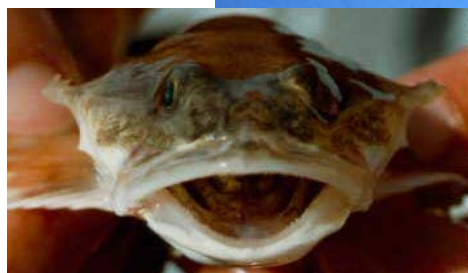


# Science Support for Wetland Restoration

## in the Napa-Sonoma Salt Ponds,

## San Francisco Bay Estuary

## 2000 Progress Report



J. Y. Takekawa, A. K. Miles, D. H. Schoellhamer,  
G. M. Martinelli, M. K. Saiki and W. G. Duffy  
U. S. Geological Survey, Western Region



**Science Support for  
Wetland Restoration in the Napa-Sonoma Salt Ponds,  
San Francisco Bay Estuary, 2000 Progress Report**

**\*\*Preliminary Results. Do Not Cite Without Permission.\*\***

**Lead Authors:**

John Y. Takekawa, U. S. Geological Survey, Western Ecological Research Center, San Francisco Bay Estuary Field Station, P. O. Box 2012, Vallejo, CA 94592, tel: 707/562-2000 fax: 707/562-3001 email: john\_takekawa@usgs.gov

A. Keith Miles, U. S. Geological Survey, Western Ecological Research Center, Davis Field Station, 1 Shields Avenue, 278 Kerr Hall, Davis, CA 95616, tel: 530/752-5365 fax: 530/752-8561, email: keith\_miles@usgs.gov

David H. Schoellhamer, U. S. Geological Survey, Water Resources, 6000 J. Street, Placer Hall, Sacramento, CA 95819 tel: 916/278-3126, email: dschoell@usgs.gov

Greg M. Martinelli, U. S. Geological Survey, Western Ecological Research Center, San Francisco Bay Estuary Field Station, P. O. Box 2012, Vallejo, CA 94592, tel: 707/562-2001 fax: 707/562-3001 email: gmartinelli@usgs.gov

Michael K. Saiki, U. S. Geological Survey, Western Fisheries Research Center, Dixon Duty Station, 6924 Tremont Road, Dixon, CA 95620, tel: 707/678-0682x617, fax: 707/678-5039, email: michael\_saiki@usgs.gov

Walter G. Duffy, U. S. Geological Survey, California Cooperative Fishery Research Unit, Humboldt State University, Arcata, CA 95521, tel: 707/826-5644; fax: 707/826-3269, email: wgd7001@axe.humboldt.edu

**Contributing Authors:**

Nils Warnock, Point Reyes Bird Observatory, 4990 Shoreline Hwy., Stinson Beach, CA, 94970, tel: 415/868/1221, fax: 415/868/1946, email: nilsw@prbo.org

Catherine Hickey, University of California, Davis, Graduate Group in Ecology, 369 Ocean Parkway #21, Bolinas, CA 94924, tel: 415/868/2470, email: cmhickey@ucdavis.edu.

Deborah Giovanis, U. S. Geological Survey, Western Ecological Research Center, Davis Field Station, 1 Shields Ave., 278 Kerr Hall, Davis, CA 95616, tel: 530/752-5365 fax: 530/752-8561, email: dgiovanis@usgs.gov

Jeff Schlosser, California Cooperative Fishery Research Unit, Humboldt State University, Arcata, CA 95521, tel: 707/822-6505; fax: 707/826-3269, email: jps14@axe.humboldt.edu.

**Suggested Citation: Takekawa, J.T., A.K. Miles, D. H. Schoellhamer, G.M. Martinelli, M.K. Saiki, and W.G. Duffy. 2000. Science Support for Wetland Restoration in the Napa-Sonoma Salt Ponds, San Francisco Bay Estuary, 2000 Progress Report. Unpubl. Prog. Rep., U. S. Geological Survey, Davis and Vallejo, CA. 66pp.**

## Science Support for Wetland Restoration in the Napa-Sonoma Salt Ponds, San Francisco Bay Estuary, 2000 Progress Report

***\*\*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. They support large numbers of waterbirds and have become an integral part of the ecosystem during the past century. 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 processes within these hypersaline systems and their importance in the ecosystem.
- In 1999, we initiated an interdisciplinary research study in the northern estuary 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. This report provides preliminary information from the 2000 field season, the second year of the study to determine nutrient concentrations, algal community primary productivity, the structure of pelagic and benthic invertebrate communities, abundance and composition of aquatic macrophytes, abundance, life stages, and composition of estuarine fishes and their food habits as well as waterbird abundance and distribution, diet, and movements.
- We selected 6 ponds across a range of salinities for intensive studies. These included low (#1, 2), mid (#3, 4), and high salinity (#4, 7) ponds that varied from 7.8 – 264 ppt depending on rainfall, and a restored pond with breached levees (#2A). The ponds were divided into a 250x250 m sampling blocks along Universal Transverse Mercator grid lines in a geographic information system coverage. We used waterbird surveys to select 10 accessible grids where birds were present (random grids were used if birds were not counted) for sampling fish, invertebrates, and water quality within each pond bimonthly. Overall, we found a correlation between increasing salinity and decreasing taxa richness in all groups except waterbirds.
- Sixty-five species and counts of over 280,000 birds were recorded from Jan 1999 to Nov 2000 in the ponds. Pond 4 contained the greatest number of birds at over 129,000 individuals, whereas ponds 1, 2, 3, 2A, and 7 were substantially lower. Diving benthivores made up the majority of the birds in all the ponds, while shallow probers were second, and surface feeders, dabbling birds, deep probers, and others made up the remainder.
- Diversity and bird community distribution between the ponds seemed to be more strongly influenced by water depth than by salinity, with the exception of the hypersaline pond 7. These differences are evident when the foraging guilds are examined by pond. Ponds 1, 2, 3 and 4 supported the majority of diving benthivores, while pond 2A, a revegetated pond with shallow open water areas, supported

primarily dabbling ducks rather than diving benthivores. The most diverse ponds were Pond 1 (48 species), a muted tidal pond adjacent to San Pablo Bay, and Pond 4 (46 species). These ponds were the most varied water depths as well, with both shallow areas for shorebirds and deeper areas for waterfowl. This diversity in water depths varied spatially in Pond 1, with the southern end typically very shallow and the northern end deeper and temporally in Pond 4, which was relatively deep in the winter and much shallower or dry in the summer. Water was not flowing through the siphon system from Ponds 3 and 5 by the summer because of concentrated dense salt water in the pipes. As a result, the Pond 4 was at more than 50% dry during summer months and continued to be dry through fall and into winter 2000.

- We radio-marked and tracked 59 black-necked stilts (*Himantopus mexicanus*) at breeding areas near salt ponds, during late incubation or just following hatch in early Jun. Twenty-three of the 26 birds marked in the North Bay stayed in the subregion through the summer. However, stilts used North Bay salt ponds less than expected, and instead, they remained in areas adjacent to the ponds. This contrasted with stilts in the South Bay where most of the use by 33 radio-marked birds was in salt ponds.
- We identified 62 different macroinvertebrate taxa groups, primarily at the family and genus taxonomic levels. Polychaete worms were most diverse with 12 different genera present, mostly in low salinity Ponds 1 and 2. We also identified 6 different species of bivalves, 20 different crustacean taxa, 12 insect families, and 12 other miscellaneous taxa. The greatest number of taxa occurred in Ponds 1 and 2. Pond 3 was notably lower at 9 taxa and Ponds 4 and 7 contained 6 and 3 taxa, respectively. Polychaete and bivalve presence decrease rapidly with increasing salinity.
- Striped bass (*Morone saxatilis*) occurred in all ponds supporting fish life. The slope of the length-weight equation for striped bass is greater in Pond 1 than in Pond 2, indicating that bass of a given length weigh more in Pond 1 than in Pond 2. Available evidence suggests that striped bass are overstocked for current resources in Pond 2.
- Although occurring together in other aquatic systems, the longjaw mudsucker (*Gillichthys mirabilis*) is found only in Pond 3 and the Pacific staghorn sculpin (*Leptocottus armatus*) was only found in Pond 1.
- Hydrodynamic, salinity, and suspended-solids concentration data were continuously collected at 6 sites in tidal sloughs outside of the salt ponds from Jan 1999 to Aug 2000. These slough readings provided comparisons with pond sampling stations.
- Field work will continue through the spring of 2001. We will be adapting the study to examine research questions raised during the initial phase of the study.

## TABLE OF CONTENTS

<b>INTRODUCTION</b> .....	<b>5</b>
<b>OBJECTIVES</b> .....	<b>5</b>
<b>METHODS</b> .....	<b>6</b>
Document nutrient concentrations, algal community primary productivity, and zooplankton community taxonomic composition .....	6
Examine the structure of the pelagic and benthic invertebrate assemblages.....	7
Examine abundance and composition of aquatic macrophytes .....	7
Compare abundance, life stages, and composition of estuarine fishes, document food habits, and relate to fish-forage organisms and within-pond water quality.....	8
Fish surveys .....	8
Fish identification, gut analysis, and other measurements .....	8
Determine waterbird abundance and distribution, diet, and movements .....	8
Abundance and distribution surveys .....	8
Diet studies .....	9
Movement studies.....	9
Measure the salinity gradient in the ponds and the hydrodynamics of the tidal sloughs adjacent to the ponds.....	10
Salt pond measurements .....	10
Tidal slough measurements .....	10
<b>RESULTS AND DISCUSSION</b> .....	<b>10</b>
Nutrients and Plankton .....	10
Pelagic and Benthic Invertebrates .....	11
Aquatic Macrophytes .....	13
Estuarine Fishes .....	13
Waterbirds .....	14
Number and distribution .....	14
Diet studies .....	15
Radio telemetry .....	15
Hydrology and water quality .....	17
Salinity and hydrodynamics .....	17
Tidal slough measurements .....	17
<b>LOGISTICAL ISSUES</b> .....	<b>18</b>
<b>FUTURE RESEARCH</b> .....	<b>18</b>
<b>ACKNOWLEDGMENTS</b> .....	<b>19</b>
<b>LITERATURE CITED</b> .....	<b>19</b>
<b>TABLES AND FIGURES</b> .....	<b>23</b>

## INTRODUCTION

The San Francisco Bay estuary has experienced tremendous human population growth during the past 150 years and a subsequent loss of natural habitats and degradation of water quality. More than 91% of the tidal wetlands (also referred to as intertidal wetlands in the estuarine zone) have been lost to reclamation for farmland, salt evaporation ponds and residential or industrial property (Josselyn 1983, Nichols *et al.* 1986, Goals Project 1999). Many native species dependent on tidal wetlands are now endangered or candidate species for listing.

In recent attempts to reverse the decline of tidal wetland species, several conservation groups have supported conversion of salt ponds and other bayland areas to tidal wetlands in the estuary. 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 in the estuary will likely remain through the next century. However, artificial salt evaporation pond systems have become an integral habitat component for wildlife in the estuary during the past century (Ver Planck 1958). The salt ponds currently support large and diverse communities of migratory birds. For example, the Napa Marshes in the North Bay were designated as a "Globally Important Bird Area" by the American Bird Conservancy because a large proportion of the shorebirds and waterfowl in the entire estuary are found in the salt pond habitats of that region (Anderson 1970, Accurso 1992, G. Page, unpubl. data, Takekawa *et al.* 2001).

Only a few descriptive studies (Carpelan 1957, Anderson 1970, Lonzarich and Smith 1997) have examined ecological processes in these salt systems including their value for wildlife. Hypersaline systems such as salt ponds typically support simple macroalgal, macroinvertebrate, or fish assemblages, but the physical and biological processes affecting these assemblages may be quite complex (*e.g.* Caumette *et al.* 1994; Rodriguez-Valera *et al.* 1985, Pinkney and Pearl 1997). Ecological interactions and physical processes in these artificial salt ponds are poorly understood (*see* Lonzarich and Smith 1997), but the importance of lower trophic organisms and their use by migratory waterbirds has been identified in similar systems (Herbst and Bradley 1993, Herbst and Castenholz 1995, Elphick and Rubega 1995).

Therefore, the goal of this research project was to examine the ecological and hydrological function of the Napa-Sonoma salt ponds (Fig. 1) and their importance for waterbirds, including integrated studies on primary productivity, macroinvertebrates, plants, and fishes. Migratory bird diversity and habitat use was estimated monthly at selected salt ponds. Black-necked stilts (*Himantopus mexicanus*) and long-billed dowitchers (*Limnodromous scolopaceus*) were radio-marked as indicator species to determine precise distribution, movements, and habitat use of shorebirds common to the ponds. We compared nutrient concentrations, algal primary productivity and zooplankton community composition in salt ponds of varying salinity and determined their importance as year-around habitats for forage fishes and as nurseries for larval or juvenile life stages, including fishes of recreational and commercial importance. This progress report presents the preliminary research results from the first two years of the fieldwork.

