospio sp.	x	x	x	
Bivalvia	*Macoma balthica*	x	x		
	Mya arenaria		x		
	Potamocorbula amurensis	x			
Crustacea	*Ampelisca sp.*	x	x		
	Ampithoidae	x	x		
	Artemia sp.			x	x
	Cirripedia		x		
	Copepoda	x			
	Corophium sp.	x	x	x	
	Crangon franciscorum		x		
	Cumacea	x		x	
	Ericthonius sp.	x	x		
	Gammaridae	x	x		
	Mysis sp.	x	x		
	Ostracoda	x	x	x	
	Palaemon macrodactylus		x		
	Pancolus californiensis		x		
	Sphaeromatidae		x		
	Synidotea sp.	x			
Insecta	Corixidae	x	x	x	x
	unknown Diptera			x	x
	Dolichopodidae				x
	Drosophila sp.		x		
	Ephydra sp.		x	x	x
	Hydrophilidae			x	x
	Muscidae			x	x
Other	Lineidae		x	x	
	Assiminea californica		x		
	Diadumene sp.	x	x		
	Bryozoa	x	x	x	
	Coelomate			x	
	Edwardsia sp.	x	x		
	Anthozoa		x		
	Obelia sp.		x	x	
	Mitrella carinata	x			
	Opisthobranchia	x			
	Poynoidae	x			
TOTAL # TAXA		31	36	21	7

Table 20. Pond 1 benthic macroinvertebrates, Napa-Sonoma salt ponds, San Francisco Bay, CA. Reported as mean number per grab, *N*=30.

	Taxonomic Group	Feb-01	Jun-01	Nov-01	Jun-02
Nematoda	Nematoda	0.13	0.10		
Oligochaeta	Oligochaeta	0.07			
Polychaeta	*Tubificoides* sp.	0.77	0.13	4.63	0.17
	Capitella sp.	0.83	0.13	0.67	0.13
	Cirratulus sp.	7.77	7.63		
	Eteone sp.	0.33	0.23	0.43	0.07
	Heteromastus sp.	31.90	38.30	103.67	12.37
	Nereis sp.	0.07	0.17		
	Polydora sp.	3.37	6.90	17.83	0.93
	Pseudopolydora sp.	0.77	0.67	16.60	0.37
	Spionidae	0.10			
	Streblospio sp.	0.50	1.17	2.67	0.07
Bivalvia	*Macoma balthica*	0.07	0.03		0.10
	Potamocorbula amurensis		0.03	0.13	
Crustacea	*Ampelisca* sp.	1.00	0.97	4.50	27.40
	Ampithoidae	0.03			0.03
	Copepoda	0.03			
	Corophium sp.		0.10	4.10	0.80
	Cumacea	3.47	2.87	1.80	0.23
	Ericthonius sp.	0.10	3.13	0.47	0.57
	Gammaridae				0.03
	Mysis sp.	0.03			0.70
	Ostracoda	0.73	6.07	7.10	0.03
	Synidotea sp.			0.03	
Insecta	Corixidae		0.20	0.07	0.00
Other	Bryozoa	0.03			
	Edwardsia sp.	0.03		0.03	0.00
	Mitrella carinata	0.03			
	Diadumene sp.	0.03		0.03	
	Opisthobranchia			0.67	
	Polynoidae	0.07			

Table 21. Pond 2 benthic macroinvertebrates, Napa-Sonoma salt ponds, San Francisco Bay, CA. Reported as mean number per grab, *N*=30.

	Taxonomic group	**Feb-01**	**Jun-01**	**Nov-01**	**Jun-02**
Nematoda	Nematoda	4.57	1.53	0.03	0.33
Oligochaeta	*Tubificoides* sp.	10.77	5.77		8.17
Polychaeta	*Capitella* sp.	0.57	6.27	0.30	0.70
	Cirratulus sp.			0.03	1.40
	Eteone sp.	9.20	0.70	0.03	0.23
	Heteromastus sp.	27.80	51.47	0.03	16.57
	Nereis sp.	0.03		0.97	
	Polydora sp.	10.93	17.43	1.77	18.10
	Pseudopolydora sp.	0.37	4.63	2.30	0.97
	Spionidae	0.03			
	Streblospio sp.	14.87	12.70	13.07	13.10
Crustacea	*Ampelisca* sp.		0.60	0.03	0.10
	Ampithoidae			0.80	0.47
	Cirripedia	0.07	3.00	0.03	0.27
	Corophium sp.	1.93	24.63	0.03	15.17
	Crangon franciscorum			0.27	
	Cumacea	0.57	1.77	0.37	1.70
	Ericthonius sp.	0.13	26.97	2.53	8.10
	Gammaridae		0.23	10.67	0.57
	Mysis		0.07		0.20
	Ostracoda	0.63	0.67	0.03	1.83
	Palaemon macrodactylus	0.07	0.03	0.23	
	Pancolus californiensis	0.07	1.00	3.23	14.40
	Sphaeromatidae		0.03		0.37
Bivalvia	*Macoma balthica*	0.30	0.13	0.03	0.00
	Mya arenaria	0.17		0.07	
Insecta	Corixidae			9.90	0.03
	Drosophila sp.				0.07
	Ephydra sp.			4.80	
Other	*Obelia* sp.	0.03	0.07		0.03
	Assiminea californica	0.13	0.10	0.20	3.80
	Bryozoa	0.43	0.70	0.57	0.40
	Anthozoa	0.20			
	Diadumene sp.	0.03		1.27	0.47
	Edwardsia sp.	0.33	1.20	0.03	0.90
	Lineidae				0.40

Table 22. Pond 3 benthic macroinvertebrates, Napa-Sonoma salt ponds, San Francisco Bay, CA. Reported as mean number per grab, *N*=30.

	Taxonomic group	Feb-01	Jun-01	Nov-01	Jun-02
Nematoda	Nematoda	45.53	11.47	0.20	
Oligochaeta	*Tubificoides* sp.	0.03		0.03	
Polychaeta	*Capitella* sp.	1.70			
	Heteromastus sp.	0.20	0.03	0.03	
	Polydora sp.	76.80	23.97	1.03	0.07
	Pseudopolydora sp.			0.03	
	Streblospio sp.	0.97	5.97	0.03	
Crustacea	*Artemia* sp.			0.17	33.07
	Corophium sp.	1.30	0.03		
	Cumacea	0.03			
	Ostracoda		0.20		
Insecta	Corixidae	0.07	0.83	12.07	20.15
	unknown Diptera				0.07
	Ephydra sp.		0.07	0.17	0.45
	Hydrophilidae		0.03	0.07	0.13
	Muscidae				0.03
Other	Bryozoa	0.03		0.07	0.23
	Coelomate	0.13			
	Lineadae	1.00			
	Obelia sp.	0.87	0.10	0.20	0.07

Table 23. Pond 4 benthic macroinvertebrates, Napa-Sonoma salt ponds, San Francisco Bay, CA. Reported as mean number per grab, *N*=30. *Water levels in pond 4 were too low in November 2001 to collect samples.

	Taxonomic group	Feb-01	Jun-01	Nov-01*	Jun-02
Crustacea	*Artemia* sp.	1.23	15.00		104.17
Insecta	Corixidae		0.07		0.11
	unknown Diptera	0.20	0.07		17.07
	Ephydra sp.	75.62	1.95		10.99
	Hydrophilidae	0.70	0.03		0.42
	Muscidae		0.03		0.03
	Dolichopodidae	0.03			

Table 24. Chlorophyll-*a* concentrations (mg/m^3), Napa-Sonoma salt ponds 1, 2, 3, and 4.

Pond	Oct-02	Dec-02	Feb-03	Apr-03	May-03	Jul-03	Oct-03
1	3.93	17.53		29.14	2.40	8.97	3.40
2		5.74		20.83	7.81	12.34	1.56
3	59.89	150.61	18.16	19.02	1.20	3.20	0.65
4		30.55	31.77	48.66	11.18	22.83	1.84

Table 25. Monthly counts of waterbird species in major foraging guilds, Napa-Sonoma salt ponds, San Francisco Bay, CA. Sample dates January 2002 – December 2003.

		2002								2003											
Species		Jan	Mar	May	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dabblers	American coot	268	1				1		1	101	23		158						4	19	136
	American wigeon	111	32						38	38	272	124	71						530	199	419
	cinnamon teal													1					1	155	10
	green-winged teal										140	117	25						9	170	64
	gadwall	20	6	40			3		2	24	368	59	425	109	563	18	4		240	112	27
	mallard	37	55	14		1	1	38	1	9	70	104	86	164	135	628	1821	16634	79	289	218
	northern pintail	25	44	1				1	5	3	528	138	221	25	2			336	5811	4513	1697
	northern shoveler	115	109						2	75	1560	1003	2905	5	1			54	3094	3084	404
Divers	bufflehead	688	514					84	81	681	1144	710	7	2						93	1232
	ruddy duck	3827	1051	12		3	304	1357	2120	2139	3694	3673	2434	240	56	38	10	7	582	1516	1393
	canvasback	185	12					8	211	361	70	12									1392
	redhead	7	2								93			6							
	common goldeneye	989	203	2				48	10	60	125	436	31		2				2	27	16
	scaup (lesser, greater)	3730	410	2				218	3372	187	2357	836	626	640	52	206	28	54	12	165	214
	Clark's grebe	1	6								1		4	10	6						
	eared grebe	479	1169	32	2	52	21	474	436	467	484	631	733	4		1			9	58	211
	pied-billed grebe	3							7	14	2							3	11	13	1
	western grebe	10	25	10			27	7	11	15	78	20	20	3	7				2	2	
Piscivores	American white pelican	4		3	30	64	71	103	9		2	3	41	34	52	451	857	415	216	364	5
	black skimmer															1					
	Caspian tern			85	134	1	16						75	44	221	314	83	279			
	least tern															5					
	Forster's tern	5	9	153	41	31	12	7	21	8	32	2	30	113	362	163	391	143	14	30	1
	double-crested cormorant	15	47	169	165	336	127	138	159	7	57	62	59	120	215	686	227	156	88	64	1
	snowy egret	73	4	21	8	32	8	20	23	3	15	32	12	5	10	18	55	22	41	116	48
	great egret	9	4	5	4	27	8	6	50	2	17	2	3	3	9	14	16	35	6	16	5
	great blue heron	2				1	1	1	3	1	5			1		3	4	2	5	9	1

Table 25 Cont.

Species		2002 Jan	Mar	May	Aug	Sep	Oct	Nov	Dec	2003 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	common merganser								5												1
	red-breasted merganser		3								1										
Shallow Probers	black-bellied plover	13	15		20	5	515	58	293		11	139	69	27	11	155	746	689	1659	642	121
	semipalmated plover				1		1		1							56	1	1	5	17	
	snowy plover													1	12	13	1		1		
	killdeer		2			11	1								3	4	2			5	
	dunlin	365	2093	15				2733	6056	1246	3307	2158	23740	19		8		222	30	11320	2063
	sanderling												12					3			
	least sandpiper	22	607			15	178	67	112	426	503	224	257			306	390	226	5253	497	37
	semipalmated sandpiper	22												1							
	Baird's sandpiper					3				1											
	western sandpiper	1598	6002		4083	201	428	14	101	1001	9515	1892	18330	17		12541	7266	28657	8796	56204	6254
	‘peeps’	4089	471	18		5164	1130	2058	1197	2009	291	1585									
Deep Probers	dowitcher (long, short-billed)	272	4	23	12	326	1		4		35		28			58	3	106	71	1908	504
	greater yellowlegs				11	8		6								13	3	1	14	12	12
	lesser yellowlegs								4												7
	long-billed curlew	183	20		5	4	5	1	1			7			5	101	351	1442	564	142	185
	marbled godwit	319	57	3	17	559	674	25	308	107	2740	31	41	23	434	861	1839	1270	1150	1449	2052
	white-faced ibis																1				
	whimbrel										2									3	
	willet	1565	1145	5	8	380	87	161	717	378	1052	1057	262	47	6	585	376	573	42	494	575
Sweepers	American avocet	8384	989	44	1318	2404	2393	1558	1120	1257	888	838	787	387	749	1721	3379	5585	5365	3743	5507
	black-necked stilt	315	269	11	7	101	193	216	3	156	123	28	29	32	109	269	552	398	30	29	1
	red-necked phalarope	37		26					1								59	617			
Other	black rail	1	1	1	1	1		1		1											
	sora																1				
	Virginia rail	2							2										1	2	
	Bonaparte's gull	242	605						198	17						11	31	2			291

Table 25 Cont.

	2002								**2003**												
Species	Jan	Mar	May	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
California gull	3	4	11		120	63								73	56	1428	33	45	51	
glaucous-winged gull									5											
herring gull									19	19										
ring-billed gull				4			9	20	5				1	1	1	21	262	23	9	106
Thayer's gull									1											
western gull	468	15	2		1	34	25	135	2	11	3	13	43		19	116	74	128	22	2
gull (unidentified)	235	2	2	42	1308	964	27	356	155	233	61	17	36	182	476	336	124		13	16
turkey vulture									2							1				
Canada goose		2							1	25	18	35	18	40	20					
mute swan															8			2		
greater flamingo			3		2	2						2	6							
northern harrier	3		2			2	1		12	6	10	6		2	1	1	1			
osprey					2	1		1												
peregrine falcon											1		1				1			
red-tailed hawk	1	2	1						2			1					1			
white-tailed kite	2					1														
red-winged blackbird	25																			
marsh wren	5																			
song sparrow	167																			
Total	**28941**	**16011**	**716**	**5913**	**11163**	**7273**	**9470**	**17197**	**10998**	**29899**	**16016**	**51595**	**2188**	**3320**	**19829**	**20400**	**58428**	**33935**	**87576**	**25229**

Table 26. Total counts of waterbird species,in major foraging guilds, Napa-Sonoma salt ponds, San Francisco Bay, CA. Samples collected January 2002 – December 2003.