## OBJECTIVES

*Objective 1. Document nutrient concentrations, algal community primary productivity, and zooplankton community taxonomic composition*

- Objective 2. Examine the structure of the pelagic and benthic invertebrate assemblages*
- Objective 3. Examine abundance and composition of aquatic macrophytes*
- Objective 4. Compare abundance, life stages, and composition of estuarine fishes, document food habits, and relate to fish-forage organisms and within-pond water quality*
- Objective 5. Determine waterbird abundance and distribution, diet, and movements*
- Objective 6. Measure the salinity gradient in the ponds and the hydrodynamics of the tidal sloughs adjacent to the ponds*

## **METHODS**

Ponds were divided into a 250-m<sup>2</sup> Universal Transverse Mercator (UTM) grid (6.25 ha cells), and all integrated samples were located within this grid. Sampling grids were selected following a top-down trophic-level-process (Matveev 1995, Posey *et al.* 1995) by identifying major bird use areas, because the intent of the project was to understand relationships among trophic levels where we observed bird use. Results from monthly waterbird surveys were used to select 10 grids to sample within each pond bimonthly (or random selection was used when birds were not counted in all 10 cells) beginning in Mar 1999.

- Objective 1. Document nutrient concentrations, algal community primary productivity, and zooplankton community taxonomic composition*

Zooplankton, nutrient concentrations and algal community primary productivity were sampled bimonthly. Water samples (1.0 L) were collected for both chlorophyll *a* and nutrient analysis. Chlorophyll *a* samples were collected from the surface in darkened plastic bottles, avoiding light exposure, placed in a cooler and filtered within 6 hours. Nutrient samples were collected from the sediment-water interface and placed in the cooler. Sample water was returned to the laboratory for later analysis.

Zooplankton samples were collected from each site using a Miller high-speed plankton tow, adapted with a flow meter. A 5-10 meter tow was conducted at a depth of approximately 0.2 meters. Samples were then preserved in 70% ethanol, and returned to the laboratory for later analysis.

All chlorophyll *a* and nutrient sample concentrations were determined spectrophotometrically. Chlorophyll *a* samples were filtered through a 0.45 µm filter. Pigments were then extracted with 90% acetylene acetone. Soluble reactive phosphorus was filtered through a 0.45 µm filter then concentration determined using an ammonium molybdate procedure. Total phosphorus was analyzed using the persulfate digestion method (Wetzel and Likens 1991; Lind 1985). Nitrogen analysis for nitrate and ammonia was determined spectrophotometrically. All nutrient analyses were determined with standard methods (Clesceri *et al.* 1989).

Zooplankton samples were transferred to 20 ml vials upon returning to the laboratory. Samples were identified to species and enumerated using a dissecting microscope in accordance with the Stenson-Hensel pipette method (Clesceri *et al.* 1989). Biomass was measured volumetrically (Wetzel and Likens 1991).

*Objective 2. Examine the structure of the pelagic and benthic invertebrate assemblages*

The objective of this portion of the research was to characterize the taxa composition, distribution and abundance of benthic macroinvertebrate (>1.0 mm) assemblages and determine their relationship to salinity, pH, dissolved oxygen, water depth, turbidity, and biological influences. Macroinvertebrate studies are being conducted on Ponds 1, 2, 3, 4, 2a, and 7. Ponds 1-4 are sampled 6 times per year and 2a and 7 are sampled 2 times per year.

Sample Collection- Samples were collected from 10 randomly selected grids on each pond where birds were present during the monthly bird surveys. Within each grid, we collected 3 cores from randomly selected areas. Benthic macroinvertebrates were sampled using a standard Ekman grab sampler (15.2 cm x 15.2 cm x 15.2 cm). Samples were collected by slowly lowering the dredge into the water, 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 portion of the dredge was filled. Grab samples were washed in the field using a 1mm mesh screen and preserved in 70% ethyl alcohol and rose bengal dye. In addition, sweep samples were gathered from Pond 4 and Pond 7 during Spring 2000 to obtain data on the brine shrimp, *Artemia franciscana*. Sweep samples were collected using a D-ring dip net in the water column and sweeping for 10 meters.

Sample Sorting/Biomass Measurements- Samples were sorted and invertebrates identified and enumerated with the assistance of lab technicians in the invertebrate laboratory at the Davis Field Station. Wet weight and dry weight biomass of organisms was determined using an Ohaus, Model 3130 scale.

Quality Assurance/Quality Control- Invertebrate identification was cross-checked in at least 20% of the samples or two samples per sorter for each pond per sample period, whichever was greatest. Samples of each taxonomic group will be sent out for external review for accuracy of identifications. Detailed procedures for the methods described are in the project SOP.

Water Quality Monitoring and Water Depth- 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 of 10 grids.

Substrate Characterization- 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.

*Objective 3. Examine abundance and composition of aquatic macrophytes*

Line-intercept samples for macrophytes were taken at each sample location in pond 2A twice a year. Transects were sampled 15 m in a random direction while recording species (4-letter codes) and intercept length for each species. Quadrat samples were conducted at 3 points (0, 5, 10 m) along the transect and documented percent cover, rooted stem count, and maximum height. Cover was defined as the percentage of surface covered by a perpendicular projection of vegetation of one species over the surface, equivalent to the area of the quadrat that would be in



shadow with a light source directly above the quadrat (Bonham 1989, Greig-Smith 1983) and summed to a total of 100%. Stem counts of dense vegetation were done in a quarter quadrats (25cm<sup>2</sup>).

*Objective 4. Compare abundance, life stages, and composition of estuarine fishes, document food habits, and relate to fish-forage organisms and within-pond water quality*

Fish surveys- Fish species assemblages were surveyed bimonthly. After experimenting with various sampling gear, we used beach seines and gill nets to assess the distribution and relative abundance of juvenile and adult fishes, with special emphasis on small species likely to occur in the study area (e.g., rainwater killifish, *Lucania parva*; topsmelt, *Atherinops affinis*; yellowfin goby, *Acanthogobius flavimanus*)(LES 1992). Fishing effort for each gear type was standardized and replicated to allow for statistical comparisons of fish catch among dates and sites. A 5.5-m bag seine with 6.4-mm mesh in the bag and 12.7-mm mesh in the wings was used along shorelines in water shallower than 1.5 m. Six sites were sampled with five hauls of a bag seine at each site by manually dragging the seine 7.6-m perpendicular or parallel to the shore. In addition, six 38.1-m-long (1.8-m deep) variable-mesh monofilament gill nets with 12.7-mm, 15.4-mm, 38.1-mm, 50.8-mm, and 63.5-mm square mesh panels were fished for a maximum of six hours, checking them every one to two hours for endangered fish species such as Sacramento splittail (*Hypomesus transpacificus*), and delta smelt (*Pogonichthys macrolepidotus*).

Fish identification, gut analysis, and other measurements- At each site, captured fish were identified to species with taxonomic keys by Miller and Lea (1972), Moyle (1976), Eschmeyer *et al.* (1983), and McGinnis (1984). Fish that were not reliably identified in the field were preserved and later identified by taxonomic specialists. The first 25 individuals of each species were measured for standard length (to the nearest mm) and weighed (damp-dry biomass to the nearest 0.1 g).

For each sampling period, twenty-five individuals representing a broad range of fish sizes from selected species were fixed in the field in 10% formalin, and then transferred after four days to 50% isopropyl alcohol for subsequent analysis of stomach contents. Stomach contents were removed by dissection from the anterior end of the esophagus to the pyloric sphincter or other standard anatomical features, and food items were identified with the help of taxonomic keys (Pennak 1953, Usinger 1971, Merrit and Cummins 1978), then weighed (damp-dry biomass to the nearest 0.0001 g).

*Objective 5. Determine waterbird abundance and distribution, diet, and movements*

Abundance and Distribution Surveys- Three elements of waterbird use of ponds were examined. First, populations were assessed monthly through complete counts of all waterbirds at each pond during the high tide when numbers were at peak. Species and flock size were mapped and entered into GIS point coverages, and initial surveys were used to locate sample locations within ponds. Primary species by foraging guild included 1) sweepers-- American avocet (*Recurvirostra americana*) and black-necked stilt; 2) probers-- western sandpipers (*Calidris mauri*), dunlin (*Calidris alpina*), least sandpipers (*Calidris minutilla*); 3) deep probers -- marbled godwits (*Limosa fedoa*), willets (*Catoptrophorus semipalmatus*), and long-billed dowitchers; 4) diving benthivores -- greater or lesser scaup (*Aythya marila* or *A. affinis*) and ruddy ducks (*Oxyura jamaicensis*); and 5) dabbling ducks – Mallards (*Anas platyrhynchos*). Black-necked

stilts and long-billed dowitchers were selected for radio telemetry studies of distribution (see below).

*Diet Studies-* Actively feeding shorebirds and waterfowl were collected for diet analyses to determine forage-use patterns in the salt ponds. Collections, which began 15 Oct 1999, were planned for a species representative of each of the five foraging guilds. Proposed species included American avocet or black-necked stilts, western sandpipers, dowitchers or marbled godwits, ruddy ducks, and northern shovelers. We planned to collect 10 samples for each of the 5 selected species during each season (wet and dry) from ponds of varying salinity (low, high) for a maximum total of 100 birds per year. Esophageal contents were dissected immediately and placed in 80% ethanol for preservation. The esophageal contents were stored for later sorting, identification to the lowest possible taxonomic level, weight, examination, and gizzard contents for diet composition were examined to determine presence and absence of all prey. Macroinvertebrates taken in the specific ponds will be used to determine local prey density and availability for preference analyses.

*Movement Studies-* Distribution, movements and home range within the pond system and adjacent wetlands for black-necked stilt and long-billed dowitchers were examined with radio telemetry.

We radio-marked 59 breeding stilts in the north and south sub-regions of the Bay from 06 June through 29 June 1999. We captured birds in 7 separate areas around the estuary (3 areas in the north and 4 in the south); capture sites were mostly in muted tidal marsh or salt ponds. We captured adult stilts using spring traps placed either over their nest or over captured chicks. We attempted to capture equal numbers of individuals in the north and south sub-regions of the Bay but operated more opportunistically when catching males versus females. We marked 26 stilts in the North Bay and 33 stilts in the South Bay. Thirty of the 59 birds were female and 29 were male. We gave all adults captured a unique color-band combination, a unique U.S. Fish and Wildlife Service band, and fitted the birds with radio transmitters with unique frequencies (Model DB-2, Holohil Systems Ltd, Woodlawn, ON). We placed the transmitters, glued to a metal band, on the upper left tibia of each bird. We then weighed and measured each bird before release at the capture site.

We attempted to locate each bird twice daily on low and high tides from Jun through mid-Sep. Individual birds were followed from time of banding until: 1) the end of their radio lifespan, 2) the bird was lost, 3) the bird was reported dead or, 4) if radios were still active, the end of the study period. Trackers primarily used null-peak telemetry systems from trucks to obtain stilt locations. Universal Transverse Mercator (UTM) coordinates of each bird were estimated by taking at least two bearings, and noting the truck location and azimuth. Also, one aerial flight was conducted for the purpose of locating birds that had not been sited for more than two weeks.

Thirty-two long-billed dowitchers were radio marked in the North Bay from November 15 to December 13, 2000. One bird was captured by mist net in Pond 1, while the other 31 were captured using a rocket net in the West End club, a muted tidal pond. A rocket net was deployed from a triangular plywood box. The box was elevated above the mudflats in known dowitcher foraging areas. We measured and weighed all individuals and fitted them with Fish and Wildlife Service leg bands and a radio transmitter.

We attempted to locate each bird twice daily on high and low tides from November to early January. Trackers primarily used null-peak telemetry systems from trucks to obtain locations, although due to the wide dispersal, aerial flights were conducted weekly to obtain distant locations. Universal Transverse Mercator (UTM) coordinates of each bird were estimated by taking at least two bearings, and noting the truck location and azimuth. Individuals were followed from the time of banding until the end of the radio lifespan.

*Objective 6. Measure the salinity gradient in the ponds and the hydrodynamics of the tidal sloughs adjacent to the ponds*

*Salt Pond Measurements-* We installed water level staff gauges in ponds to measure water height. Four to five sites in each pond were measured monthly. The sites were located in accessible corners of the ponds when possible. Sampling was conducted near the time of the bird counts. Measurements were made with a Hydrolab Minisonde® instrument capable of measuring water temperature, pH, turbidity, dissolve oxygen, and specific conductance (Buchanan, pers. com.). The instrument was calibrated before and after each field trip. For salinities greater than 70 ppt, the specific gravity of the water was measured with a hydrometer and converted to salinity. Near surface and near-bottom measurements were made at each site if water depth was greater than 60 cm. Data were entered into a spreadsheet, referenced to the 250 m grid, and sent electronically to all investigators.

*Tidal Slough Measurements-* Water velocity was measured with calibrated current meters and current profilers. Specific conductance and SSC were measured with standard techniques that have been used for years in San Francisco Bay (Buchanan 1999, Buchanan and Schoellhamer 1998). Measurements were made at six sites every 15 minutes beginning in September 2000 and continuing until March 2001.

## RESULTS AND DISCUSSION

### Nutrients and Plankton

The salt ponds had a wide variability in concentrations of nutrients through time, although some ponds are more variable than others are. Pond 1 nitrate levels showed an increase in concentration and variability through the sampling period (Table 1). Ammonia, soluble reactive phosphorous, and total phosphorous levels also followed this trend, but there was a spike in the concentration of these nutrients in September of 2000. This may have been attributable to a high wind event and increased mixing which would put nutrients into suspension. Low dissolved oxygen conditions can also change the redox conditions and force phosphorous into the water column. An early rain event could also have produced this effect but more research is needed before any definitive conclusions can be drawn. It should be noted that Pond 1 is tidally influenced, so this could also be a contributing factor to nutrient fluctuations.

Pond 2 had a little variability in nitrate levels (Table 2), with significant increases occurring in April and December. Ammonia, soluble reactive phosphorous, and total phosphorous levels, however, varied widely. Pond 2 contained a huge population of striped bass, and concentrations of ammonia could also be related to the fish releasing ammonia directly, and to decaying fish carcasses. Fluctuating levels of nutrients in Pond 2 could be influenced by phytoplankton and zooplankton community dynamics, as well as newly recruited striped bass fry interacting with the zooplankton community.

Pond 3 is the largest of the ponds. There were ephemeral populations of small fish in this pond, and the phytoplankton community was dense which gives this pond its characteristic green color throughout the year. The nitrate levels showed some trends indicative of an influx of nitrates during the winter and blooms of algae during the summer (Table 3). Pond 3 ammonia levels were fairly constant throughout the period with reduction in March of 2000 that is probably related to spring rain runoff. The increase in ammonia in September of 2000 could be related to a late summer die-off of algae and the fish populations that inhabit the pond, but this event also showed up in ponds 2 and 4.

The pond with the highest salinity of the four ponds was pond 4 (Table 4). This high salinity probably limited the biological communities, which, in turn regulated some of the nutrient fluctuation. The phosphorous levels for pond 4 were fairly constant, except for the spike that occurred in September of 1999. The nitrate levels were quite variable in Pond 4. These could be related to the algal population, which gives Pond 4 its characteristic orange color. A decrease in nitrate levels during the summer months suggested that algal blooms could be causing a reduction in nitrate levels. Evaporation of pond water and influx of water from outside sources could also be playing a role in the nutrient fluctuations for Pond 4, and this was probably true for all other ponds as well. These nutrient data evaluations are preliminary, and more concrete conclusions will be possible when rainfall records, pond water transfers, chlorophyll a concentrations, and zooplankton populations have been assessed. These nutrient data suggest that these ponds are a great deal more dynamic than previously believed.

### **Pelagic and Benthic Invertebrates**

*Status of Invertebrate Processing-* Eleven sample collections were completed: April, May, July, August, September, and November 1999, and January, March, May, September, and November 2000. Preliminary results from the first eight collection periods on the ponds are reported here, including two collections on Pond 2A and Pond 7.

*Invertebrate Composition-* We identified 62 different taxonomic groups of macroinvertebrates, most at the family and genus levels (Table 5). This includes polychaete worms (12 different genus' present) mostly in Ponds 1 and 2. There were also 6 different species of bivalves, 20 different crustacean taxa, 12 insect families, and 12 other taxa. The highest taxa richness occurred in Ponds 1 and 2 (28 taxa, see Fig.2). Pond 3 had notably fewer taxa (9) and Ponds 4 and 7 contained 6 and 3 taxa, respectively. There is a relationship between increasing salinity and decreasing taxa richness. Polychaete and bivalve presence decrease rapidly with increasing salinity. Preliminary data analyses were conducted using TWINSpan and DECORANA from the PC-Ord software program. Results suggested that the communities on each pond are distinct. Ponds 1 and 2 had many taxa in common, although their abundance differed. Additionally, Pond 2 contained several unique taxa (see description below). Pond 3 was dominated by tube-building *Polydora*. Ponds 4 and 7 contained only organisms tolerant of high salinity conditions (i.e., *Artemia*, *Ephydra*, and *Hydrophilidae*).

*Pond 1-* Pond 1 was dominated by polychaete worms, particularly *Heteromastus*, (Table 5). *Capitella*, *Pseudopolydora* and *Streblospio* were also prevalent. The bivalve *Gemma gemma* was especially abundant during September and November 1999. Of the 11 crustaceans found, *Corophium*, *Erichthonius*, and *Cumacea* were abundant.

The substrate of Pond 1 was consistently soft, fine-grained and mucky with abundant shell fragments. Due to the muted tidal exchange, there was moderate water level fluctuation in this pond. There was also a water depth gradient from north to south, with the southern end being most shallow.

Pond 2- Taxa richness of Pond 2 was similar to Pond 1, although there were differences in species presence and abundance (Table 5). Polychaetes were abundant and dominated by *Heteromastus*, *Polydora*, and *Capitella*. *Streblospio* and *Eteone* were also common. *Macoma balthica* was the predominant bivalve and *Gemma gemma* and *Mya arenaria* were common. *Cumacea* was abundant during April and May 1999. Taxa unique to Pond 2 were *Cirripidea*, *Lineidae*, *Bryozoa*, *Diadumene*, and *Ostreidae*. Pond 2 invertebrate abundance peaked during May 1999 and November 1999.

The substrate of Pond 2 varies significantly. Some areas are very fine soft muck, whereas others are medium to very hard and contain much shell or organic material. A minor tidal water level fluctuation also occurred on this pond.

Pond 3- Pond 3 contained significantly fewer taxa than Ponds 1 and 2 (Table 5). Of the 10 taxa found, only 3 were present in significant numbers. Those were *Polydora*, *Capitella*, and *Corophium*. *Polydora* was by far most abundant. Although there appeared to be a greater number of *Polydora* during spring, this may or may not have been the case. The substrate of Pond 3 is extremely variable and patchy. *Polydora* seemed to be most abundant on medium to hard substrates in certain areas of the pond. Since we did not sample from the same grids across sampling periods it is not certain whether abundance differences reflect different sampling areas or actual seasonal changes.

As previously stated, the substrate on Pond 3 was extremely variable. In some areas it was extremely fine, black muck, whereas other areas were medium to very hard. In certain areas the substrate contained a thin brittle and crusty layer. *Polydora* seemed to be most abundant in this type of substrate. It is not clear whether the *Polydora* were creating this layer or simply prefer it. When examined up close, there were *Polydora* tubes within the crust. Water levels in this pond dropped significantly during late summer 1999.

Pond 4- Pond 4 contained 3 abundant taxa during the sampling periods (Table 5). They were *Artemia*, *Ephydra*, and *Hydrophilidae*. *Artemia* were very abundant until late summer, when the water levels were extremely low and anoxic conditions prevailed. *Ephydra* increased in abundance during the late summer.

The substrate on Pond 4 was generally medium to hard, and sometimes contains a brittle crusty layer and/or salt crystals. Water levels were extremely low during fall of both years.

Pond 7- Pond 7 (a hypersaline pond) was sampled during May and November of each year. Pond 7 contained low numbers of *Artemia* and *Hydrophilidae* in May 1999 and May 2000 (Table 5). No organisms were present during November 1999 and November 2000.

The substrate on Pond 7 was generally hard. During fall the water levels dropped dramatically and only salt crystals were present on the surface.

Pond 2A- Pond 2A was a former salt pond that is now an emergent brackish marsh. We sampled from tidal channels and shallow ponds during August 1999 and February 2000. Taxa richness was high, with 30 different taxa present during both periods (Table 5). Eight of those taxa were unique to this pond. The most abundant taxa were an Oligochaete worm, *Capitella*, *Sabellidae*, *Assimineia californica*, and *Ericthonius*. We noted that insect diversity in this pond was four times higher in comparison to the other five ponds. Dipterans were especially diverse. This can probably be attributed to the presence of emergent vegetation.

The substrate in Pond 2A was generally very soft in both shallow ponds and tidal channels.

Pond 1 Epibenthic Trials- During December 1999, we tested 2 methods for obtaining information about epibenthic invertebrates in Pond 1. Drop nets were baited with chicken liver, chicken gizzards and necks, and bait fish. On two different days, nets were dispersed in the pond and left for 3-4 hours periods. We anticipated catching crab, shrimp, isopods or amphipods. However, we did not catch any organisms and did not observe any signs that the bait had been eaten. Since this method failed to provide information, we conducted three 50 meter seines along the shoreline (2 on the east side and 1 on the west side). We were successful in capturing organisms with this method. A variety of amphipods, isopods, shrimp and other miscellaneous taxa were found. Although we were able to obtain information this way, we did not continue this type of sampling because seining is only practical immediately adjacent to the shore, which is not representative of the pond in general.

### **Aquatic Macrophytes**

We examined the distribution of plants along line transects and in quadrats in Pond 2a during Mar-Apr and Sept-Oct 1999 and June 2000. Species composing < 1% of the samples were recorded as “present” in the transect or quadrat. We found only a few major wetland species on the transects. Litter and duff represented a significant percentage of all the quadrats and transects in both sampling periods. *Scirpus maritimus* has established itself as the dominant species in the June 2000 survey. *Scirpus maritimus* was counted in all transects except one, where another form of *Scirpus* dominated, *Scirpus californicus*. Other notable species include *Salicornia virginica* and *Typha latifolia*. *Spartina foliosa* was considered a dominant species in the previous sampling periods, but was not observed during the June 2000 survey.

### **Estuarine Fishes**

During July 1999-September 2000, a total of 3,976 fish representing 16 species was captured from Ponds 1, 2, and 3 (Table 6). Gillnetting yielded 685 fish (17.2%), whereas bag seining yielded 3,291 fish (82.8%). Judging from gill net catches, fish abundance was high in both Pond 1 (323 fish) and Pond 2 (343 fish), with far fewer fish captured in Pond 3 (19 fish). No fish were captured in Pond 4. By comparison, bag seine catches indicated that fish abundance was highest in Pond 1 (2,559 fish), followed by Pond 3 (617 fish), and then by Pond 2 (115 fish).

Gillnetting and bag seining sampled different segments of the fish species assemblage in each pond. In Pond 1, gill nets captured mostly American shad (*Alosa sapidissima*, 38.4%), striped bass (*Morone saxatilis*, 41.2%), and striped mullet (*Mugil cephalus*, 9.0%), whereas bag seines captured mostly Pacific staghorn sculpin (*Leptocottus armatus*, 51.8%) and yellowfin goby (*Acanthogobius flavimanus*, 41.2%). In Pond 2, gill net catches consisted almost exclusively of striped bass (95.0%), while bag seine catches consisted mostly of inland silverside (*Menidia*

*beryllina*, 49.6%) and striped bass (39.1%). In Pond 3, gill nets captured striped bass (47.4%), longjaw mudsucker (*Gillichthys mirabilis*, 36.8%), and yellowfin goby (15.8%), and bag seines captured mostly longjaw mudsucker (56.2%), *Tridentiger* goby (*Tridentiger trigonocephalus*, 26.1%), and inland silverside (11.2%). Gut analysis of representative fish species from Ponds 1-3 were still in progress.

Except for temperature, which averaged 15.5-20.1 °C, water quality conditions varied significantly among the four ponds (Table 7). Mean concentrations of dissolved oxygen were similar in Ponds 1, 2, and 3 (6.9-8.0 mg/L) but considerably lower in Pond 4 (1.6 mg/L). On average, pH values differed significantly between Pond 2 (8.6) and Pond 4 (7.5). However, mean pH values in Ponds 1 and 3 (7.9-8.3) did not differ significantly from values measured in the other two ponds. Mean salinity concentrations varied among ponds, with similar concentrations occurring in Pond 1 (23.7 parts per thousand; ppt) and Pond 2 (24.9 ppt), but progressively higher concentrations occurring in Pond 3 (43.8 ppt), and Pond 4 (>70 ppt). Finally, mean turbidity levels were similar among Ponds 2-4 (36.4-60.6 NTU) and significantly higher in Pond 1 (139.9 NTU).

## Waterbirds

Numbers and Distribution- Sixty-five species and estimates of over 280,000 birds were recorded from January 1999 to November 2000 in the ponds (Table 8). Pond 4 contained the greatest number of birds at over 129,000 individuals, whereas ponds 1, 2, 3, 2A, and 7 were substantially lower (Table 9, Fig. 3). Diving benthivores comprised the majority of birds in all ponds, (over 121,000 birds), while shallow probers were second in abundance (85,000). Surface feeders, dabblers, piscivores, deep probers and other species made up the remainder.