Species			Pond 1	2	3	4	2A	7A
Dabblers	American coot	*Fulica americana*	352	4	180	158	17	1
	American wigeon	*Anas americana*	61	82	1568	33	45	45
	cinnamon teal	*Anas cyanoptera*	0	0	166	0	1	0
	green-winged teal	*Anas crecca*	0	0	280	0	245	0
	gadwall	*Anas strepera*	37	42	1254	570	101	16
	mallard	*Anas platyrhynchos*	58	58	14976	4939	349	4
	northern pintail	*Anas acuta*	619	5	9248	3458	19	1
	northern shoveler	*Anas clypeata*	192	21	10902	997	89	210
Divers	bufflehead	*Bucephala albeola*	63	230	481	4447	7	8
	ruddy duck	*Oxyura jamaicensis*	8127	8433	6472	1097	134	193
	canvasback	*Aythya valisineria*	551	12	1660	13	15	0
	redhead	*Aythya americana*	0	106	0	0	2	0
	scaup (lesser, greater)	*Aythya affinis, A.marila*	152	3207	7975	1676	7	92
	common goldeneye	*Bucephala clangula*	33	589	322	989	13	5
	Clark's grebe	*Aechmophorus clarkii*	8	19	1	0	0	0
	eared grebe	*Podiceps nigricollis*	24	291	1236	2527	0	1185
	pied-billed grebe	*Podilymbus podiceps*	7	26	7	2	0	12
	sestern grebe	*Aechmophorus occidentalis*	86	98	47	3	1	2
Piscivores	American white pelican	*Pelecanus erythrorhynchos*	771	529	1146	226	6	46
	black skimmer	*Rynchops niger*	0	0	1	0	0	0
	Caspian tern	*Sterna caspia*	339	52	857	4	0	0
	Forster's tern	*Sterna forsteri*	639	298	405	213	2	11
	least tern	*Sterna antillarum*	0	5	0	0	0	0
	double-crested cormorant	*Phalacrocorax auritis*	656	261	1933	35	4	9
	great blue heron	*Ardea herodias*	8	9	3	13	4	2
	great egret	*Casmerodius albus*	67	83	60	8	10	13
	snowy egret	*Egretta thula*	67	268	108	49	22	52
	common merganser	*Mergus merganser*	0	1	1	4	0	0
	red-breasted merganser	*Mergus serrator*	0	0	1	3	0	0
Shallow Probers	black-bellied plover	*Pluvialis squatarola*	277	0	3536	1323	0	52
	semipalmated plover	*Charadrius semipalmatus*	1	0	17	12	0	53
	snowy plover	*Charadrius alexandrinus*	0	0	0	27	0	1
	killdeer	*Charadrius vociferous*	3	0	4	2	2	17
	dunlin	*Calidris alpina*	1597	0	9644	42237	1	1896
	sanderling	*Calidris alba*	0	0	0	13	0	2
	baird's sandpiper	*Calidris bairdii*	0	0	0	2	0	2
	least sandpiper	*Calidris minutilla*	201	1	673	7253	8	984
	semipalmated sandpiper	*Calidris mauri*	22	0	0	1	0	0
	western sandpiper	*Calidris mauri*	5981	0	86348	66342	28	4201
	‘peeps’	*Calidris* spp.	2195	0	5425	9847	6	539

Table 26 Cont.

Species			1	2	3	4	2A	7A
Deep Probers	dowitcher (long, short-billed)	*Limnodromus scolopaceus, L. griseus*	518	0	2389	316	0	132
	greater yellowlegs	*Tringa melanoleuca*	13	1	5	13	17	31
	lesser yellowlegs	*Tringa flavipes*	0	0	2	1	0	8
	long-billed curlew	*Numenius americanus*	183	0	1626	1204	0	3
	marbled godwit	*Limosa fedoa*	1604	0	8432	3889	0	34
	white-faced ibis	*Plegadis chihi*	0	0	0	1	0	0
	whimbrel	*Numenius phaeopus*	0	0	0	5	0	0
	willet	*Catoptrophorus semipalmatus*	105	0	3069	6227	4	110
Sweepers	American avocet	*Recurvirostra americana*	9773	12	17598	18983	0	2050
	black-necked stilt	*Himantopus mexicanus*	446	0	1533	872	0	20
	red-necked phalarope	*Phalaropus lobatus*	0	0	151	589	0	0
Other	black rail	*Laterallus jamaicensis*	0	0	0	0	7	0
	sora	*Porzana carolina*	0	0	0	0	1	0
	Virginia rail	*Rallus limicola*	0	0	0	0	7	0
	Bonaparte's gull	*Larus philadephia*	40	0	221	649	0	487
	California gull	*Larus californicus*	886	21	880	17	0	83
	glaucous-winged gull	*Larus glaucescens*	5	0	0	0	0	0
	herring gull	*Larus argentatus*	23	0	15	0	0	0
	ring-billed gull	*Larus delawarensis*	229	6	100	26	0	101
	Thayer's gull	*Larus thayeri*	1	0	0	0	0	0
	western gull	*Larus occidentalis*	650	2	248	78	0	135
	gull (unidentified)	*Larus* spp.	517	76	3088	849	0	55
	turkey vulture	*Cathartes aura*	0	0	0	0	3	0
	Canada goose	*Branta canadensis*	8	0	72	24	3	52
	mute swan	*Cygnus olor*	0	0	10	0	0	0
	greater flamingo	*Phoenicopterus roseus*	0	0	13	2	0	0
	northern harrier	*Circus cyaneus*	0	0	1	1	45	0
	osprey	*Pandion haliaetus*	0	0	4	0	0	0
	peregrine falcon	*Falco peregrinus*	0	0	1	1	1	0
	red-tailed hawk	*Buteo jamaicensis*	0	0	0	0	8	0
	white-tailed kite	*Elanus leucurus*	1	0	0	0	2	0
	red-winged blackbird	*Agelaius phoeniceus*	0	0	0	0	25	0
	marsh wren	*Cistothorus palustris*	0	0	0	0	5	0
	song sparrow	*Melospiza melodia*	0	0	0	0	167	0
Total			**38196**	**14848**	**206395**	**182270**	**1433**	**12955**

Table 27. Pond 1 average dissolved nutrient concentrations (mg/l), Napa-Sonoma salt ponds, San Francisco Bay, CA.

Date	Ammonium (NH_4)	Nitrate (NO_3)	Phosphorous (P Soluble)	Phosphorous (P Total)	Sulfate (SO_4)
September-02					
October-02	0.24	0.07	0.51	0.37	
December-02	0.32	<0.05		0.05	
February-03	0.36	0.56	0.14		480.00
April-03	0.11	0.81	0.36	0.70	
May-03	0.03	0.77	0.52	0.95	
July-03	0.30	0.21	0.52		
August-03	0.30	<0.05	0.85		
September-03	0.34	0.07	1.13		1690.00
October-03	0.14	<0.05	0.33	0.65	
November-03	1.31	<0.05	0.88	0.80	

Table 28. Pond 2 average dissolved nutrient concentrations (mg/l), Napa-Sonoma salt ponds, San Francisco Bay, CA.

Date	Ammonium (NH_4)	Nitrate (NO_3)	Phosphorous (P Soluble)	Phosphorous (P Total)	Sulfate (SO_4)
September-02					
October-02	0.16	<0.05	0.30	0.15	
December-02	0.12	<0.05		0.05	
February-03					
April-03	0.03	0.96	0.64	0.70	
May-03	1.14	<0.05	1.66	1.60	
July-03	0.46	<0.05	0.75		
August-03	0.40	<0.05	0.55		
September-03	0.22	<0.05	0.41		610.00
October-03	0.22	<0.05	0.44	0.40	
November-03	0.21	<0.05	0.64	0.50	

Table 29. Pond 3 average dissolved nutrient concentrations (mg/l), Napa-Sonoma salt ponds, San Francisco Bay, CA.

Date	Ammonium (NH_4)	Nitrate (NO_3)	Phosphorous (P Soluble)	Phosphorous (P Total)	Sulfate (SO_4)
September-02	0.18	<0.05	0.17		1421.00
October-02	0.07	<0.05	0.14	0.45	
December-02	2.84	0.20		0.85	
February-03					
April-03	0.03	0.42	0.07	0.20	
May-03					
July-03	0.42	0.38	0.13		
August-03	0.16	0.25	0.09		
September-03	0.37	0.16	0.20		520.00
October-03	0.25	0.16	0.19	0.20	
November-03	0.18	0.39	0.11	0.05	

Table 30. Pond 4 average dissolved nutrient concentrations (mg/l), Napa-Sonoma salt ponds, San Francisco Bay, CA.

Date	Ammonium (NH_4)	Nitrate (NO_3)	Phosphorous (P Soluble)	Phosphorous (P Total)	Sulfate (SO_4)
September-02	4.42	0.13	0.71		5327.44
October-02	8.06	0.23	0.96	2.10	
December-02					
February-03					
April-03	1.87	<0.05	0.14	0.40	
May-03	1.25	<0.05	0.14	0.45	
July-03	1.09	<0.05	0.19		
August-03	0.60	0.04	0.07		
September-03	1.24	<0.05	0.06		1180.00
October-03	0.14	<0.05	0.05	0.30	
November-03	0.32	<0.05	0.10	0.10	

Figure 1. Study area. Alviso salt ponds A9-17, San Francisco Bay, CA.

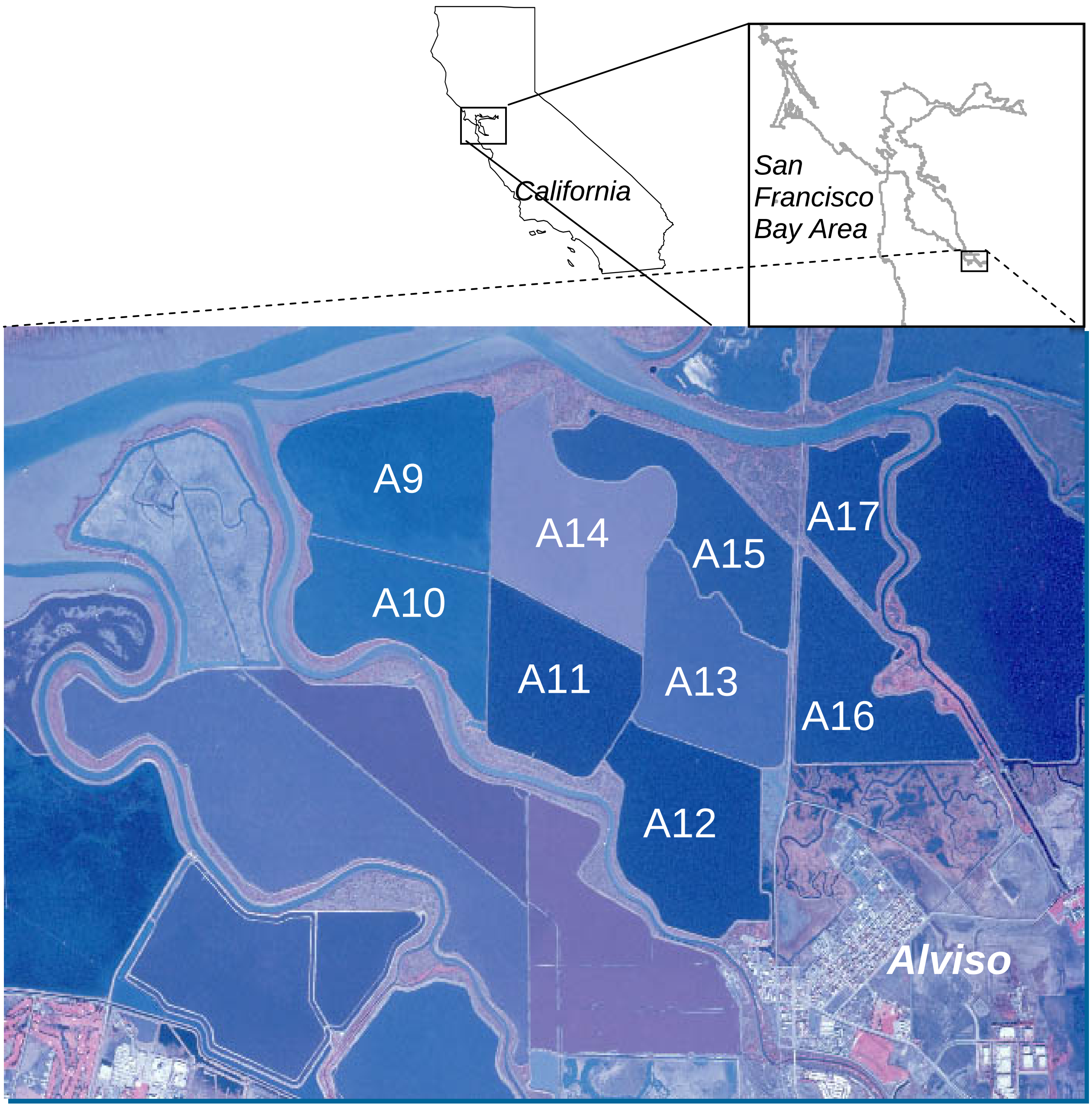

Figure 2. Mean number of macroinvertebrates, Alviso salt ponds, San Francisco Bay, CA. Mean number per Ekman grab, *N* = 15.

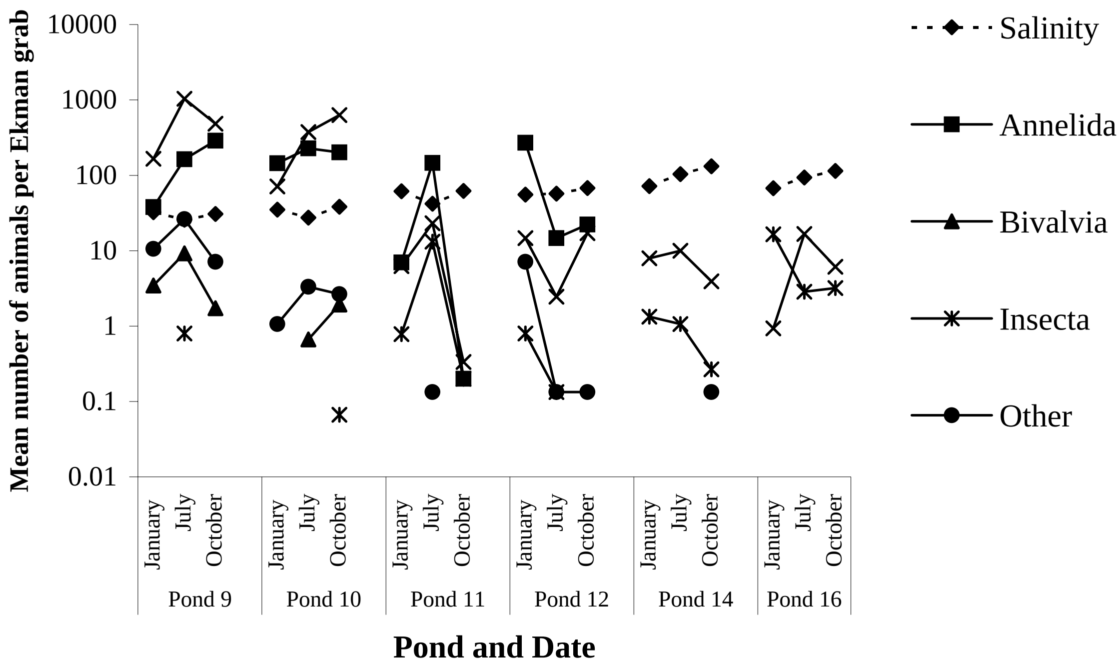

Figure 3. Maximum abundance and number of invertebrate taxa over a salinity gradient for ponds A9 – A16, Alviso salt ponds, San Francisco Bay, CA.