Diversity and bird community distribution between the ponds seem to be influenced more by water depth than by salinity, with the exception of pond 7. This was evident when the foraging guilds are examined by pond (Figs. 4a-4f). Ponds 1, 2, 3, and 4 supported the majority of diving benthivores, while Pond 2A, a revegetated pond with shallow open water areas, supported primarily dabbling ducks. The most diverse and abundant ponds were Pond 1 (48 species and 23% of the total birds), a muted tidal pond adjacent to San Pablo Bay, and Pond 4 (46 species and 46% of the total birds), a highly saline mid system pond. These ponds contained varying water depths, with both shallow areas for shorebirds and deeper areas for waterfowl. This diversity in water depths varied spatially in Pond 1, with the southern end typically very shallow and the northern end deeper and temporally in Pond 4, which was relatively deep in the winter and much shallower or dry in the summer. Water was not flowing through the siphon system (from Ponds 3 and 5) by the summer because of concentrated dense salt water in the pipes. As a result, Pond 4 was more than 50% dry during summer months. Because the problem has not been corrected, water level has remained low through Fall 2000 and into winter. This has caused a decline in diving benthivores numbers and an increase in the number of shorebirds, particularly shallow probers.

We observed variation in distribution of the five foraging guilds within and among ponds (Figures 5a-5e). Ponds 2 and 3 are more homogenous in depth than the other ponds and support diving birds almost exclusively. By comparing the two ponds, the importance of varying water depths is evident. Pond 2, which contains no islands or shallow water areas, supports almost exclusively diving ducks, over 95% of the birds counted in the pond. Pond 3 has a few islands and the diver total declines to 70% of the birds counted in the pond. Pond 7 was super-saturated

with salts and had very few birds present year-round, regardless of depth. Those birds present at Pond 7 were seen on the levees or on the snags in the pond and never in the water. Within pond differences in diversity and community distribution were also influenced by water depth, and in the case of Pond 2A, the presence of vegetation. For example, during the summer, shorebirds from all three foraging guilds were about evenly distributed in Pond 4 due to the dry or extremely shallow depth of the water. In Pond 3, typically a deeper pond, shorebirds were present only on islands and on the shore, and in Pond 1; shorebirds were abundant primarily in the southern end, which is shallower.

Dabblers and diving benthivores (Figures 5d, 5e) were present in all ponds, with the exception of Pond 7. The two guilds were spatially separated within most ponds, although there was some overlap. Diving benthivores were more common on the deep northern end of Pond 1 while dabbling ducks used the shallower southern end. Pond 4 had more overlap of these two guilds, in part explained by the water fluctuation in this pond throughout the year. The water depth was more variable and there may have been times when the water level was acceptable for both guilds.

Dabblers and shorebirds tended to congregate in the open, ponded areas of Pond 2A. Only 210 or less than 3% of the over 8,000 birds counted were diving benthivores, less than 3%, whereas 5223 (64%) were dabblers. The vegetation in Pond 2A has become more dense with emergent vegetation over time, which created less open water areas. Since the May 2000 survey, we counted over 100 waterbirds in pond 2A only once. This could be in part by the increase in vegetation height and density restricting the view of the entire pond, but more likely due to shrinking open water habitat. The dense vegetation was beneficial to a few species, such as Virginia and sora rails that were consistently heard calling during the surveys.

Diet Studies- We initiated diet collections in the fall of 1999. Birds were not distributed evenly across the ponds, thus sampling was initiated on species found in at least two salinity levels, such as American avocets and western sandpipers at low and high salinity ponds and ruddy ducks at low and mid salinities. Preliminary results showed that American avocets, ruddy ducks and Northern shovelers are opportunists, consuming the most prevalent prey available. Western sandpipers, on the other hand, seem to be very selective foragers. Of the ponds sampled, Pond 1 has the highest diversity, but esophageal samples of Western sandpipers consisted entirely of nematodes. In Pond 4, Western sandpipers were feeding primarily on *Muscidae*, a flying insect that was not found in any of the other species collected. Analysis of *Muscidae* abundance will be difficult because they were not represented in the benthic samples.

Radio Telemetry- We obtained nearly 2,000 total locations for the 59 radio-marked stilts, a mean of 34 locations/bird with 965 locations for birds banded in the North Bay (Fig. 6) and 978 locations for birds in the South Bay. Twenty-nine of the 59 birds had at least 30 locations (mean = 48.9, SE = 3.8), adequate sample sizes for fixed-kernel home range estimates.

Home Ranges- mean home range size based on 95% Utilization Distribution (UD), was 283.5 ha (n = 29, 95% CI = 196.0-667.3 ha) and 44.8 ha (n = 29, 95% CI = 36.1-117.9) for the 50% UD core area. We were unable to detect a home range difference between males and females (P = 0.351,  $F_{27} = 0.90$ ). We also found no difference between birds banded in the North Bay and birds in the South Bay (P = 0.818,  $F_{27} = 0.05$ ). Home range did vary by banding location (P = 0.021,  $F_{18} = 4.80$ ). Stilts banded at Ravenswood Marsh (mean = 2,079.9 ha, n = 4, 95% CI = 584.8 – 7,892.8 ha) had larger home ranges than stilts banded in New Chicago Marsh (mean =



112.0 ha,  $n = 8$ , 95% CI = 38.2 – 557.0 ha); both sites are in the South Bay. Home range size for birds in these two South Bay sites were not different from those for birds banded at American Canyon Landfill in the North Bay (mean = 233.0 ha,  $n = 9$ , 95% CI = 89.8 – 836.2 ha).

*Centers of activity*- Most of the stilts, 86%, had more than one center of activity, with a mean of 2.6 (SE = 0.20, range = 1 – 5). All four birds with only one center of activity were banded in the North Bay and centered their activity at American Canyon Landfill; three of those birds were banded at that site. Overall, there was no difference between the number of nuclei for male and female stilts ( $\chi^2 = 1.538$ ,  $df = 1$ ,  $P = 0.215$ ), nor for birds banded in the North and South bays ( $\chi^2 = 0.802$ ,  $df = 1$ ,  $P = 0.44$ ). Stilts with multiple centers of activity had larger overall space requirements.

*Post-breeding dispersal*- Mean maximum distance traveled from capture location was 5.2 km ( $n = 35$ , 95% CI = 4.2 – 6.4 km). The three stilts that moved from the North to South bays traveled 66.0 – 72.0 km to their post-breeding locations. We found that maximum distance traveled from capture location did not differ for males ( $n = 21$ , mean = 4.8 km, 95% CI = 3.6 – 6.4 km) and females ( $n = 14$ , mean = 5.9 km, 95% CI = 4.3 – 8.1 km;  $P = 0.305$ ,  $F_{33} = 1.08$ ) or for birds banded in the North Bay ( $n = 10$ , mean = 6.0 km, 95% CI = 4.1 – 8.9 km) versus the South Bay ( $n = 25$ , mean = 4.9 km, 95% CI = 3.8 – 6.4 km;  $F_{33} = 0.79$ ,  $P = 0.382$ ). This measure did vary by banding location ( $P = 0.037$ ,  $F_{18} = 3.99$ ), with Newark Slough birds (mean = 8.1 km,  $n = 5$ , 95% CI = 4.0 – 16.6 km) dispersing further than New Chicago Marsh birds (mean = 3.6 km,  $n = 11$ , 95% CI = 2.4 – 5.3 km), but both not differing from birds banded at American Canyon Landfill (mean = 5.9 km,  $n = 5$ , 95% CI = 3.3 – 10.6 km;  $df = 18$ , Critical Value = 2.64).

*Daily distance traveled*- We found a significant interaction between region in which a stilt was banded and month of observation ( $\chi^2 = 9.65$ ,  $df = 3$ ,  $P = 0.022$ ). Daily distance traveled was similar for birds banded in the North and South bays in all months except for in July when stilts in the North Bay moved greater distances on a daily basis. Daily distance traveled did not differ by sex.

*Variation in movement patterns*- Twenty-three of the 26 stilts banded in the North Bay stayed in that region for the entire study period. Habitat use differed between stilts banded in the freshwater marsh and those in the muted tidal marsh; the majority of stilts banded in the freshwater marsh remained there, but all that bred in muted tidal marsh in the North Bay moved to salt ponds, muted tidal marshes, and freshwater marshes. In contrast, most of the 33 birds marked in the South Bay were found primarily within the salt ponds. Three of the North Bay stilts moved to the South Bay within several weeks after marking. All birds banded in the South Bay stayed in that region. Stilts from three of four breeding areas heavily used the salt ponds on the Don Edwards San Francisco Bay Refuge tract. Four stilts banded in salt marsh on the west shore left that area after three weeks; three of the four crossed to the east side. All birds captured in a muted tidal marsh at the south end moved to nearby salt ponds where they remained until the study ended.

We obtained 419 locations for long-billed dowitchers, 404 (96.4%) were in the Northern San Pablo Bay Region (Fig. 7) with a mean of 13 locations per bird. The remaining locations were in Suisun Bay and the Central Valley (Fig. 8), ranging from Los Banos State Wildlife Refuge north to Colusa National Wildlife Refuge. No more than three locations were obtained on any of the eight birds after they moved into the Central Valley, due to the expense and logistics of obtaining locations by plane.

## Hydrology and Water Quality

Salinity and hydrodynamics- Salinity was primarily influenced by rainfall during the wet season and interpond water transfers during the dry season. Similar to 1999, Pond 4 had very low water level and very high (>260) salinity during the late dry season because CDFG could not transfer fresher water into the pond. Variability within ponds was generally small, with the exception of recent freshwater inflow and some wind conditions. Figures 9a-9j present plots of water temperature, turbidity, pH, salinity, and dissolved oxygen in the ponds. Figures 9k and 9l show the relationships between pH and salinity and dissolved oxygen and salinity.

Tidal slough measurements- Salinity and water temperature data collected at Mare Island Causeway were published in the Newsletter of the Interagency Ecological Program (Buchanan 2000).

In December 2000, John Warner (2000) completed his dissertation on the hydrodynamics, salinity, and sediment transport of the sloughs and lower Napa River. Measured data of velocity, water level, conductivity, temperature, and suspended-sediment concentration were collected at 17 sites from September 1997 to March 1998. Data analysis showed that the hydrodynamics of the system was controlled by the development of two types of convergence zones, one driven by barotropic pressure gradients and one created from converging baroclinic pressure gradients.

The slough network was characterized as three separate systems - west, middle, and east. A sill at the entrance to the western system tidally truncated the water levels, preventing a complete tidal range. The eastern system entrance was un-truncated, but asymmetries developed due to friction and off-channel wetland storage. In the middle, the east and west asymmetric tidal signals converged to produce a non-tidal signal, termed a barotropic convergence zone, controlling the exchange of water and sediment. Tidally averaged higher water surface elevations on the truncated western side during spring tides created tidally-averaged fluxes of water and sediment through the convergence zone to the east. Neap tides allowed fluxes in the opposite direction.

The baroclinic convergence zone was created due to the phase difference between the currents in two of the tidal channels - Mare Island and Carquinez Straits. The currents in Mare Island Strait turned to flood before those in Carquinez Strait. Therefore, the Mare Island Strait flood first received a decreasing salinity from the Carquinez Strait ebb, and then an increasing salinity from the Carquinez Strait flood, creating a local salinity minimum in Mare Island Strait. On a tidally-averaged time scale, converging baroclinic pressure gradients focus on the local salinity minimum, driving a converging near-bed and diverging surface current pattern. This baroclinic convergence zone was shown to have a greater convergence rate than traditional gravitational circulation, and probably accounts for the historical exceptional rates of sediment accumulation in Mare Island Strait.

John wrote drafts for 3 journal articles and an AGU abstract (Warner *et al.* 2000) on his results and he has presented his results to the 10<sup>th</sup> International Biennial Conference on Physics of Estuaries and Coastal Seas, UC Davis, Stanford University, California Department of Water Resources, and Phillip Williams and Associates. Several consultants involved with mitigation

for San Francisco Airport runway expansion and other restoration projects have asked for the data presented in Warner *et al.* (1999).

In autumn 2000, UC Davis and CALTRANS funded a set of hydrodynamic and sediment transport measurements in the sloughs to study herbicide runoff to surface waters and to supply data for the San Pablo Bay CISNet study. The deployment will be 6 months in duration. Deployment sites are the Petaluma River, Sonoma Creek, Mouth of Sonoma Creek, Napa River channel marker 5, Mare Island Causeway, and Napa River channel marker 14. Instruments will measure water velocity, water depth, salinity, water temperature, and suspended-sediment concentration. Protocols used by previous joint UCD/USGS deployments in the study area will be used (Warner *et al.* 1999).

## LOGISTICAL ISSUES

A major impediment to our sampling was access to all grids in the given pond during the dry season. Particularly in Jul-Aug and Sep-Oct, water levels in Ponds 3, 4, and 7 was very low, making it extremely difficult to navigate with a boat. The muddy substrate was difficult to traverse on foot. However, for the Sep-Oct sampling period, we used a long shaft motor (Go-devil®) that improved our mobility substantially, but sampling was still challenging in sections of the ponds. In addition, we constructed mud shoes to access soft substrate areas following an earlier shoe design (Mud Lucks®).

The lack of bathymetry data for the ponds also was a major concern. Since depth may be the major factor influencing the distribution of shorebirds, it was difficult to predict their distribution without bathymetry data. The Army Corp of Engineers has been conducting a feasibility study of the Napa-Sonoma Salt Ponds that will include some rough bathymetry maps. Thus, we hope that these data will help to interpret our distribution data for shorebirds, but more detailed bathymetry information is still needed.

The depth changes and the desiccation of Pond 4 impacted the availability of habitat and resources to migrating waterbirds this year in the Napa-Sonoma Salt Ponds. California Department of Fish and Game maintenance difficulties, such as the build-up of salt crystals in the pipes between Ponds 3 and 4, increased the problem. In systems of ponds that are no longer producing salt, water control may be the most difficult management challenge for maximizing their resource values.

## FUTURE RESEARCH

Our initial intensive survey work will be completed in May 2001. Long-term surveys will be continued in the North Bay on a seasonal basis (2-3 times/year) including the winter, migration (spring or fall), and summer periods to examine interannual variation. In the South Bay where large-scale management changes are imminent, preliminary work will be started on salt ponds working in close cooperation with the Pt. Reyes and San Francisco Bay Bird Observatories. We also will initiate directed studies that focus on habitat elements and food webs in the ponds and their comparative value for natural resources. Aspects of the continuing research will include:

1. Long-term seasonal surveys in the North Bay to examine interannual variation.
2. Preliminary surveys on selected South Bay salt ponds across a range of salinities.

3. Food webs and carrying capacity in the ponds including fish and bird consumption of invertebrates, avian predation on fish, and invertebrate biomass and patch depletion rates.
4. Effects of water depth and salinity on the foraging ecology of waterbirds.
5. Key elements of habitat morphology and their use by avian and fish species.
6. Contaminants present in pond substrates and in birds and fish using the ponds.
7. Ecology of *Artemia* and *Ephydra* as prey of birds in hypersaline ponds.
8. Biophysical interactions between ponds and surrounding sloughs and effects of breaches.
9. Composition of existing salt pond communities compared with surrounding seasonal wetlands, tidal salt marshes, mudflats, and shallow bays.
10. Abundance and effects of parasites on birds and fish.
11. Influence of rainfall, wind, and temperature on thermal and salinity stratification and mixing, including intensive sampling to detect short-term (daily) changes in hydrological and biologic features.

## ACKNOWLEDGMENTS

This research program is supported by the USGS Place-Based Program, L. Smith (SFB coordinator). J. Swanson, L. Wyckoff, T. Huffman, J. Schwennesen, T. Maatouck, K. Haggard, and A. Crout (California Department of Fish and Game, CDFG) provided access for the studies, technical support, and field assistance. S. Wainwright-De La Cruz, R. Laird, M. Eagan, B. Sauer, P. Buchanan, J. Warner, B. Martin, K. English, M. Ricca, M. Law, S. Spring, H. Tran, M. Disney, T. Mumm, E. Brocales, T. Rockwell, A. Wilde, A. Meckstroth, G. Downard, D. Tsao, K. Yturralde (USGS), S. Nebel, Kady (Simon Frasier University) and J. Lament (Ducks Unlimited), provided field and analysis assistance. Our thanks to L. Vicencio and B. Winton (Fish and Wildlife Service) for assistance with logistics. We also appreciate the assistance provided by L. Allen and B. Bonnet (Can Duck Club). D. Tsao and S. Wainwright-De La Cruz assisted with compiling and editing the report.

## LITERATURE CITED

- Accurso, L. M. 1992. Distribution and abundance of wintering waterfowl on San Francisco Bay 1988-1990. Unpubl. Master's Thesis. Humboldt State Univ. Arcata, CA. 252pp.
- Anderson, W. 1970. A preliminary study of the relationship of salt ponds and wildlife-south San Francisco Bay. California Fish and Game 56(4):240-252.
- Bonham, C. D. 1989. Measurements for terrestrial vegetation. John Wiley & Sons, New York New York USA

- Buchanan, P. A., 1999. Specific conductance, water temperature, and water level data, San Francisco Bay, California, water year 1998: Interagency Ecological Program Newsletter, v. 12, no. 4, p. 46-51.
- Buchanan, P.A., 2000, Specific conductance, water temperature, and water level data from San Francisco Bay, California, in water year 1999: IEP Newsletter, v. 13, no. 3, p. 17-20. URL <http://www.iep.ca.gov/report/newsletter/2000summer/>
- Buchanan, P. A., and D. H. Schoellhamer. 1998. Summary of suspended-solids concentration data in San Francisco Bay, California, water year 1996: U.S. Geological Survey Open File Report 98-175, 59 p.
- Carpelan, L. H. 1957. Hydrobiology of the Alviso salt ponds. *Ecology* 38(3):375-390.
- Caumette, P., R. Matheron, N. Raymond, and J. C. Relexans. 1994. Microbial mats in the hypersaline ponds of Mediterranean salterns (Salins-de-Giraud, France). *FEMS (Federation of European Microbiological Societies). Microbiology Ecology* 13:272-286.
- Clesceri, L. S., A. E. Greenberg and R. R. Trussell, Editors. 1989. Standard methods for the examination of water and wastewater, 17th edition. American Public Health Association, Washington, DC.
- Elphick, C. S., and M. A. Rubega. 1995. Prey choices and foraging efficiency of recently fledged California gulls at Mono Lake, California. *Great Basin Naturalist* 55:363-367.
- Eschmeyer, W.N., E.S. Herald, and H. Hammann. 1983. A field guide to Pacific Coast fishes of North America from the Gulf of Alaska to Baja California. Houghton Mifflin Company, Boston. 336 pp.
- Goals Project. 1999. Baylands Ecosystem Habitat Goals. A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. U. S. Environmental Protection Agency, San Francisco, Calif./S.F. Bay Regional Water Quality Control Board, Oakland, Calif.
- Greig-Smith, P. 1983. Quantitative plant ecology. Blackwell Press, Oxford
- Herbst, D. B., and R. W. Castenholz. 1995. Growth of the filamentous green alga *Ctenocladus circinnatus* (Chaetophorales, Chlorophyceae) in relation to environmental salinity. *Journal of Phycology* 30:588-593.
- Herbst, D. B., and T. J. Bradley. 1993. A population model for the alkali fly at Mono Lake: depth distribution and changing habitat availability. *Hydrobiologia* 267:191-201.
- Josselyn, M. 1983. The ecology of San Francisco Bay tidal marshes: a community profile. FWS/OBS-83/23, U.S. Fish and Wildlife Service, Washington, DC.
- LES (Lewis Environmental Associates, Inc.) and Wetlands Research Associates, Inc. 1992. Napa salt ponds biological resources. Unpublished final report prepared for Cargill Salt, Newark, California. 59 pp.

- Lind, O. T. 1985. Handbook of common methods in limnology, 2<sup>nd</sup> edition. Department of Biology and environmental studies, Baylor University, Waco, TX.
- Lonzarich, D. G., and J. J. Smith. 1997. Water chemistry and community structure of saline and hypersaline salt evaporation ponds in San Francisco Bay, California. *Calif. Fish and Game* 83(3):89-104.
- McGinnis, S.M. 1984. Freshwater fishes of California. University of California Press, Berkeley. 316 pp.
- Matveev, V. 1995. The dynamics and relative strength of bottom-up vs. top-down impacts in a community of subtropical lake plankton. *Oikos* 73:104-108
- Merritt, R.W., and K.W. Cummins, eds. 1978. An introduction to the aquatic insects of North America. Kendall-Hunt Publishing Company, Dubuque, Iowa. 441 pp.
- Miller, D.J, and R.N. Lea. 1972. Guide to the coastal marine fishes of California. California Department of Fish and Game, Fish Bulletin 157, 249 pp.
- Moyle, P.B. 1976. Inland fishes of California. University of California Press, Berkeley. 405 pp.
- Nichols, F. H., J. E. Cloern, S. N. Luoma, and D. H. Peterson. 1986. The modification of an estuary. *Science*. 231:569-573.
- Pennak, R. W. 1989. Freshwater invertebrates of the United States, 3<sup>rd</sup> Edition. John Wiley & Sons, New York. 628 pp.
- Pinckney, J. L., and H. W. Pearl. 1997. Anoxygenic photosynthesis and nitrogen fixation by a microbial mat community in a Bahamian hypersaline lagoon. *Applied and Environmental Microbiology* 63:420-426.
- Posey, M., C. Powell, L. Cahoon, and D. Lindquist. 1995. Top down vs. bottom up control of benthic community composition on an intertidal tideflat. *J. Exp. Marine Biol. Ecol.* 185:19-31.
- Rodriguez-Valera, F., A. Ventosa, G. Juez, and J. F. Imhoff. 1985. Variations of environmental features and microbial populations with salt concentrations in a multi-pond saltern. *Microbial Ecology*. 11:107-116.
- Takekawa, J.Y., C.T. Lu, and R.T. Pratt. 2001. Avian communities in baylands and artificial salt evaporation ponds of the San Francisco Bay estuary. *Hydrobiologica*. (In press).
- Usinger, R.L. 1971. Aquatic insects of California. University of California Press, Berkeley. 508 pp.
- Ver Planck, W. E. 1958. Salt in California. *Calif. Div. Mines Bull.* 175.

- Warner, J. C., S. G. Schladow, and D. H. Schoellhamer. 1999. Summary and analysis, hydrodynamic and water-quality data for the Napa/Sonoma Marsh complex, Final Report: University of California, Davis, Department of Civil and Environmental Engineering.
- Warner, J.C., 2000, Barotropic and Baroclinic Convergence Zones in Tidal Channels: Ph. D. Dissertation, Department of Civil and Environmental Engineering, University of California, Davis.
- Warner, J.C., Schoellhamer, D.H., Burau, J.R., and Schladow, S.G., 2000, Effects of Tidal Current Phase at the Junction of Two Straits: Proceedings of the Fall meeting of the American Geophysical Union, San Francisco, California, December 15-19, 2000.
- Wetzel, R.G., and Likens, G.E. 1991. Limnological Analyses, 2<sup>nd</sup> edition. Springer-Verlag, New York, NY.

Table 1. Pond 1 average dissolved nutrient concentrations in milligrams per liter for USGS Napa Salt Ponds project. Means that are not significantly different are indicated by similar superscripts.

Sampling Date	Nitrate (NO <sub>3</sub> )	Ammonia (NH <sub>4</sub> )	Reactive phosphorous (SR PO <sub>4</sub> )	Total phosphorous (T PO <sub>4</sub> )
7/29/99	0.822 <sup>a</sup>	1.722 <sup>a</sup>	1.294 <sup>a</sup>	1.722 <sup>a</sup>
9/27/99	0.291	1.628 <sup>a</sup>	1.367 <sup>ab</sup>	1.628 <sup>a</sup>
3/28/00	0.767 <sup>a</sup>	1.723 <sup>a</sup>	1.607 <sup>ab</sup>	1.723 <sup>a</sup>
6/9/00	1.201 <sup>a</sup>	2.46 <sup>b</sup>	2.496	2.46 <sup>b</sup>
7/22/00	2.888 <sup>b</sup>	0.700	1.451 <sup>a</sup>	0.700
9/28/00	1.236 <sup>ab</sup>	4.039	4.212	4.039
12/19/00	3.454 <sup>b</sup>	2.468 <sup>ab</sup>	2.115 <sup>b</sup>	2.468 <sup>b</sup>
7/29/99	0.822 <sup>a</sup>	1.722 <sup>a</sup>	1.294 <sup>a</sup>	1.722 <sup>a</sup>



Table 2. Pond 2 average dissolved nutrient concentrations in milligrams per liter for USGS Napa Salt Ponds project. Means that are not significantly different are indicated by similar superscripts.

Sampling Date	Nitrate (NO <sub>3</sub> )	Ammonia (NH <sub>4</sub> )	Reactive phosphorous (SR PO <sub>4</sub> )	Total phosphorous (T PO <sub>4</sub> )
7/23/99	0.306 <sup>a</sup>	4.846 <sup>a</sup>	3.522 <sup>a</sup>	3.775 <sup>a</sup>
9/21/99	0.568 <sup>a</sup>	7.509 <sup>b</sup>	4.859 <sup>b</sup>	4.774 <sup>b</sup>
4/2/00	4.877	5.406 <sup>ac</sup>	2.001 <sup>c</sup>	2.077 <sup>c</sup>
6/10/00	0.359 <sup>a</sup>	6.144 <sup>c</sup>	3.524 <sup>a</sup>	3.866 <sup>a</sup>
7/25/00	1.150	6.377 <sup>c</sup>	1.224	0.971
9/28/00	0.335 <sup>a</sup>	7.812 <sup>b</sup>	4.402 <sup>b</sup>	4.876 <sup>b</sup>
12/18/00	2.715	6.395 <sup>abc</sup>	2.918 <sup>ac</sup>	3.036 <sup>c</sup>
7/23/99	0.306 <sup>a</sup>	4.846 <sup>a</sup>	3.522 <sup>a</sup>	3.775 <sup>a</sup>

Table 3. Pond 3 average dissolved nutrient concentrations in milligrams per liter for USGS Napa Salt Ponds project. Means that are not significantly different are indicated by similar superscripts.