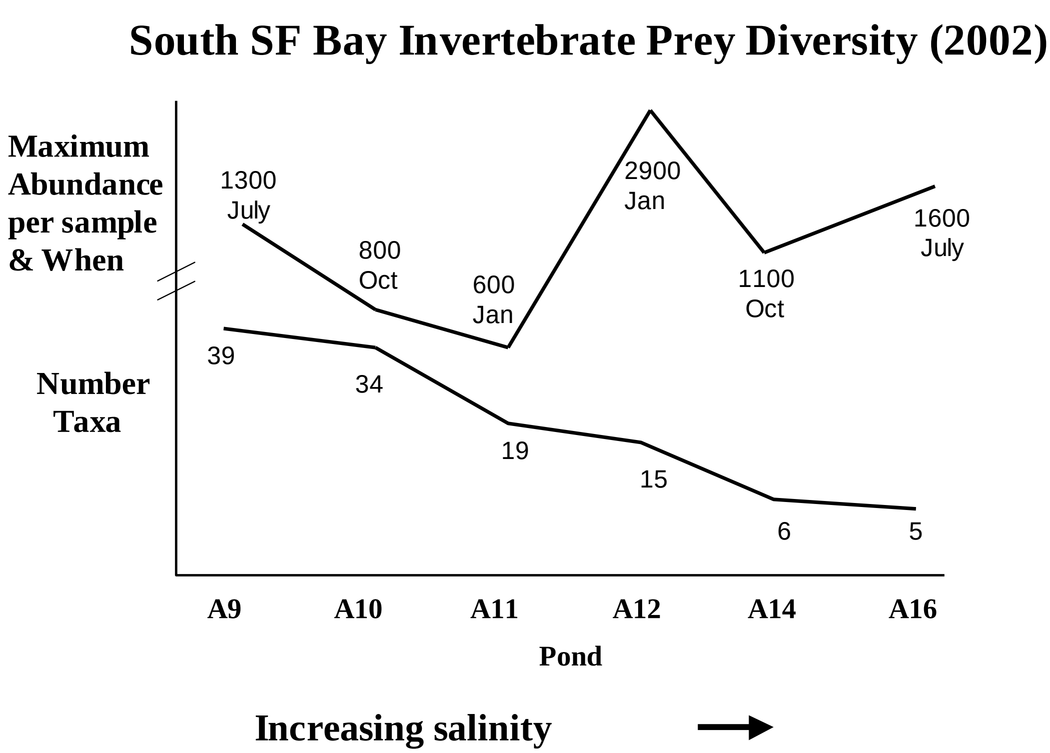

Figure 4. Proportion of total bird counts per pond for each foraging guild, Alviso salt ponds, San Francisco Bay, CA.

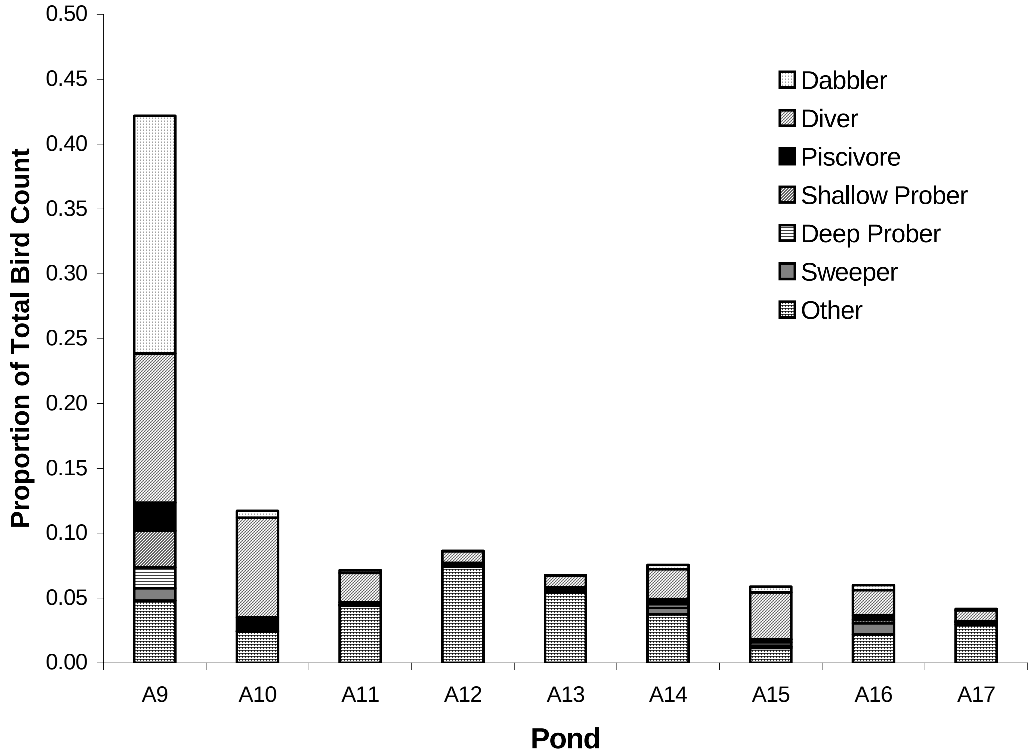

Figure 5. Proportion of total bird counts per hectare for each foraging guild, Alviso salt ponds, San Francisco Bay, CA.

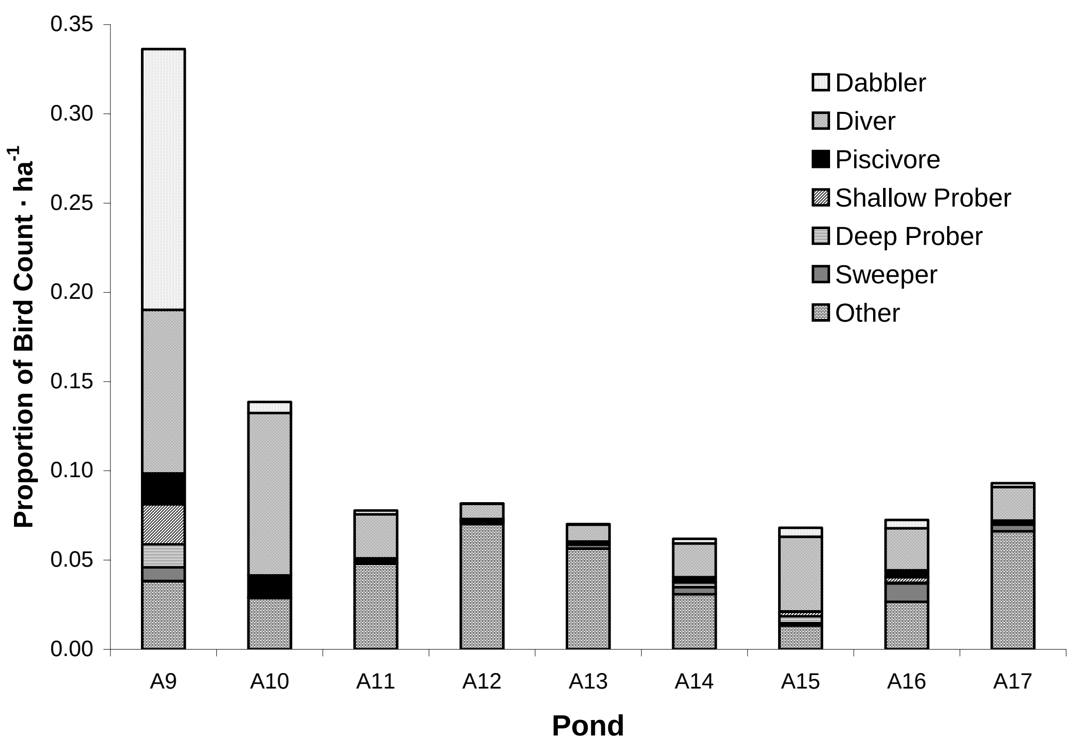

Figure 6. Pond A9 total bird counts, Alviso salt ponds, San Francisco Bay, CA.

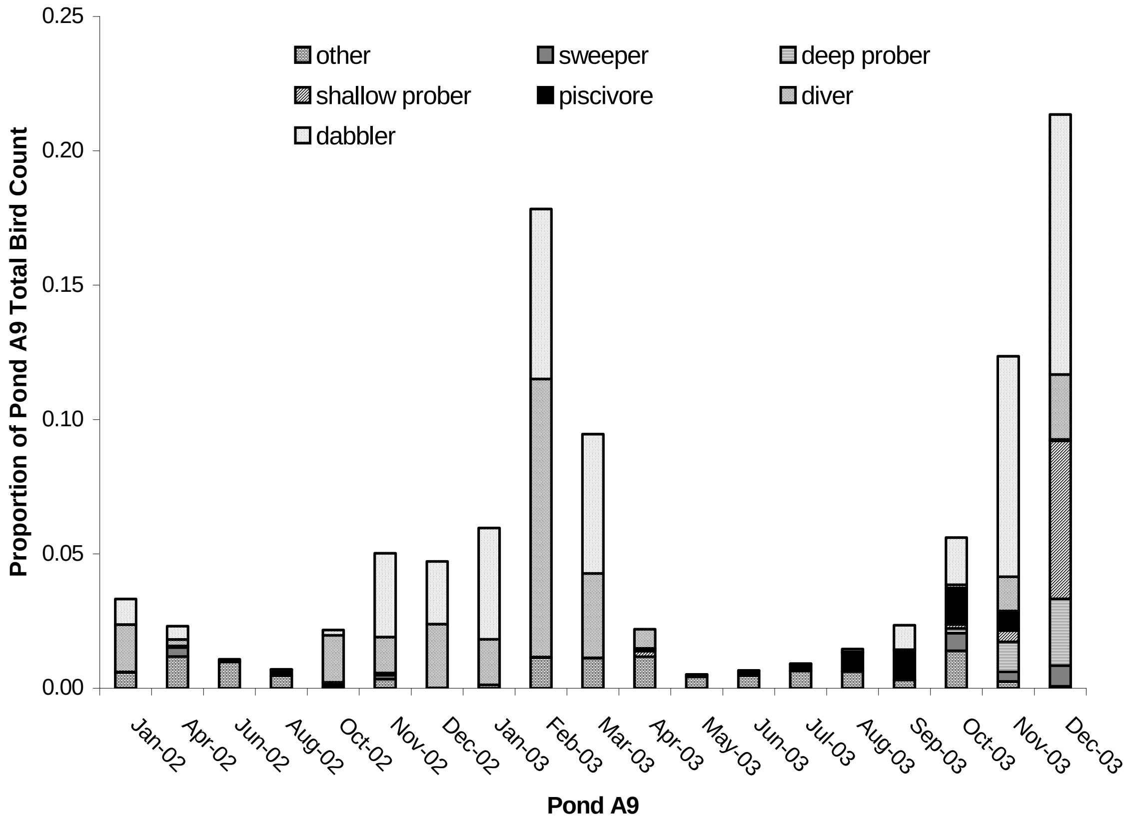

Figure 7. Pond A10 total bird counts, Alviso salt ponds, San Francisco Bay, CA.

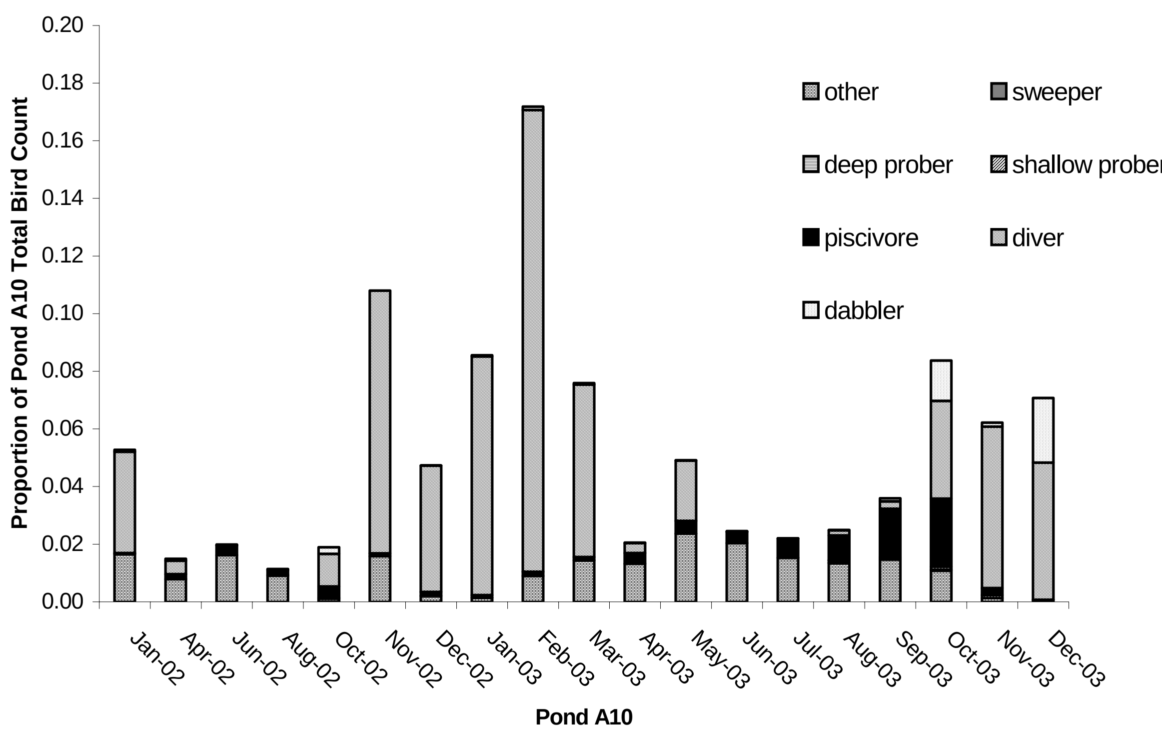

Figure 8. Pond A11 total bird counts, Alviso salt ponds, San Francisco Bay, CA.