Sampling Date	Nitrate (NO <sub>3</sub> )	Ammonia (NH <sub>4</sub> )	Reactive phosphorous (SR PO <sub>4</sub> )	Total phosphorous (T PO <sub>4</sub> )
8/2/99	8.054	10.640 <sup>a</sup>	3.183 <sup>a</sup>	3.823 <sup>ab</sup>
9/29/99	4.710 <sup>a</sup>	11.026 <sup>a</sup>	3.499 <sup>ab</sup>	3.56 <sup>ab</sup>
3/30/00	4.083 <sup>a</sup>	8.096	3.302 <sup>ab</sup>	3.318 <sup>a</sup>
6/12/00	1.646 <sup>b</sup>	11.300 <sup>a</sup>	2.524 <sup>b</sup>	2.57 <sup>bc</sup>
7/23/00	0.428	11.416 <sup>a</sup>	1.154 <sup>c</sup>	0.290
9/25/00	1.833 <sup>bc</sup>	14.974	2.773 <sup>b</sup>	2.951 <sup>a</sup>
12/21/00	2.369 <sup>c</sup>	NA	1.567 <sup>c</sup>	2.438 <sup>bc</sup>

Table 4. Pond 4 average dissolved nutrient concentrations in milligrams per liter for USGS Napa Salt Ponds project. Means that are not significantly different are indicated by similar superscripts.

Sampling Date	Nitrate (NO <sub>3</sub> )	Ammonia (NH <sub>4</sub> )	Reactive phosphorous (SR PO <sub>4</sub> )	Total phosphorous (T PO <sub>4</sub> )
6/11/99	2.612 <sup>a</sup>	NA	0.216 <sup>a</sup>	0.383 <sup>a</sup>
7/21/99	2.394 <sup>a</sup>	NA	0.154 <sup>a</sup>	0.548 <sup>ab</sup>
9/30/99	4.795 <sup>b</sup>	NA	3.143	3.348
3/30/00	5.824 <sup>cd</sup>	NA	0.491 <sup>b</sup>	0.479 <sup>ab</sup>
6/13/00	3.146 <sup>c</sup>	NA	0.925 <sup>c</sup>	1.146 <sup>c</sup>
7/26/00	3.628 <sup>c</sup>	NA	1.07 <sup>c</sup>	0.662 <sup>ab</sup>
9/26/00	4.891 <sup>b</sup>	NA	0.885 <sup>c</sup>	1.127 <sup>c</sup>

Table 5. Benthic macroinvertebrate abundance per pond. Reported as mean number per Eckman grab [15 cm X 15 cm X 7.5 cm (average depth)].

**Pond 1.**

<i>Orders</i>	<i>Taxonomic Group</i>	<i>April 1999</i>	<i>May 1999</i>	<i>July 1999</i>	<i>Sept 1999</i>	<i>Nov 1999</i>	<i>Jan 2000</i>	<i>March 2000</i>	<i>May 2000</i>	<i>Sept 2000</i>
Nematoda	<i>Nematoda</i>		0.03		0.03	4.2	3.3		0.3	
Oligochaeta	<i>Tubificoides</i>		0.7	0.1	0.2	0.2	0.1		0.1	
Polychaeta	<i>Capitella</i>	0.1	1.5	0.4	5.7	0.1	1.2	0.2	5	0.1
	<i>Heteromastus</i>	25.3	21.5	40.5	41.4	45.6	22.8	31	28.6	34.3
	<i>Polydora</i>		0.5	0.4	1.4	0.3		1.7	10.2	
	<i>Pseudopolydora</i>	3.1	4.5	1.1	2.1	0.03		0.8	1	
	<i>Streblospio</i>	0.3	0.8	0.1	1.8	1.3	1.7	0.9	3.3	
	<i>Eteone</i>		0.03	0.1	0.1	0.5	0.3	1	0.1	
	<i>Nereis</i>	0.7	0.2	0.3	0.03	0.1		0.1		0.7
	<i>Spionidae A</i>		0.2	0.1	0.1	0.2		0.1	0.1	0.1
	<i>Cirratulus</i>				0.8	0.2	0.1	0.1		
	<i>Terebellidae</i>									0.03
Bivalvia	<i>Gemma gemma</i>	15.3	13.3	251.9	527.4	528.1	209.5	90.7	32.6	
	<i>Macoma balthica</i>	0.2	0.3	2.2	0.4	1	0.1	0.5	0.2	1.9
	<i>Mya arenaria</i>			0.2						
	<i>Potamocorbula</i>	0.1	0.1	0.6	2.5	6.4	2.2	1.7	0.2	0.1
Crustacea	<i>Ampelisca</i>	0.03				0.03				0.1
	<i>Corophium</i>	2.3	1.7	9.8	63	32	38.7	2.4	6.6	
	<i>Gammaridae</i>	1.2	0.2	0.1	0.2		0.2	0.1	0.3	
	<i>Ericthonius</i>	0.1	0.03	0.6	42.9	18	5.4	1.7	1.8	
	<i>Ampithoe</i>				1	0.2	0.03			
	<i>Cumacea</i>	3.0	5.8	0.3	1.3	1.2	1.7	5.2	15.8	
	<i>Mysis</i>	0.9	1.6	0.6	0.8	0.2	0.1	0.03	0.1	0.03
	<i>P. californiensis</i>				0.03		0.03			
	<i>Copepoda</i>									
	<i>Ostracoda I</i>			0.2	0.1	0.3	0.03		0.03	0.1
	<i>Artemia</i>									
	<i>Synidotea</i>				0.03	0.03				
	<i>Sphaeromatidae</i>				0.03					
Insecta	<i>Corixinae</i>									
	<i>Ephydriidae</i>			0.03	0.03					
	<i>Hydrophilidae</i>									
	<i>Dolichopodidae</i>			0.1			0.03		0.1	
	<i>Chironomidae</i>									
Other	<i>Carabidae</i>								0.03	
	<i>Obelia</i>									
	<i>Edwardsia</i>		0.1	0.2	3.2	1.2	0.8	0.1	0.1	
	<i>Turbellaria</i>		0.03			0.1				
	<i>Lineidae</i>				0.03	0.1			0.1	
	<i>N. obsoletus</i>					0.03			0.03	
	<i>Notoplana</i>					0.03				
<b>Number of Samples</b>		N=30	N=30	N=30	N=30	N=30	N=30	N=30	N=30	N=30

Table 5. continued

**Pond 2**

<i>Orders</i>	<i>Taxonomic Group</i>	<i>April 1999</i>	<i>May 1999</i>	<i>July 1999</i>	<i>Sept 1999</i>	<i>Nov 1999</i>	<i>Jan 2000</i>	<i>March 2000</i>	<i>May 2000</i>	<i>Sept 2000</i>
Nematoda	<i>Nematoda</i>		0.1		0.5		0.1	0.3		
Oligochaeta	<i>Tubificoides</i>	0.3	0.3		0.1	0.2	0.9	0.8	0.5	0.9
Polychaeta	<i>Capitella</i>	1	7.4	0.5	1.8	1.7	0.8	2.3	0.7	0.1
	<i>Heteromastus</i>	46	90	38.6	40.8	102	73.7	70.3	69.1	7.1
	<i>Polydora</i>	6.1	25.7	0.4	2.5		1.3	0.2	0.8	6.8
	<i>Pseudopolydora</i>	0.7	1.7	1.5	0.9	1.6		0.5	0.3	0.2
	<i>Streblospio</i>	1.6	2	0.1	0.8	27	13.2	4.2	5.9	15.9
	<i>Eteone</i>	0.2	0.4	1.7	0.1	0.2	1.6	2.8	3.3	7.2
	<i>Nereis</i>	0.03						0.03		
	<i>Spionida A</i>	0.1	0.2	0.4	0.2	0.03	0.03	0.1		
	<i>Sabellidae</i>				0.03					
	<i>Terebellidae</i>							0.4		
Bivalvia	<i>Gemma gemma</i>	5.5	0.7	0.6	0.2	0.5	0.1	0.03		
	<i>Macoma balthica</i>	8.7	10	8.6	3.5	7.4	4.1	3.3	2.9	0.6
	<i>Mya arenaria</i>	0.7	1.3	2.4	1.5	2.8	3.6	1	1.2	0.1
	<i>Potamocorbula</i>	0.03			0.2					
	<i>Ostreidae</i>	0.3	0.03				0.03			
	<i>Tapes japonica</i>	0.03								
Crustacea	<i>Corophium</i>	0.2	0.2		0.03					0.2
	<i>Gammaridae</i>	0.1	0.2		0.3					2.7
	<i>Erichthonius</i>				0.1	2.5	0.3	0.2	1.9	6.3
	<i>Ampithoe</i>						0.03			0.1
	<i>Ampelisca</i>								0.03	
	<i>Cumacea</i>	17.9	22.4		0.2	0.03	0.1	0.2	0.5	0.1
	<i>Mysis</i>			0.6	0.5	0.1				0.03
	<i>P. californiensis</i>	2.3	2.2		1.8		0.3			5
	<i>Copepoda</i>		0.1							
	<i>Ostracoda I</i>					0.1	0.03	0.03	0.1	0.5
	<i>Sphaeromatidae</i>		0.2		0.4		0.2	0.03		1.7
	<i>H. oregonensis</i>				0.03					
	<i>C. franciscorum</i>									0.03
Insecta	<i>Corixinae</i>									
	<i>Hydrophilidae</i>									
	<i>Dolichopodidae</i>									
	<i>Chironomidae</i>		0.03	0.1						0.03
	<i>Ceratopogonidae</i>								0.03	
Other	<i>Obelia</i>	0.03							0.1	0.2
	<i>Diadumene</i>	0.4	1		0.6					0.3
	<i>Bryozoa</i>				0.1				1	0.5
	<i>Turbellaria</i>	0.2								
	<i>Cirripidea</i>		0.4	3.1	6.9		6.7		0.3	0.2
	<i>A. californica</i>								0.7	
	<i>Edwardsia</i>							0.43	0.4	0.4
	<i>Lineidae</i>	0.7	0.1	0.1			0.03		0.03	0.1
	<b>Number of Samples</b>	N=30	N=30	N=30	N=30	N=30	N=30	N=30	N=30	N=30

Table 5. continued

**Pond 3**

<i>Orders</i>	<i>Taxonomic Group</i>	<i>April 1999</i>	<i>May 1999</i>	<i>July 1999</i>	<i>Sept 1999</i>	<i>Nov 1999</i>	<i>Jan 2000</i>	<i>March 2000</i>	<i>May 2000</i>	<i>Sept 2000</i>
Nematoda	<i>Nematoda</i>	1.6	0.2	0.03	0.03	6.6	0.2	2.4	7.1	1.7
Oligochaeta	<i>Tubificoides</i>	0.1								
Polychaeta	<i>Capitella</i>	2.3	7.1	8.6	14	3.2	22.4	24.2	40.9	11.4
	<i>Heteromastus</i>		0.1		0.5					
	<i>Polydora</i>	150.5	318.8	36.2	94.6	31.7	16.6	25.2	99.8	112.7
Crustacea	<i>Streblospio</i>	0.1					0.2	1.3		52.5
	<i>Corophium</i>	0.4	3	3.6	4.6	0.1	0.2	0.2	29	77.2
	<i>Gammaridae</i>	0.1								
	<i>Ericthonius</i>				0.1					
	<i>P. californiensis</i>				0.03					
	<i>Copepoda</i>	0.1		0.1						0.03
Insecta	<i>Artemia</i>								0.1	
	<i>T. reticulata</i>	0.03	0.03							0.1
Other	<i>Hydrophilidae</i>		0.1	0.1					0.03	
	<i>Lineidae</i>									0.5
	<i>Obelia</i>	0.1	0.5	0.3	0.03	0.2	0.1	0.1	0.3	0.3
<b>Number of Samples</b>		N=30	N=30	N=30	N=29	N=30	N=30	N=30	N=30	N=30