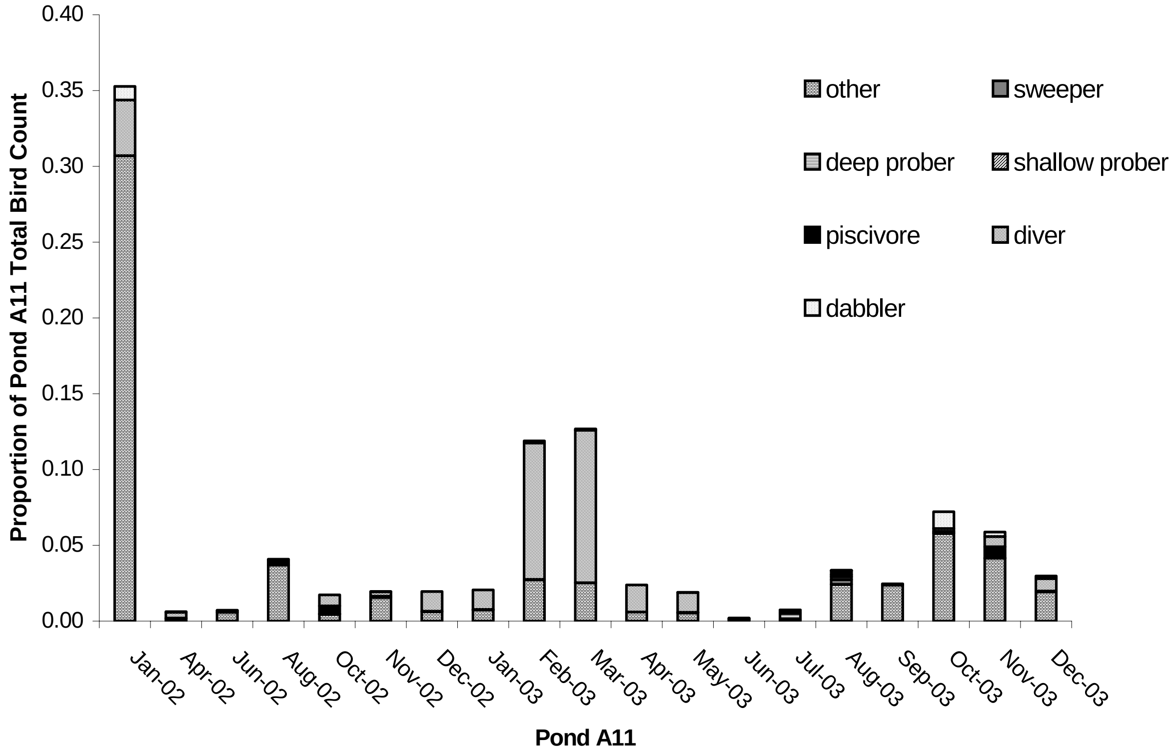

Figure 9. Pond A12 total bird counts, Alviso salt ponds, San Francisco Bay, CA.

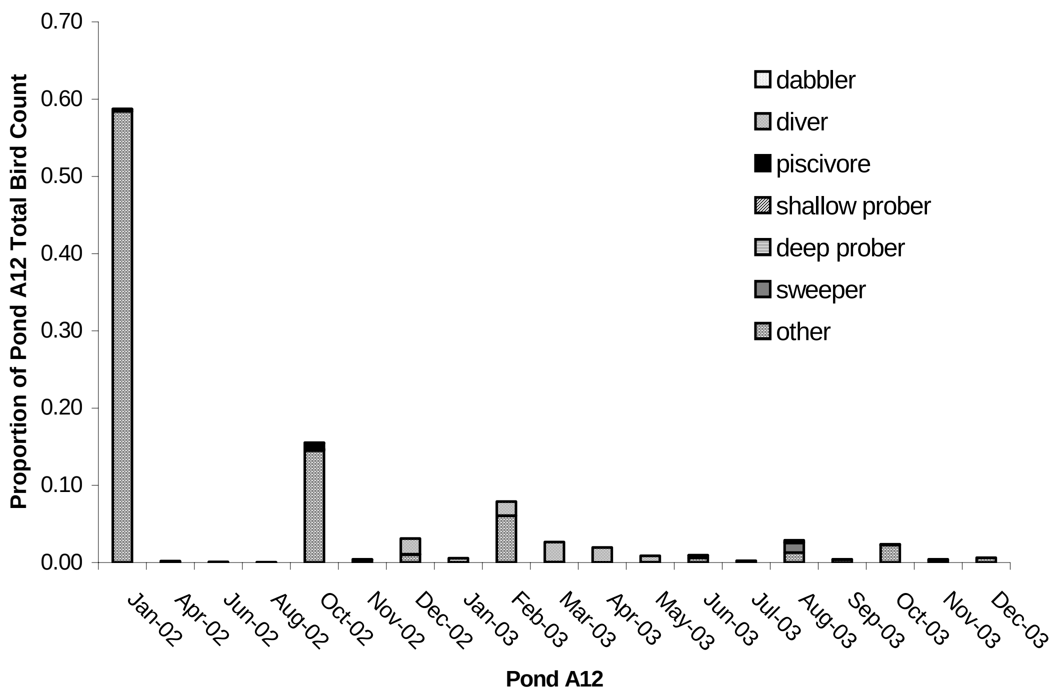

Figure 10. Pond A13 total bird counts, Alviso salt ponds, San Francisco Bay, CA.

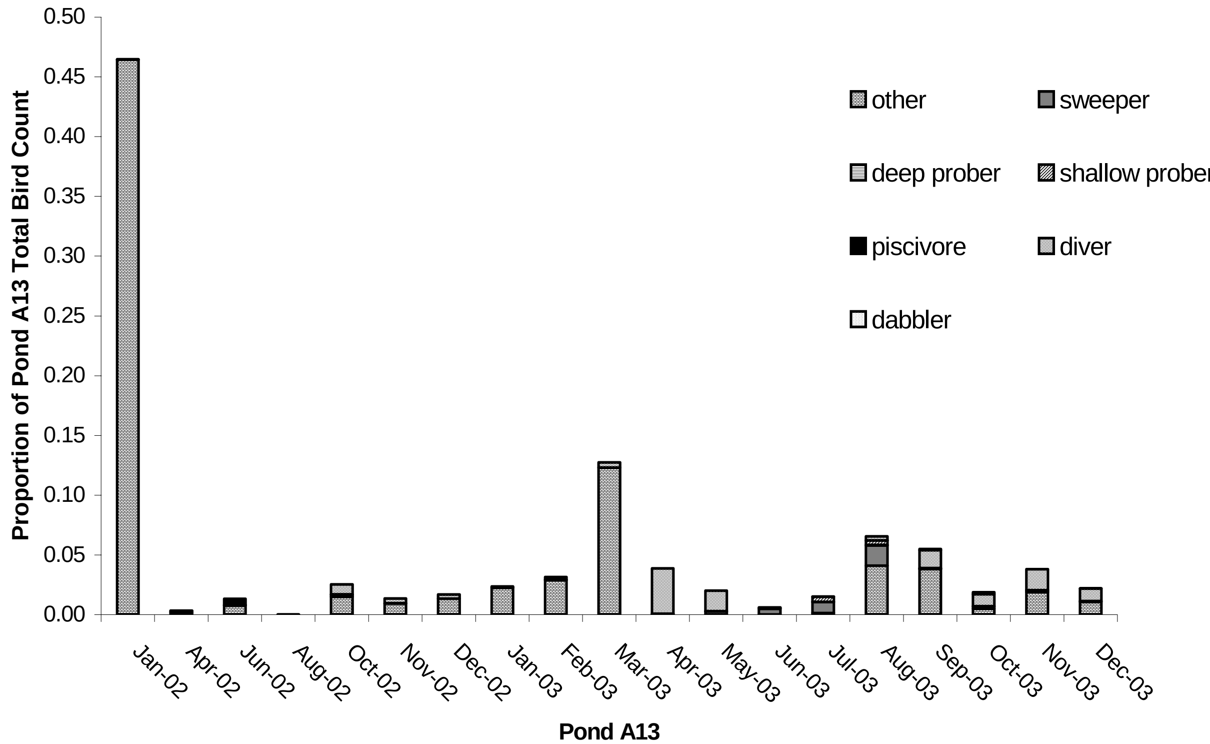

Figure 11. Pond A14 total bird counts, Alviso salt ponds, San Francisco Bay, CA.

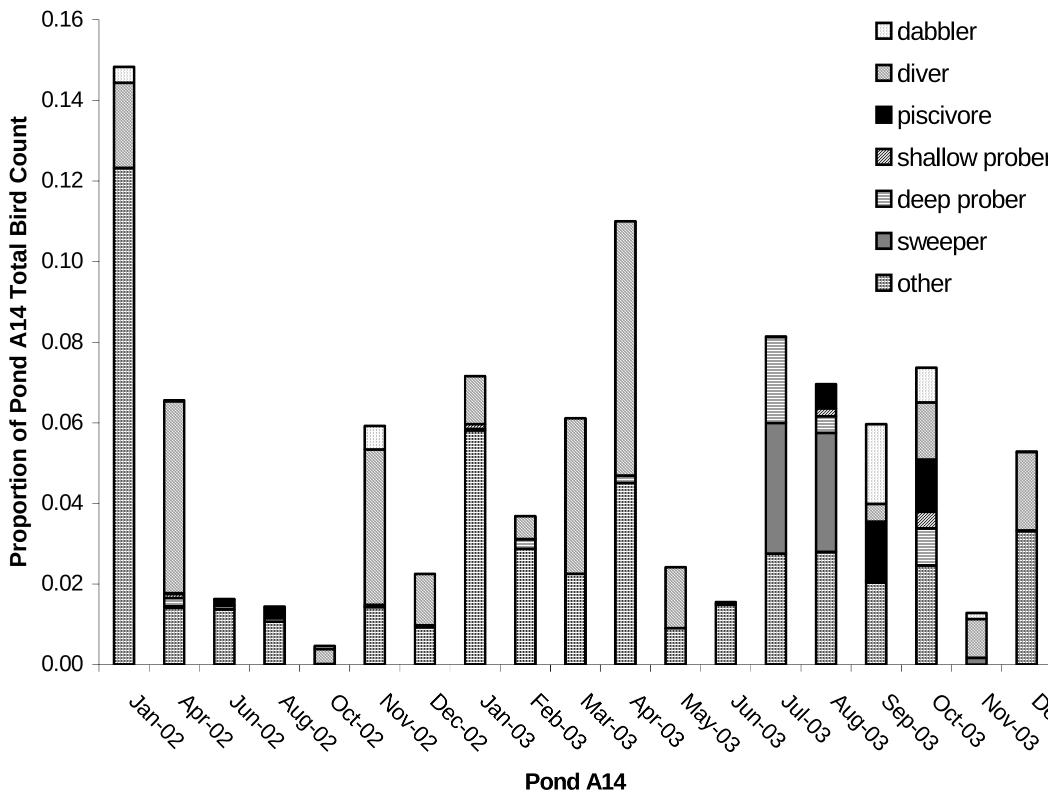

Figure 12. Pond A15 total bird counts, Alviso salt ponds, San Francisco Bay, CA.

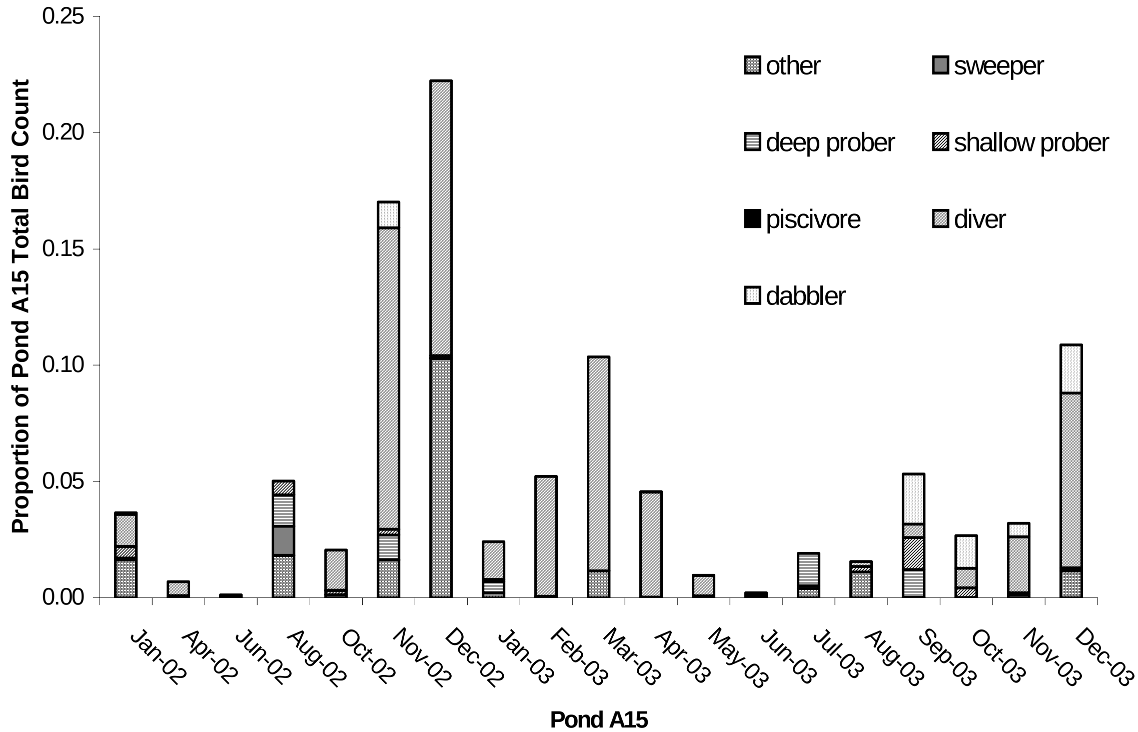

Figure 13. Pond A16 total bird counts, Alviso salt ponds, San Francisco Bay, CA.

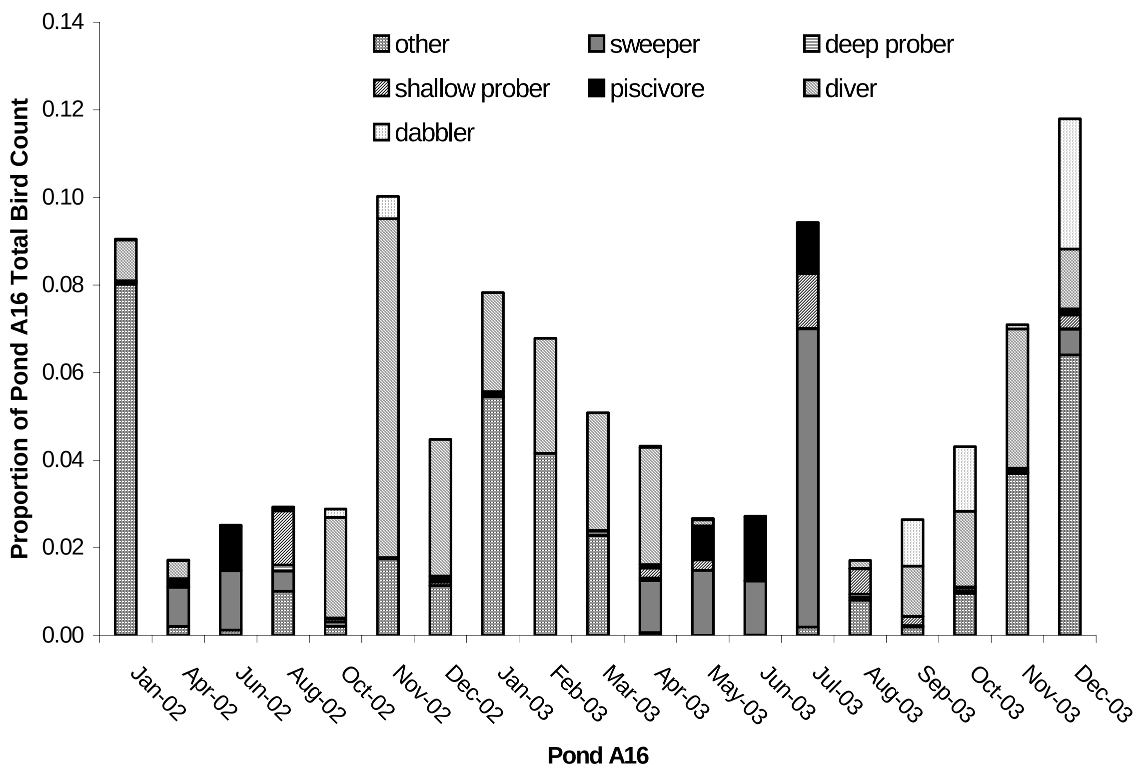

Figure 14. Pond A17 total bird counts, Alviso salt ponds, San Francisco Bay, CA.

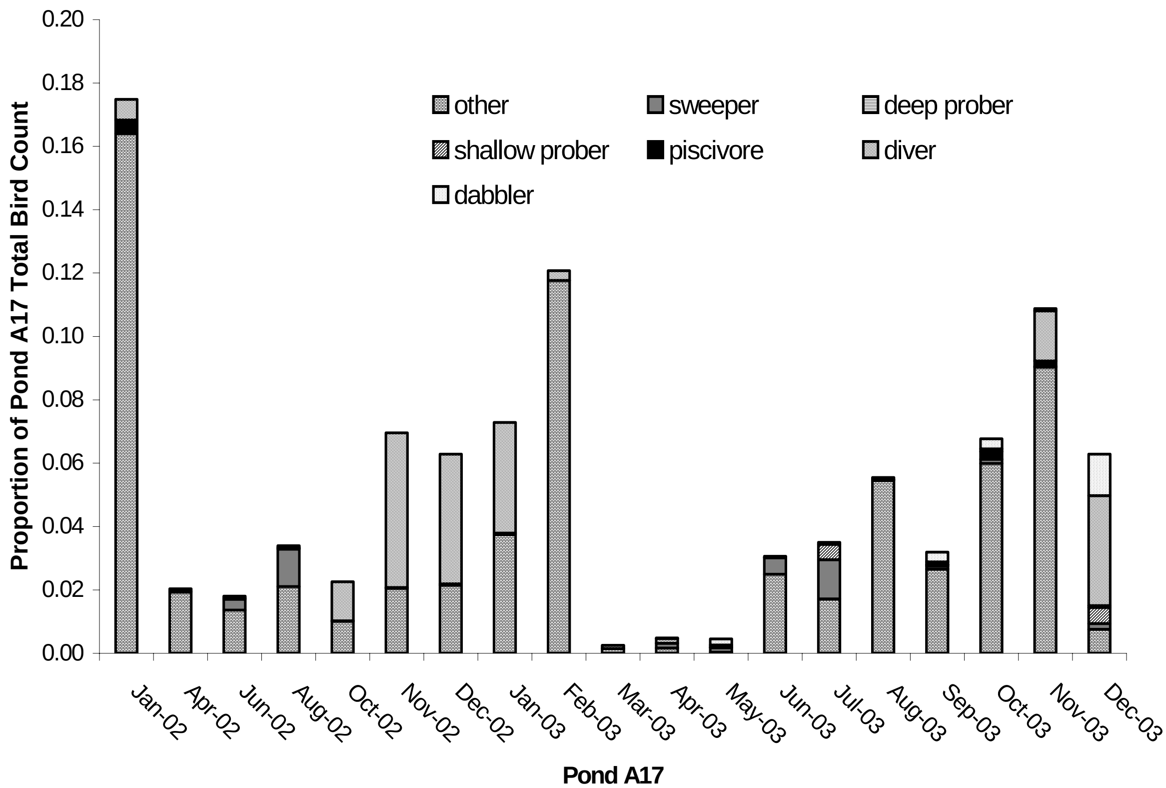

Figure 15. Average water temperature (ºC), Alviso salt ponds, San Francisco Bay, CA.

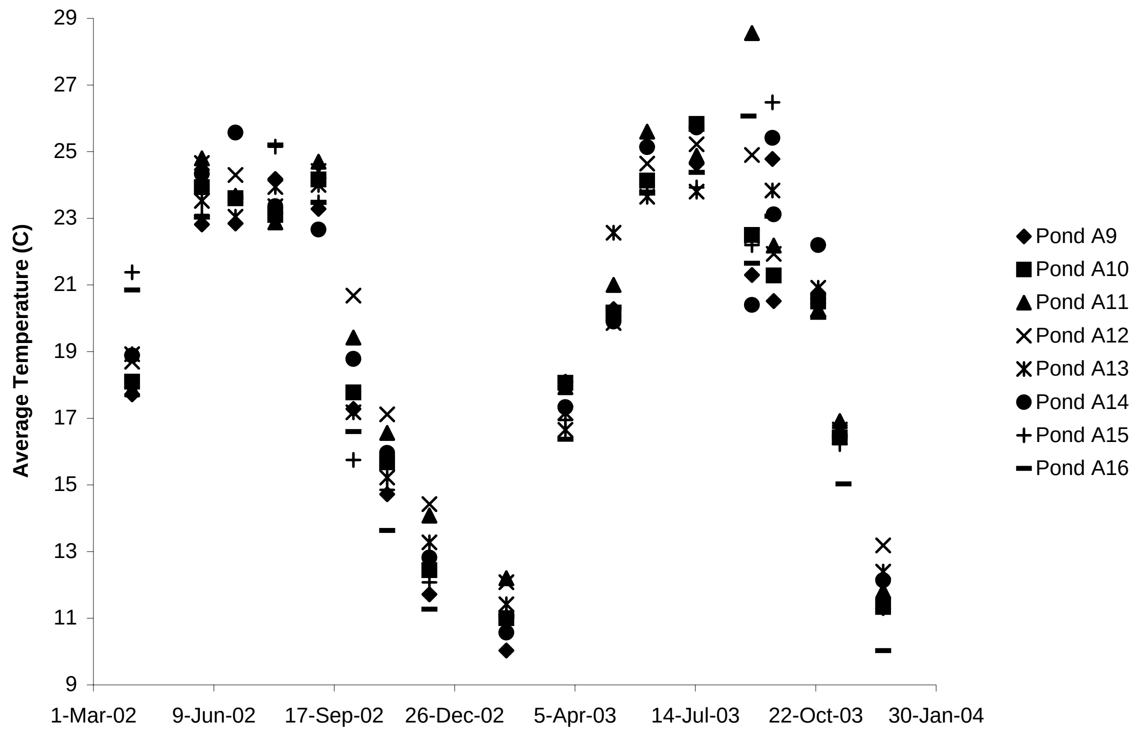

Figure 16. Standard deviation of water temperature, Alviso salt ponds, San Francisco Bay, CA.

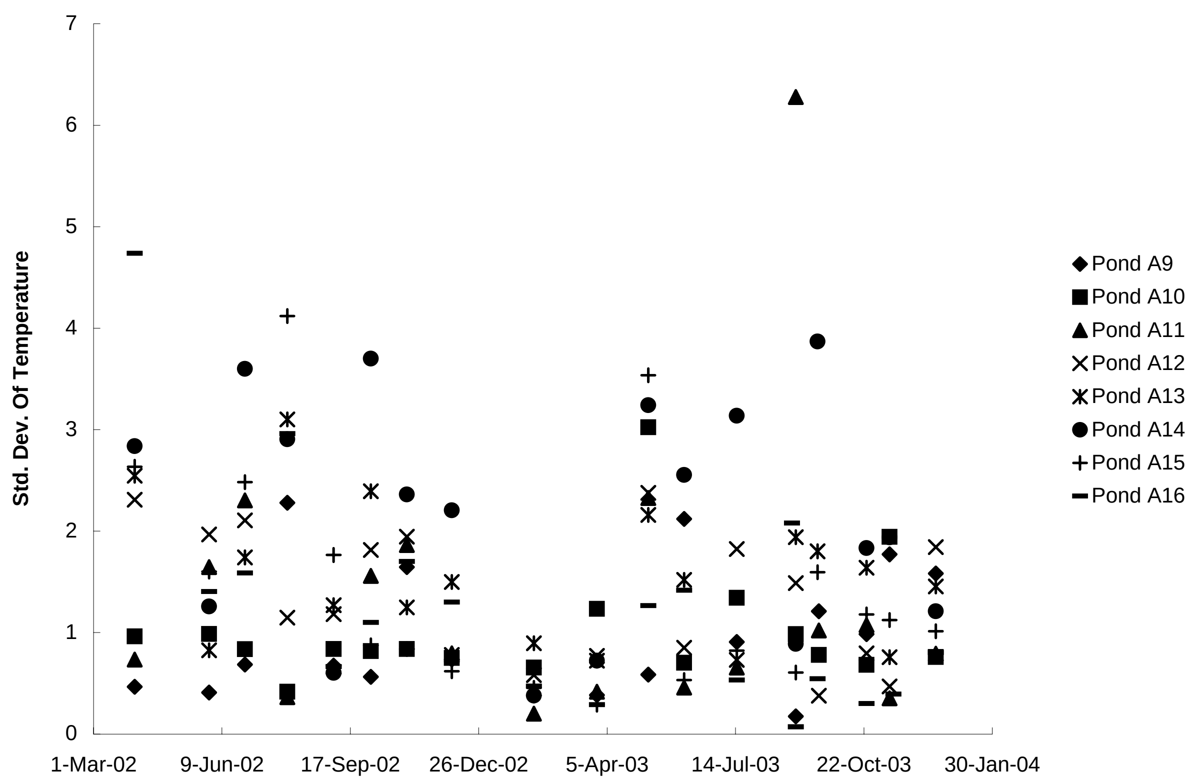

Figure 17. Average turbidity (NTU), Alviso salt ponds, San Francisco Bay, CA.

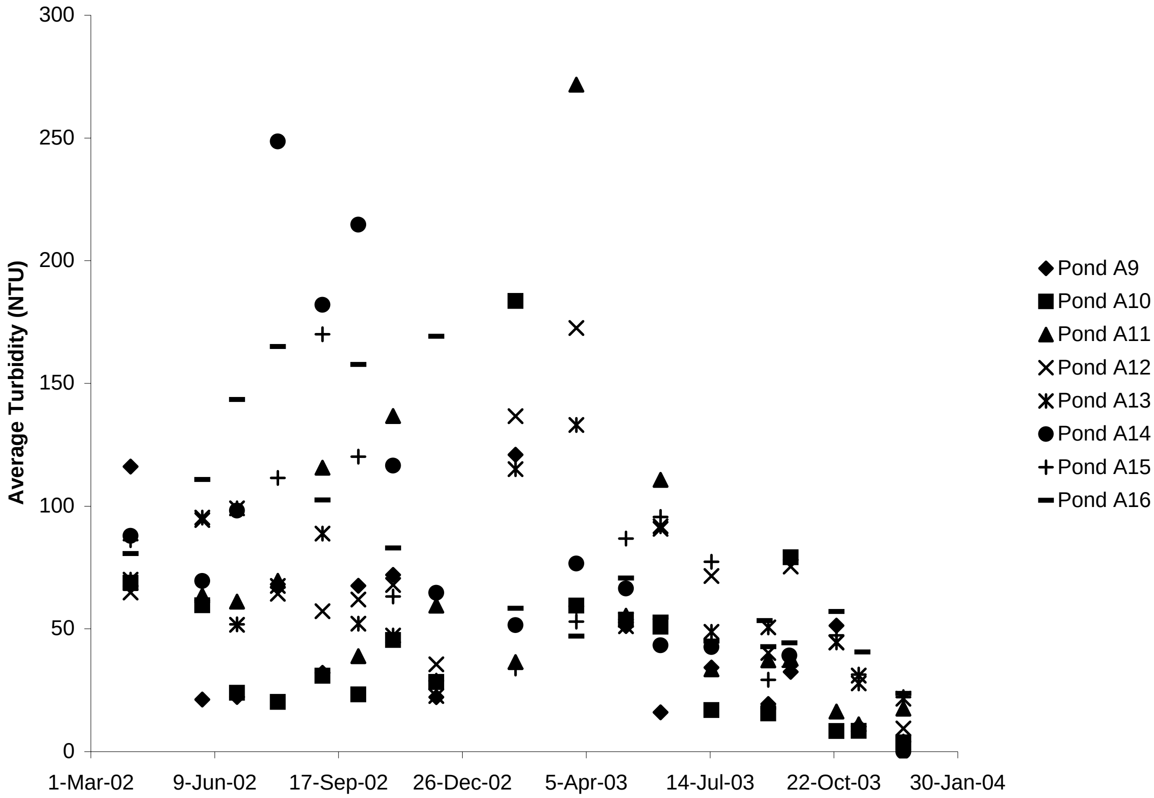

Figure 18. Standard deviation of average turbidity, Alviso salt ponds, San Francisco Bay, CA.

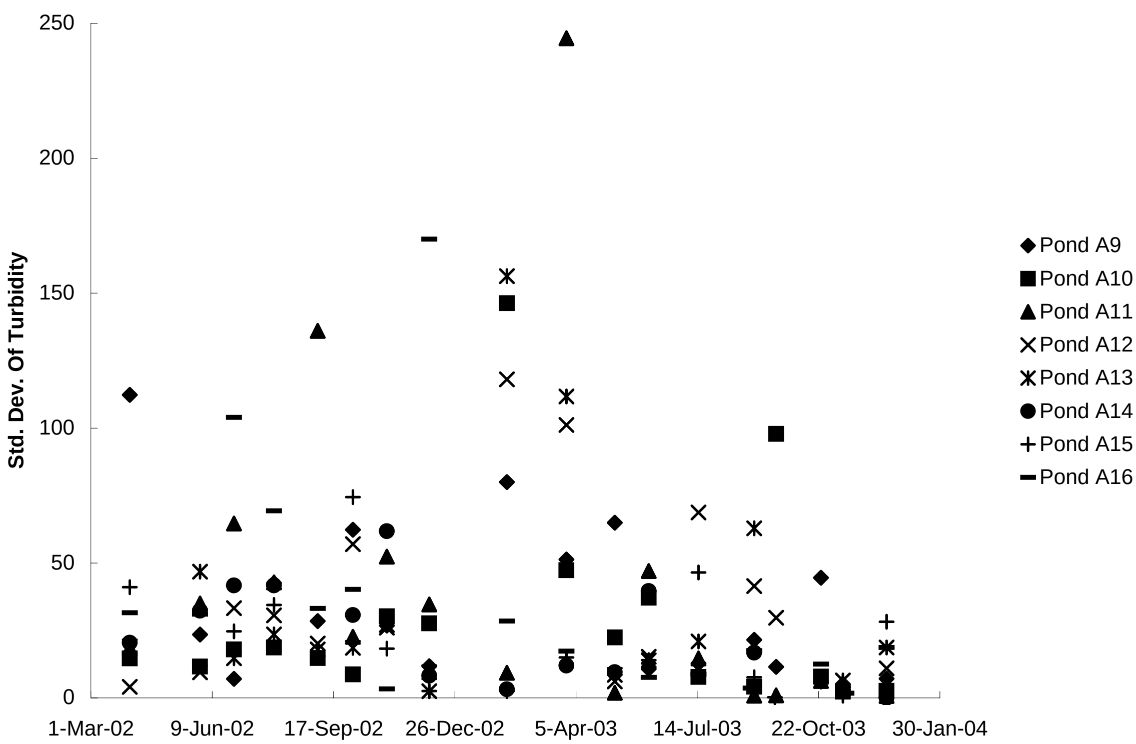

Figure 19. Average pH, Alviso salt ponds, San Francisco Bay, CA.