**Pond 4**

<i>Orders</i>	<i>Taxonomic Group</i>	<i>April 1999</i>	<i>May 1999</i>	<i>July 1999</i>	<i>Sept 1999</i>	<i>Nov 1999</i>	<i>Jan 2000</i>	<i>March 2000</i>	<i>May 2000</i>	<i>Sept 2000</i>
Nematoda	<i>Nematoda</i>	0.1								
Crustacea	<i>Artemia</i>	47.2	93.6	62.2	4.6	1.3	4.6	19.9	91.5	50.8
	<i>Isopoda</i>									
Insecta	<i>Corixinae</i>						2.7			
	<i>Ephydra gracilis</i>	0.3	0.7	44.1	116.4	71.7	86	36.3	14.3	183.1
	<i>Ephydra sp.</i>							0.03		
	<i>Hydrophilidae</i>	0.1	0.03	5.8	1	1.6	2.5	0.4	3.1	1.3
	<i>Dolichopodidae</i>									
	<i>Muscidae</i>						0.1	0.1		0.03
	<i>Diptera pupa</i>						0.5	12.5	0.5	1.4
	<i>Chironomidae</i>									
<b>Number of Samples</b>		N=20	N=30	N=30	N=8	N=12	N=30	N=30	N=30	N=30

Table 5. continued

**Pond 7**

<i>Orders</i>	<i>Taxonomic Group</i>	<i>May 1999</i>	<i>Nov 1999</i>	<i>May 2000</i>
Crustacea	<i>Artemia</i>	1	0	3.9
	<i>Idoteidae</i>			
	<i>Flabellifera</i>			
Insecta	<i>Corixinae</i>	0.1	0	0.03
	<i>Ephydriidae</i>	0.03	0	0.03
	<i>Hydrophilidae</i>			
	<i>Dolichopodidae</i>			
	<i>Chironomidae</i>			
<b>Number of Samples</b>		N=30	N=30	N=30

Table 5. continued

**Pond 2A**

<i>Orders</i>	<i>Taxonomic Group</i>	<i>August 1999</i>	<i>Feb 2000</i>	
Nematoda	Nematoda	1.3	9.4	
Oligochaeta	Oligochaeta	78.1	41.8	
Polychaeta	Capitella	27.6	73.6	
	Heteromastus	0.1		
	Polydora		0.3	
	Pseudopolydora	0.03		
	Streblospio	0.3	25.2	
	Eteone		0.7	
	Nereis	0.2	0.6	
	Sabellidae	20.7	162.9	
	Bivalvia	Macoma balthica	0.8	0.1
		Mya arenaria	0.03	
Potamocorbula		0.03	0.03	
Gastropoda	A. californica	15.2	5.4	
Crustacea	Corophium	3.6	0.7	
	Gammaridae	0.4	0.2	
	Ericthonius	47.7	4.7	
	Cumacea	0.4	2	
	Ostracoda II	5.9		
	Cirripedia	0.1	0.1	
	Insecta	Corixidae A	5.3	
		Corixidae B	18.3	
		Ephydriidae	1.1	0.03
		Hydrophilidae	0.1	
Dolichopodidae		0.1	0.7	
Psychodidae		0.4	12.4	
Muscidae			0.5	
Syrphidae			0.03	
Chironomidae		0.1	0.03	
Ceratopogonidae		0.7	3.5	
Other	Hemiptera	1.4	2.4	
	Elmidae		0.3	
	Melyridae		0.03	
	Obelia	0.1		
	Edwardsia	0.4	3.9	
	Turbellaria	0.1	0.1	
	Opisthobranchia	0.2	1.1	
	Collembola		0.4	
<b>Number of Samples</b>		<b>N=27</b>	<b>N=21</b>	



Table 6. Composition of 3,976 fish captured by gillnetting and bag seining during July 1999-September 2000. Values are numbers of individuals<sup>a</sup>.

Species	Gill net			Bag seine		
	Pond 1	Pond 2	Pond 3	Pond 1	Pond 2	Pond 3
American shad	124	15	0	0	0	0
<i>Tridentiger</i> goby	0	0	0	55	4	161
Delta smelt	0	0	0	0	1	0
Inland silverside	0	0	0	40	57	69
Longjaw mudsucker	0	0	7	0	0	347
Northern anchovy	0	0	0	6	0	0
Rainwater killifish	0	0	0	71	0	37
Sacramento splittail	1	0	0	0	0	0
Striped bass	133	326	9	3	45	1
Threespine stickleback	0	0	0	4	0	0
Starry flounder	12	0	0	1	0	0
Striped mullet	29	0	0	0	0	0
Pacific staghorn sculpin	11	0	0	1,325	0	0
Threadfin shad	2	0	0	0	0	0
Tule perch	0	1	0	0	0	0
Yellowfin goby	11	1	3	1,054	8	2

<sup>a</sup>No fish were captured in Pond 4.

Table 7. Summary of water temperature (Temp), dissolved oxygen (DO) concentration, pH, salinity (Sal), and turbidity (Turb) measured at bi-monthly intervals during July 1999-September 2000. Values are grand means based on bi-monthly averages for each of four ponds.<sup>a</sup>

Pond or F-value	Temp(°C)	DO (mg/L)	pH	Sal (ppt)	Turb (NTUs)
1	15.5	7.7 A	7.9 BC	23.7 C	139.9 A
2	17.5	8.0 A	8.6 A	24.9 C	51.3 B
3	18.4	6.9 A	8.3 AB	43.8 B	60.6 B
4	20.1	1.6 B	7.5 C	>70.0 A	36.4 B
F <sub>3,31</sub> <sup>b</sup>	2.32	25.08 <sup>b</sup>	15.60 <sup>b</sup>	142.97 <sup>b</sup>	10.90 <sup>b</sup>

<sup>a</sup>Within each column, grand means followed by the same capital letter are not significantly different.

<sup>b</sup> = P<0.0001.

Table 8. Waterbird species of the major foraging guilds in the baylands and salt ponds of the North Bay subregion, San Francisco Bay estuary. Species unique to baylands surveys (<sup>B</sup>) are indicated.

**Guild**

Common Name	Latin Name
<b>Surface Feeders</b>	
American avocet	<i>Recurvirostra americana</i>
black-necked stilt	<i>Himantopus mexicanus</i>
red-necked phalarope	<i>Phalaropus lobatus</i>
Wilson's phalarope <sup>B</sup>	<i>Phalaropus tricolor</i>
<b>Shallow Probers</b>	
black-bellied plover	<i>Pluvialis squatarola</i>
dunlin	<i>Calidris alpina</i>
killdeer	<i>Charadrius vociferous</i>
red knot	<i>Calidris canutus</i>
semipalmated plover	<i>Charadrius semipalmatus</i>
snowy plover	<i>Charadrius alexandrinus</i>
spotted sandpiper <sup>B</sup>	<i>Actitis macularia</i>
least sandpiper	<i>Calidris minutilla</i>
western sandpiper	<i>Calidris mauri</i>
<b>Deep Probers</b>	
lesser <sup>B</sup> , greater yellowlegs	<i>Tringa flavipes, melanoleuca</i>
long-billed curlew	<i>Numenius americanus</i>
long-billed, short-billed dowitcher	<i>Limnodromus scolopaceus, griseus</i>
marbled godwit	<i>Limosa fedoa</i>
whimbrel	<i>Numenius phaeopus</i>
willet	<i>Catoptrophorus semipalmatus</i>
<b>Diving Benthivores</b>	
Barrow's goldeneye <sup>B</sup>	<i>Bucephala islandica</i>
bufflehead	<i>Bucephala albeola</i>
canvasback	<i>Aythya valisineria</i>
common goldeneye	<i>Bucephala clangula</i>
Clark's grebe	<i>Aechmophorus clarkii</i>
eared grebe	<i>Podiceps nigricollis</i>
horned grebe	<i>Podiceps auritus</i>
lesser, greater scaup	<i>Aythya affini, marila</i>
pie-billed grebe	<i>Podilymbus podiceps</i>
redhead <sup>B</sup>	<i>Aythya americana</i>
red-necked grebe <sup>B</sup>	<i>Podiceps grisegena</i>
ring-necked duck <sup>B</sup>	<i>Aythya collaris</i>
ruddy duck	<i>Oxyura jamaicensis</i>
surf scoter <sup>B</sup>	<i>Melanitta perspicillata</i>
western grebe	<i>Aechmophorus occidentalis</i>

Table 8. Continued.

**Guild**

Common Name	Latin Name
<b>Dabblers</b>	
American coot	<i>Fulica Americana</i>
American wigeon	<i>Anas americana</i>
blue-winged teal <sup>B</sup>	<i>Anas discors</i>
cinnamon teal	<i>Anas cyanoptera</i>
Eurasian wigeon <sup>B</sup>	<i>Anas penelope</i>
gadwall	<i>Anas strepera</i>
green-winged teal	<i>Anas crecca</i>
mallard	<i>Anas platyrhynchos</i>
northern pintail	<i>Anas acuta</i>
northern shoveler	<i>Anas clypeata</i>
<b>Piscivores</b>	
American white pelican	<i>Pelecanus erythrorhynchos</i>
black-crowned night heron	<i>Nycticorax nycticorax</i>
Caspian tern	<i>Sterna caspia</i>
common merganser	<i>Mergus merganser</i>
double-crested cormorant	<i>Phalacrocorax auritus</i>
Forster's tern	<i>Sterna forsteri</i>
great blue heron	<i>Ardea herodias</i>
great egret	<i>Casmerodius albus</i>
green heron <sup>B</sup>	<i>Butorides striatus</i>
hooded merganser <sup>B</sup>	<i>Lophodytes cucullatus</i>
red-breasted merganser	<i>Mergus serrator</i>
snowy egret	<i>Egretta thula</i>
<b>Other</b>	
American bittern <sup>B</sup>	<i>Botaurus lentiginosus</i>
black rail <sup>B</sup>	<i>Laterallus jamaicensis</i>
Bonaparte's gull	<i>Larus philadephia</i>
California clapper rail <sup>B</sup>	<i>Rallus longirostris</i>
California gull	<i>Larus californicus</i>
Canada goose	<i>Branta canadensis</i>
common loon	<i>Gavia immer</i>
common snipe <sup>B</sup>	<i>Gallinago gallinago</i>
greater white-fronted goose <sup>B</sup>	<i>Anser albifrons</i>
glaucous-winged gull <sup>B</sup>	<i>Larus glaucescens</i>
greater flamingo	<i>Phoenicopterus ruber</i>
herring gull <sup>B</sup>	<i>Larus argentatus</i>
mew gull <sup>B</sup>	<i>Larus canus</i>
osprey	<i>Pandion haliaetus</i>
ring-billed gull	<i>Larus delawarensis</i>
Ross' goose <sup>B</sup>	<i>Chen rossi</i>
snow goose <sup>B</sup>	<i>Chen caerulescens</i>
sora	<i>Prozana carolina</i>
tundra swan <sup>B</sup>	<i>Cygnus columbianus</i>
Virginia rail	<i>Rallus limicola</i>
wandering tattler <sup>B</sup>	<i>Heteroscelus incanus</i>
western gull	<i>Larus occidentalis</i>

Table 9. Number of birds by species per pond, Napa-Sonoma salt ponds, Jan 1999 - Nov 2000. DIVE, DABB, DUCK, GULL, PEEP, SHOR, and TERN are generic terms for divers, dabblers, ducks, gulls, small sandpipers, larger shorebirds and terns, respectively, when they were unidentifiable in the field.