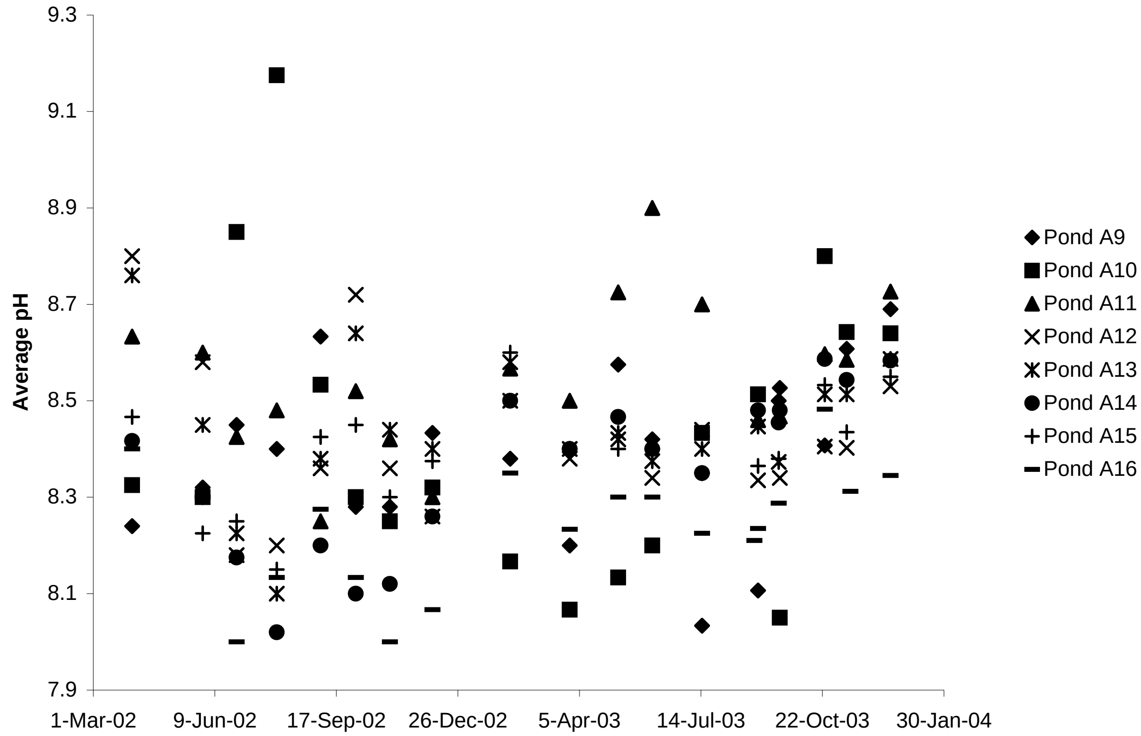

Figure 20. Standard deviation of average pH, Alviso salt ponds, San Francisco Bay, CA.

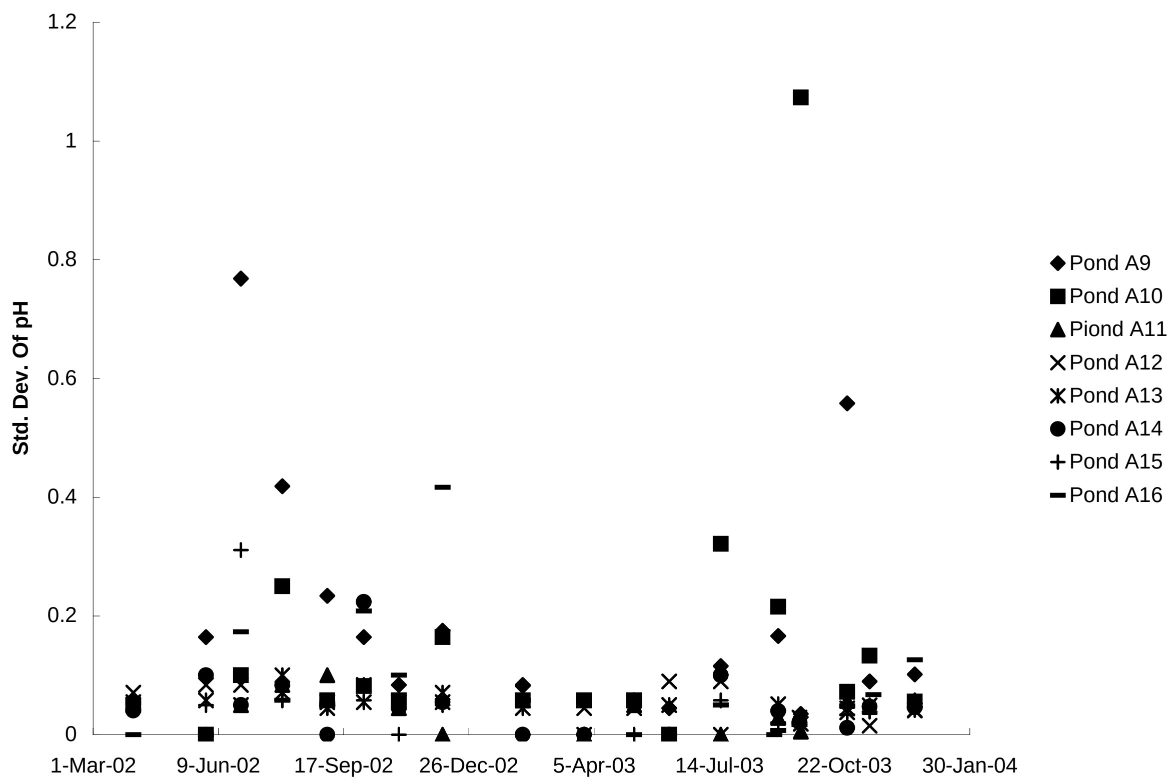

Figure 21. Average dissolved oxygen (mg/l), Alviso salt ponds, San Francisco Bay, CA.

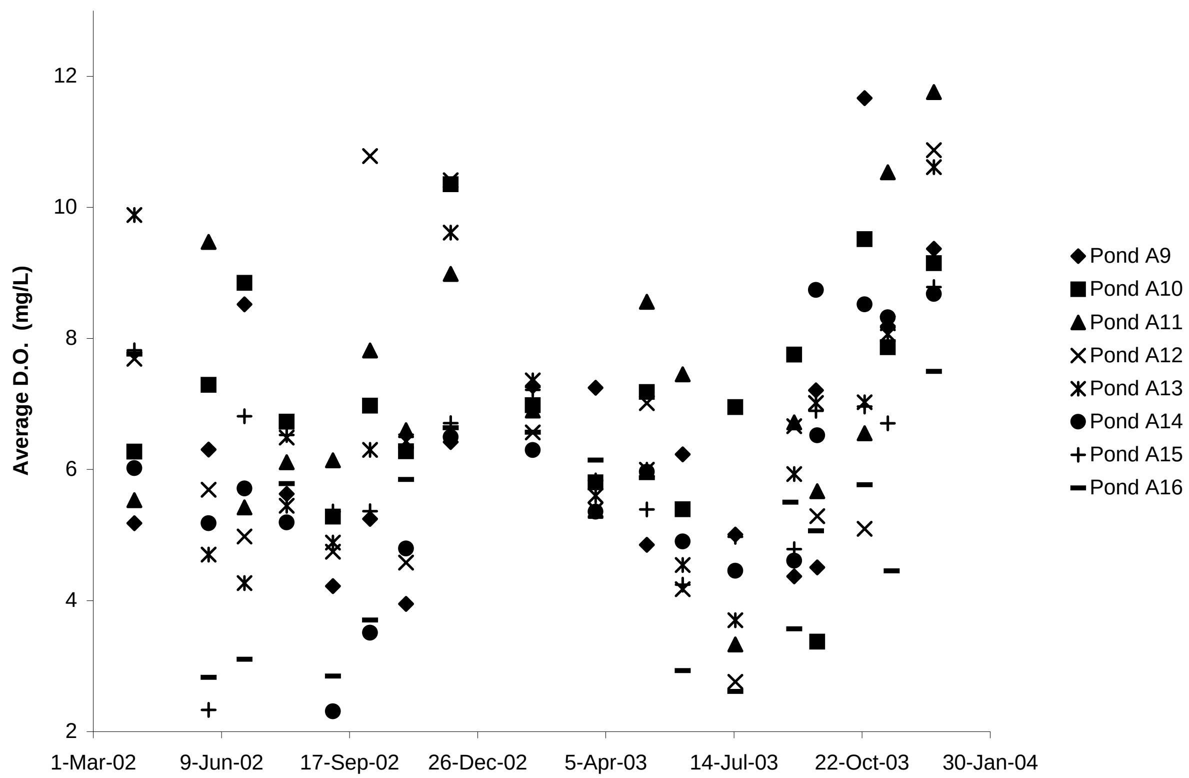

Figure 22. Standard deviation of dissolved oxygen, Alviso salt ponds, San Francisco Bay, CA.

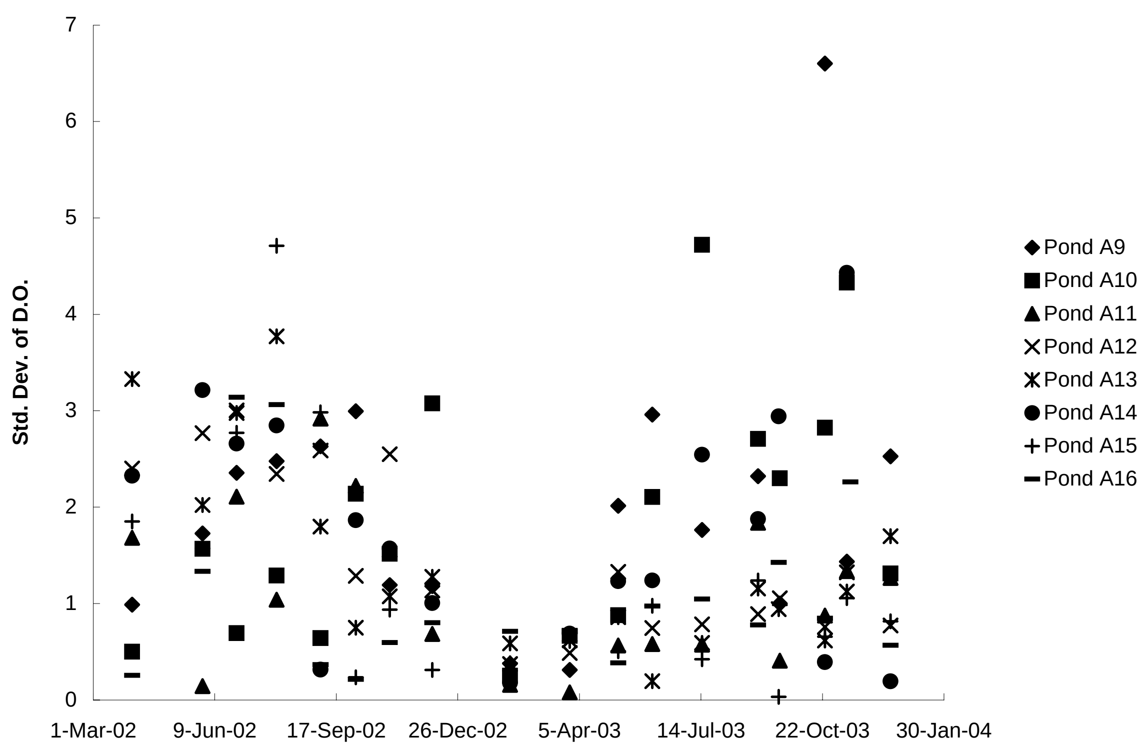

Figure 23. Average salinity (ppt), Alviso salt ponds, San Francisco Bay, CA.

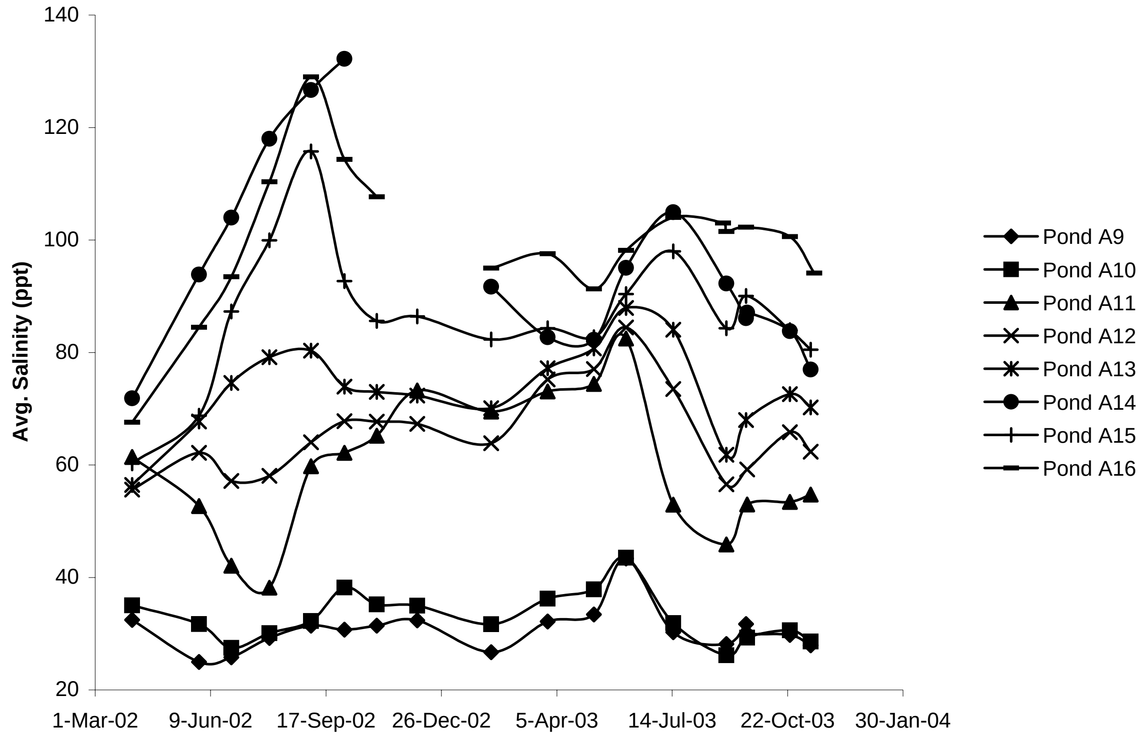

Figure 24. Standard deviation of salinity, Alviso salt ponds, San Francisco Bay, CA.

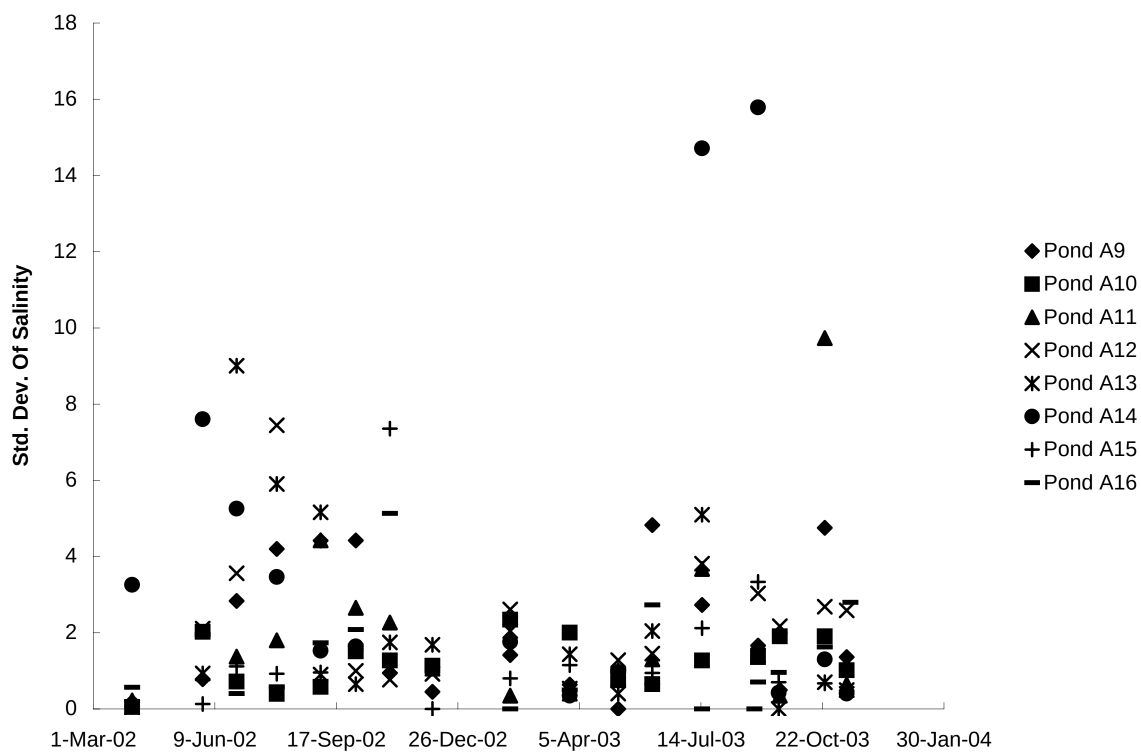

Figure 25. Average pH vs. average salinity (ppt), Alviso salt ponds, San Francisco Bay, CA.

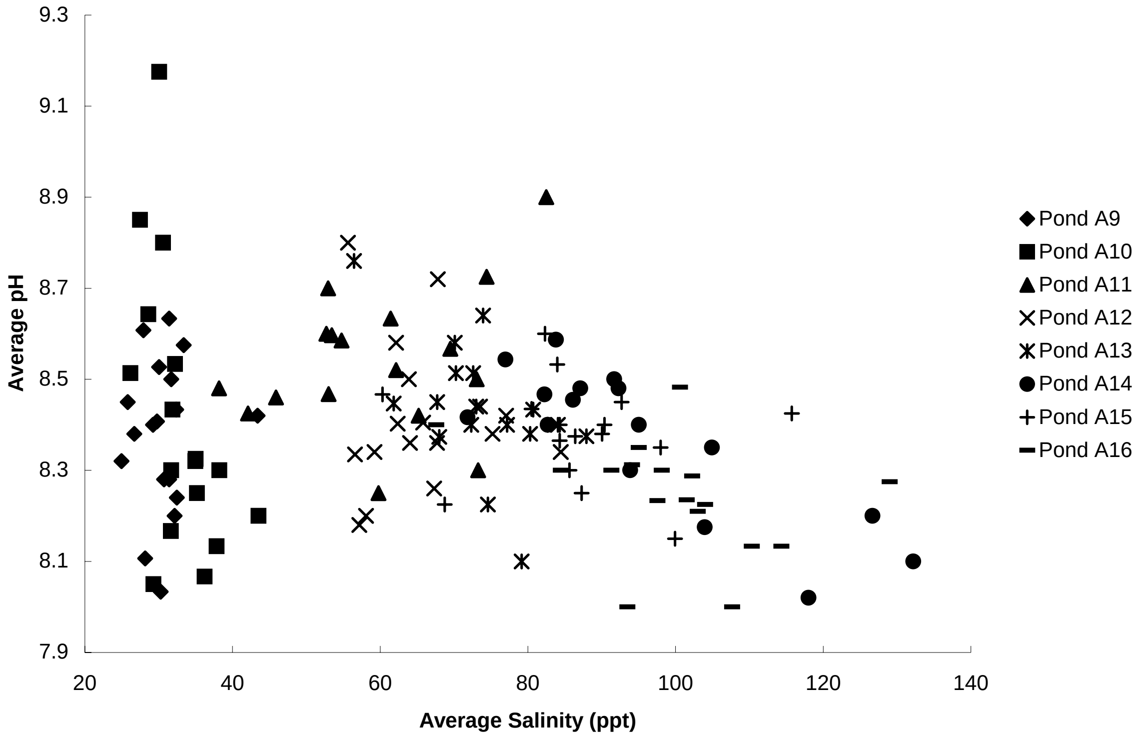

Figure 26. Average dissolved oxygen (mg/l) vs. average salinity (ppt), Alviso salt ponds, San Francisco Bay, CA.

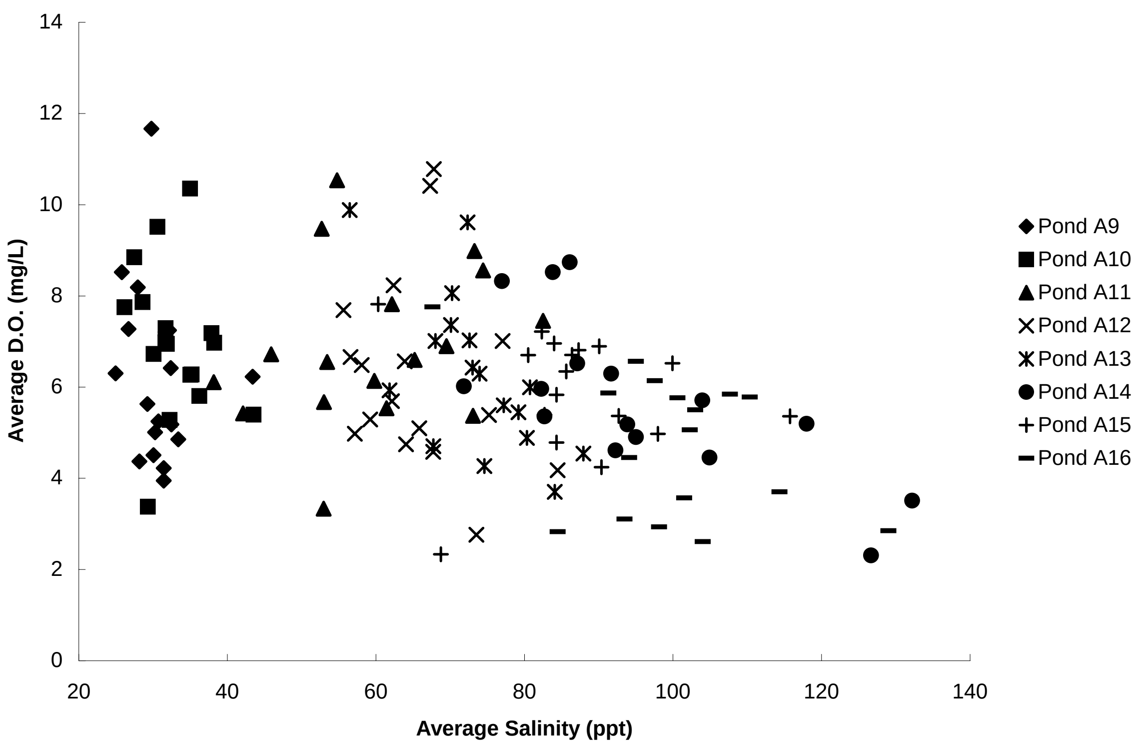

Figure 27. Study area. Napa-Sonoma salt ponds 1, 2, 2A, 3, 4, 5, and 7A. San Francisco Bay, CA.

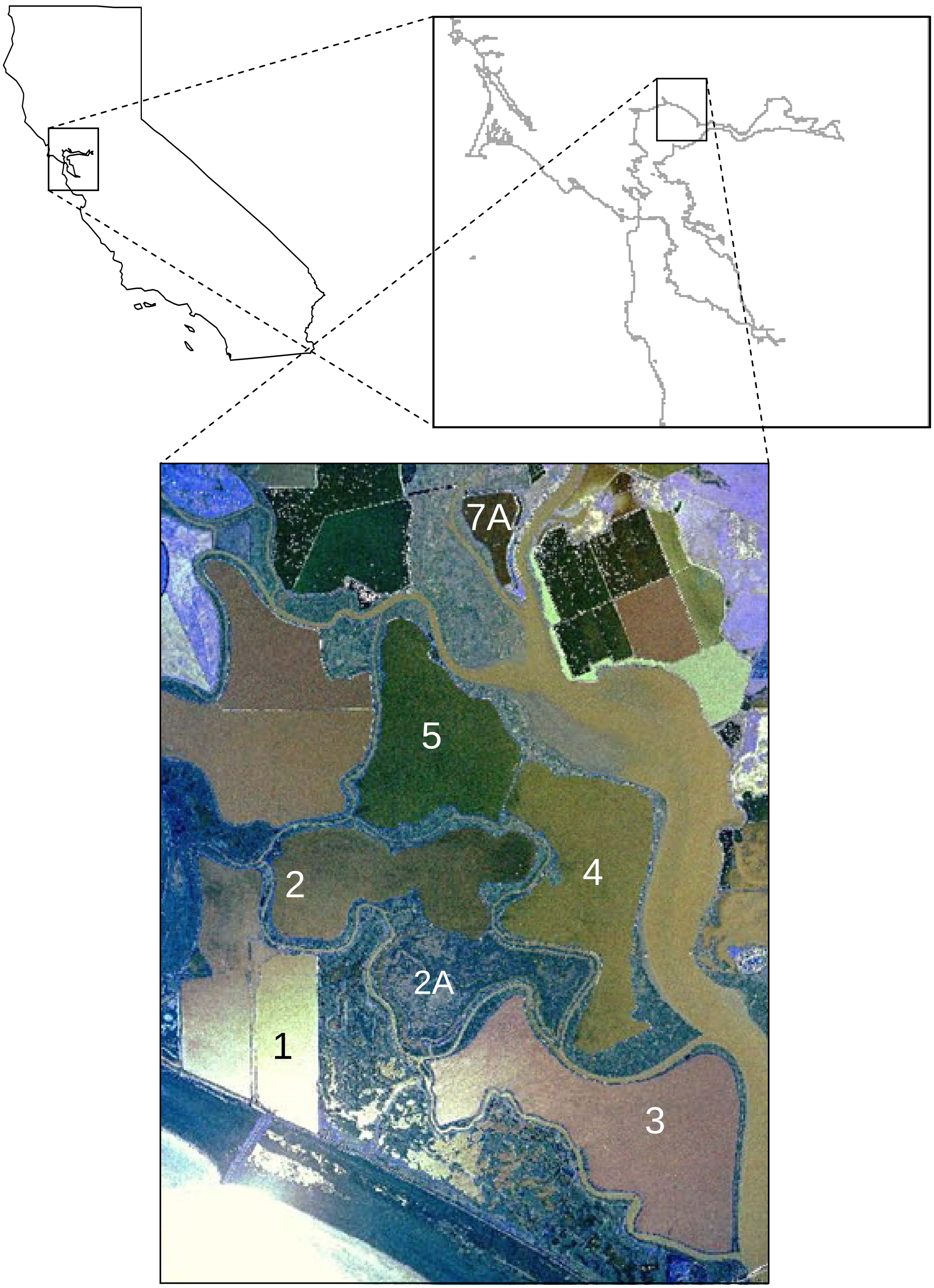

Figure 28. Proportion of total bird counts per pond for each foraging guild, Napa-Sonoma salt ponds, San Francisco Bay, CA.

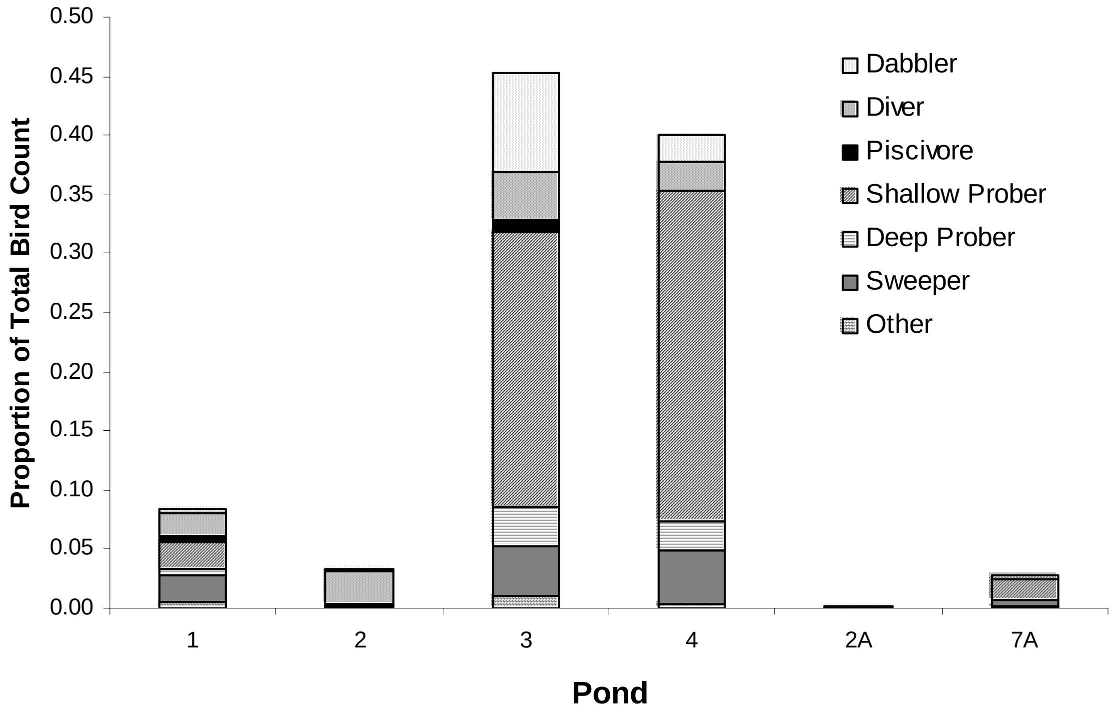

Figure 29. Pond 1 total bird count, Napa-Sonoma salt ponds, San Francisco Bay, CA. Sample dates January 2002 – December 2003.

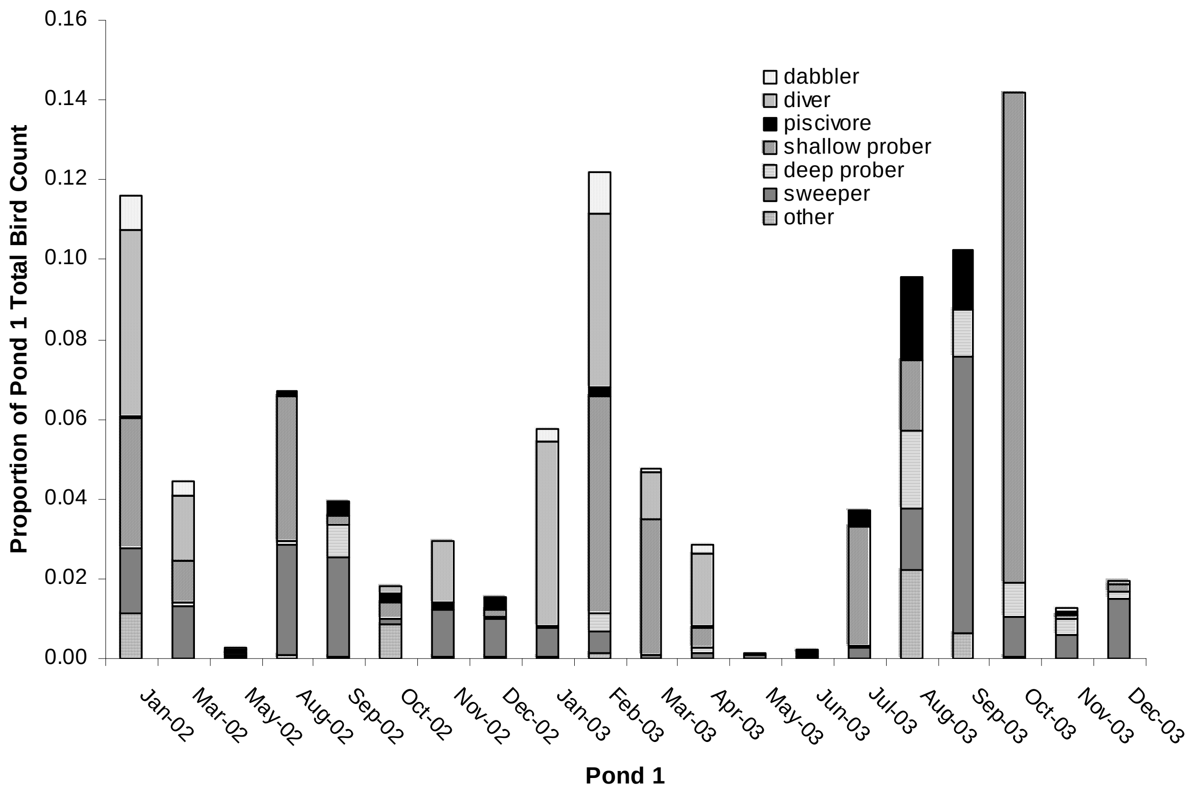

Figure 30. Pond 2 total bird count, Napa-Sonoma salt ponds, San Francisco Bay, CA. Sample dates January 2002 – December 2003.

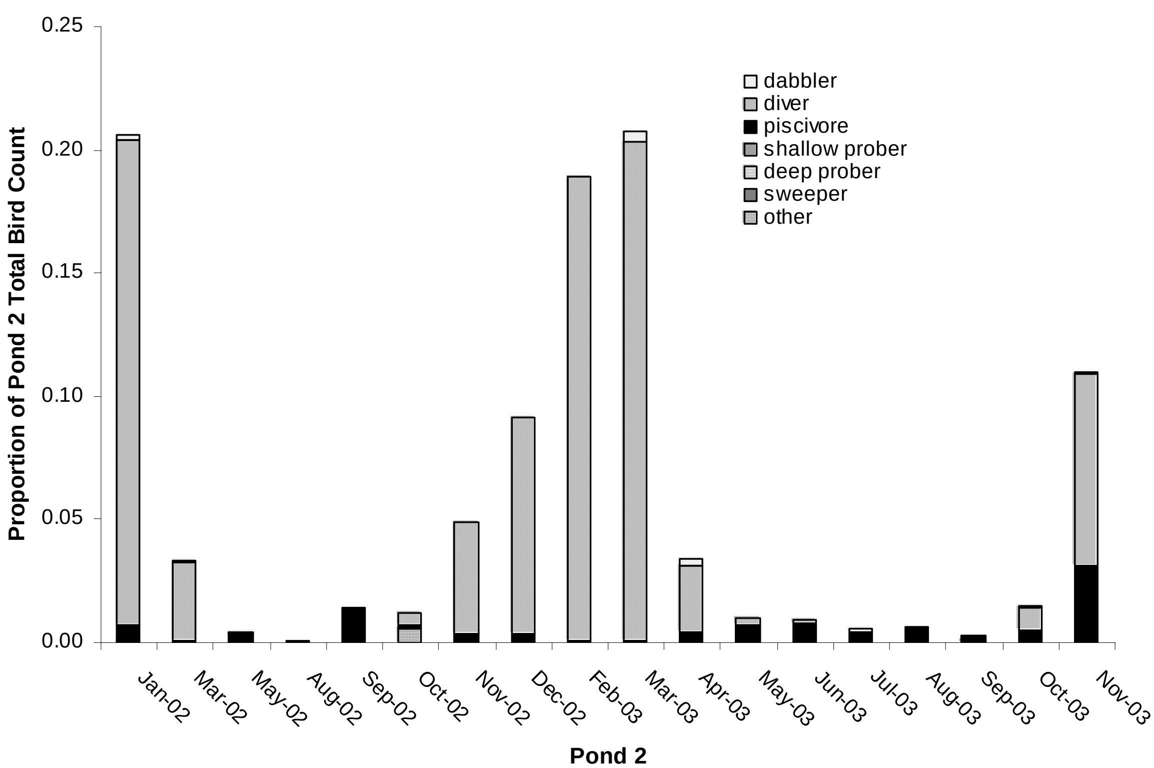

Figure 31. Pond 3 total bird count, Napa-Sonoma salt ponds, San Francisco Bay, CA. Sample dates January 2002 – December 2003.

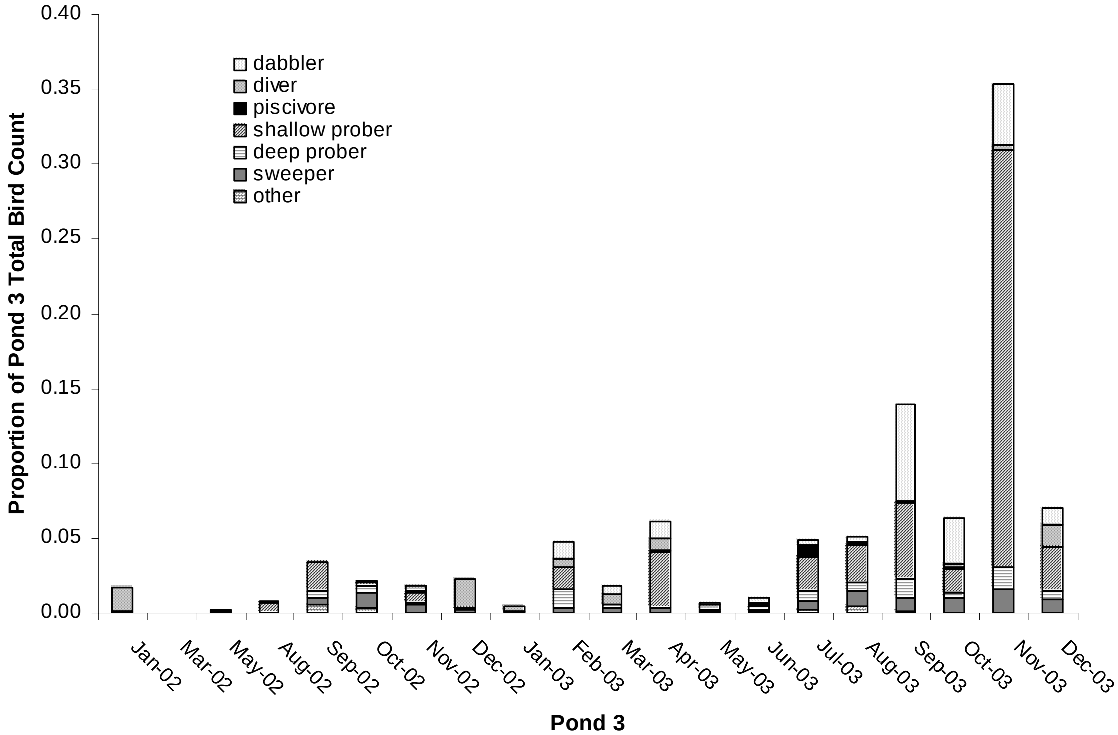

Figure 32. Pond 4 total bird count, Napa-Sonoma salt ponds, San Francisco Bay, CA. Sample dates January 2002 – December 2003.

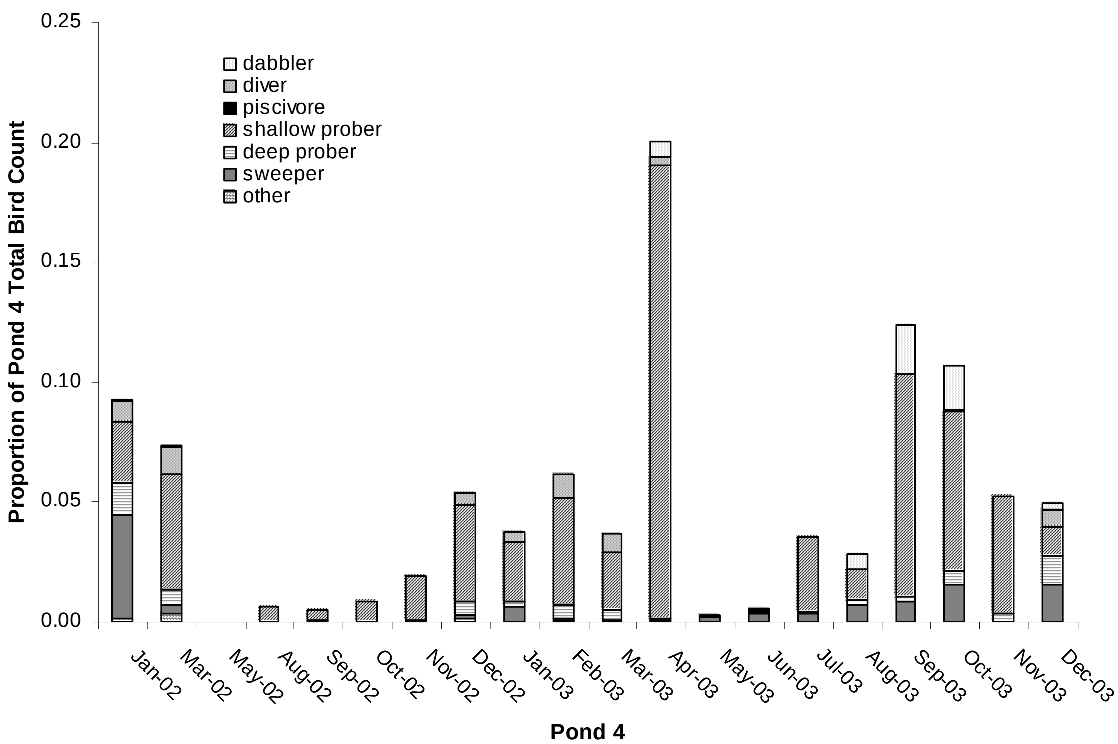

Figure 33. Pond 2A total bird count, Napa-Sonoma salt ponds, San Francisco Bay, CA. Sample dates January 2002 – December 2003.

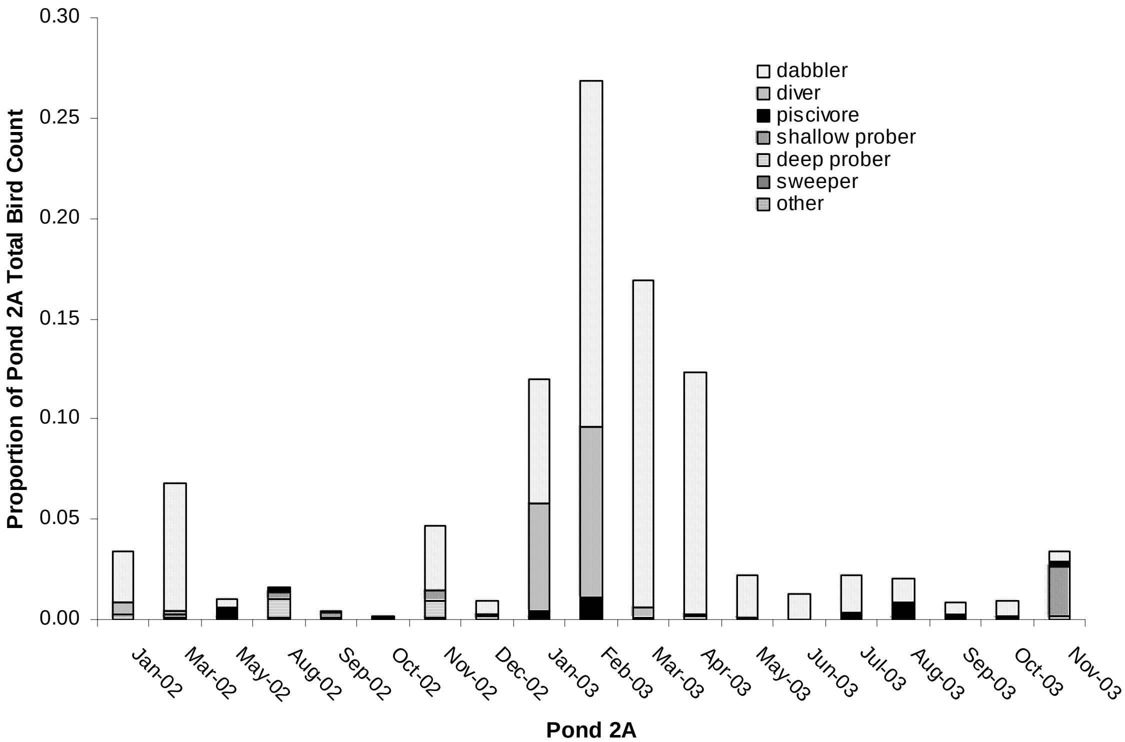

Figure 34. Pond 7A total bird count, Napa-Sonoma salt ponds, San Francisco Bay, CA. Sample dates January 2002 – December 2003.