Species	Pond						Total
	1	2	3	4	7	2A	
AMAV	9040	55	1645	9585	40	290	20655
AMCO	1044	42	91	349		708	2234
AMWI	42	112	1058	184		904	2300
AWPE	289		686	116			1091
BBPL	1314		2	284	8		1608
BCNH	1		2				3
BLRA						9	9
BNST	166		45	2136	1		2348
BOGU	46	5		424			475
BUFF	85	1343	64	2695			4187
BWTE						6	6
CAGO	18	7	6	17	6	10	64
CAGU	208	56	16	1489	47		1816
CANV	5067	1181	6405	20		90	12763
CATE	47	4	1210	37		6	1304
CITE		2				9	11
CLGR	38	38	26	1	1		104
COGO	26	442	21	453		5	947
COLO	1	7					8
COME			6				6
DABB	32	45	32	9		452	570
DCCO	263	29	2266	75	54	4	2691
DIVE	16	1003	340	1024		60	2443
DOWI	1201			19		103	1323
DUCK		140	3073	7	3	68	3291
DUNL	11005		59	14446	17	325	25852
EAGR	266	79	847	7717		1	8910
FLAM			1	6			7
FOTE	440	52	1614	21		2	2129
GADW	32	114	14	258		582	1000
GBHE	15	15	10	29	2	3	74
GOPL	84						84
GREG	86	67	21	5	4	26	209
GRYE	22				3	5	30
GULL	107	36	590	1002	3		1738
GWFG						1	1
GWTE				4		1294	1298
HOGR	6		2	85			93
KILL	181			16	2	37	236
LBCU	595			810		12	1417

Table 9. continued

Species	Pond						Total
	1	2	3	4	7	2A	
LESA	410		2	1744	4	111	2271
MAGO	2275		65	2080	2	13	4435
MALL	106	86	59	75		453	779
NOHA						5	5
NOPI	1747	2	1	60		35	1845
NOSH	1161	115	193	3804		712	5985
OSPR			2				2
PBGR	21	39		28		1	89
PEEP	2658	293	382	12405	82	244	16064
RAIL						1	1
RBGU	298		38	94			430
RBME			302				302
REDH	3	71					74
REKN	1			66	4		71
RNPH				20			20
RTHA						3	3
RUDU	9769	18928	8851	5584	1	52	43185
SCAU	1833	4770	16612	24952		1	48168
SEPL	203			1			204
SHOR	278	11	128	765	9	7	1198
SNEG	111	26	61	1	7	6	212
SNPL					1		1
SORA						82	82
TERN		3	14	236			253
TUVU	4					1	5
VIRA						118	118
WEGR	68	26	41	3			138
WEGU	41	9	78	1499	1		1628
WESA	12661		89	25139	84	1178	39151
WHIM	20			39	2		61
WILL	831	37	62	7098	26	65	8119
WTKI						1	1
YELL				4		2	6
Total	66282	29290	47132	129020	414	8103	280241



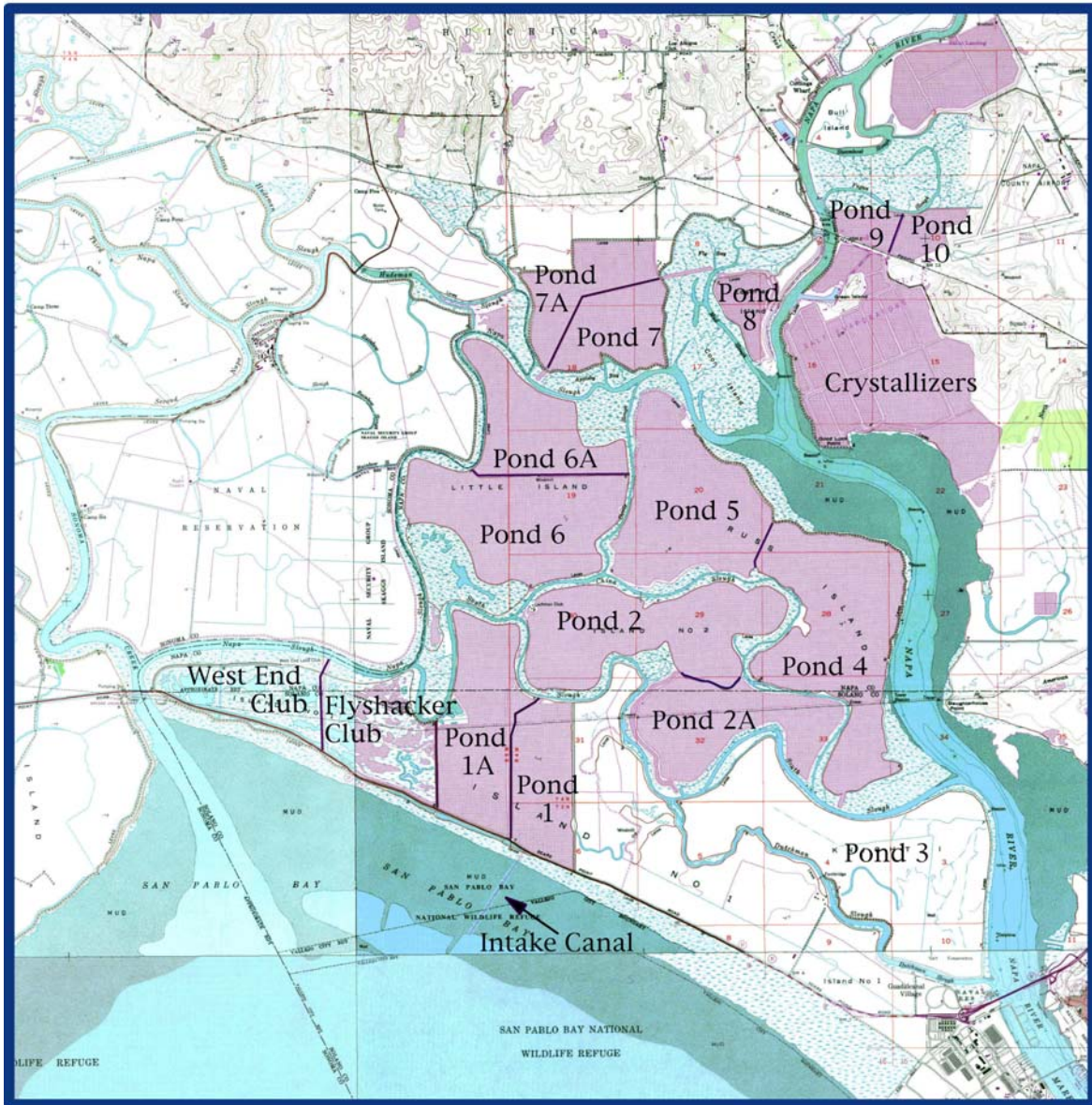


Figure 1. Napa-Sonoma Marshes State Wildlife Area, Napa and Sonoma Counties, CA. The marshes consist primarily of former salt-evaporation ponds. Salinities vary widely, with salinity generally increasing with pond number. Research is being conducted in ponds 1, 2, 2A, 3, 4 and 7.



Figure 2. Invertebrate taxa richness for the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

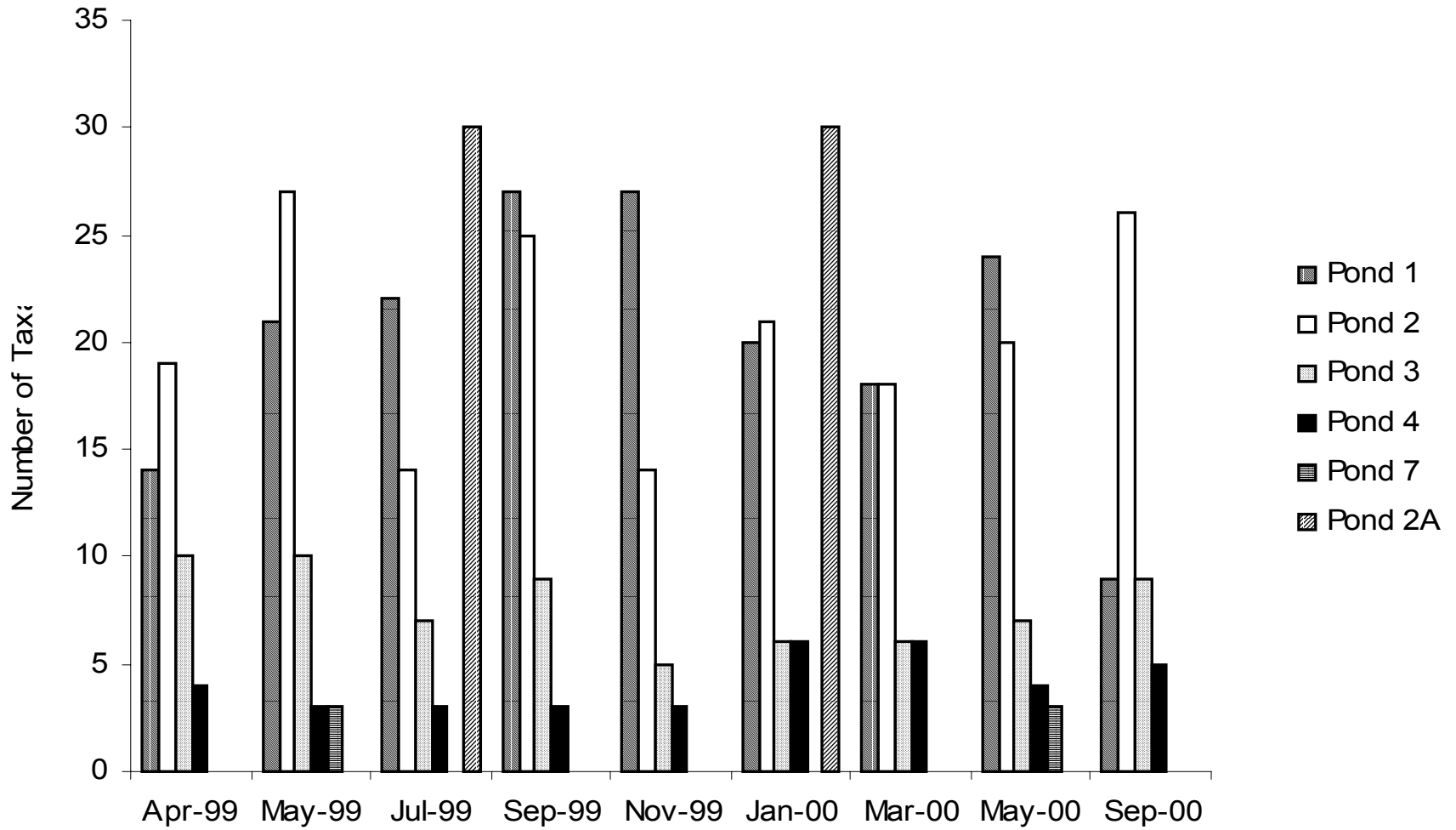


Figure 3. Total number of birds per pond from Jan 1999 to Nov 2000.

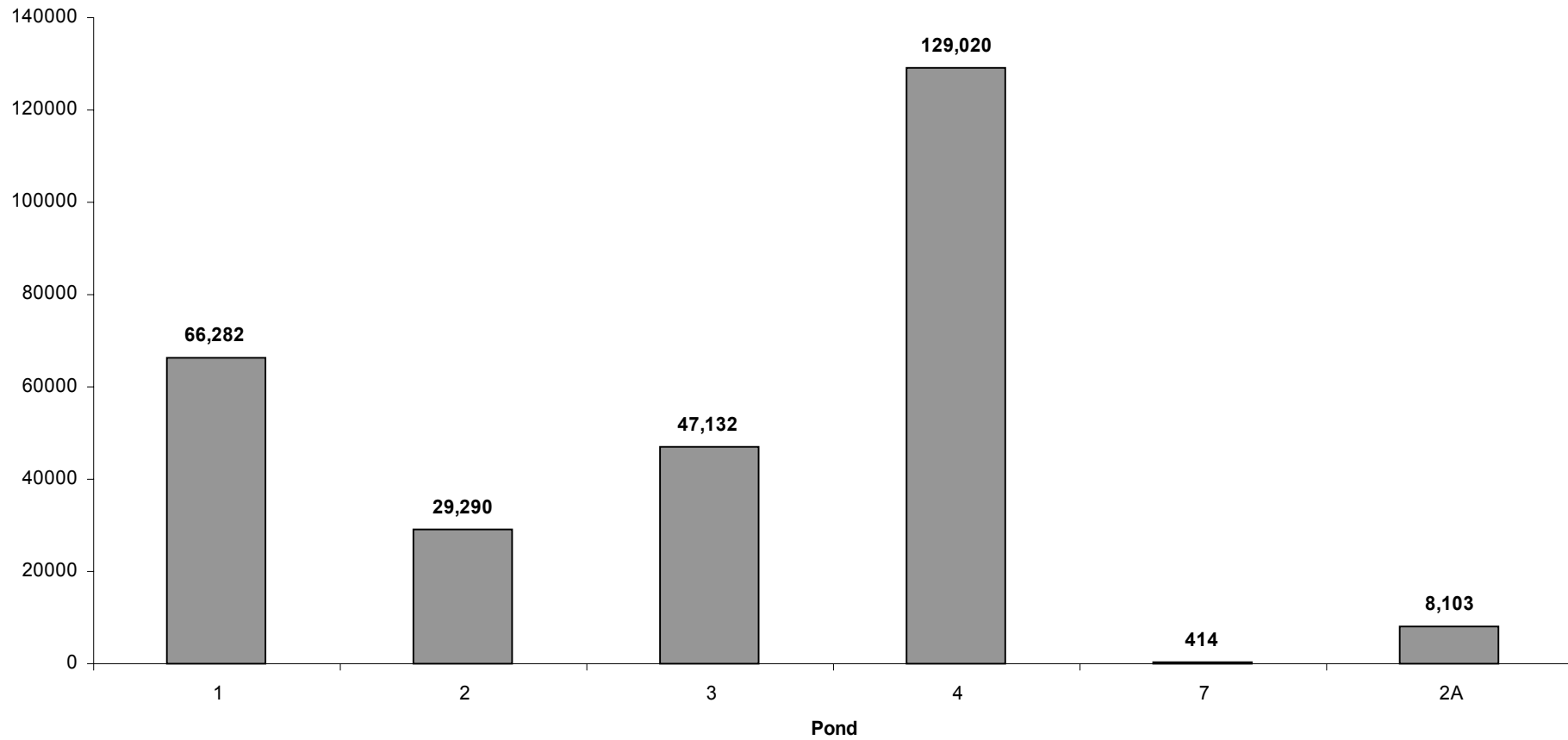


Figure 4a. Number of Individuals per guild counted in Pond 1 from Jan 1999 to Nov 2000.

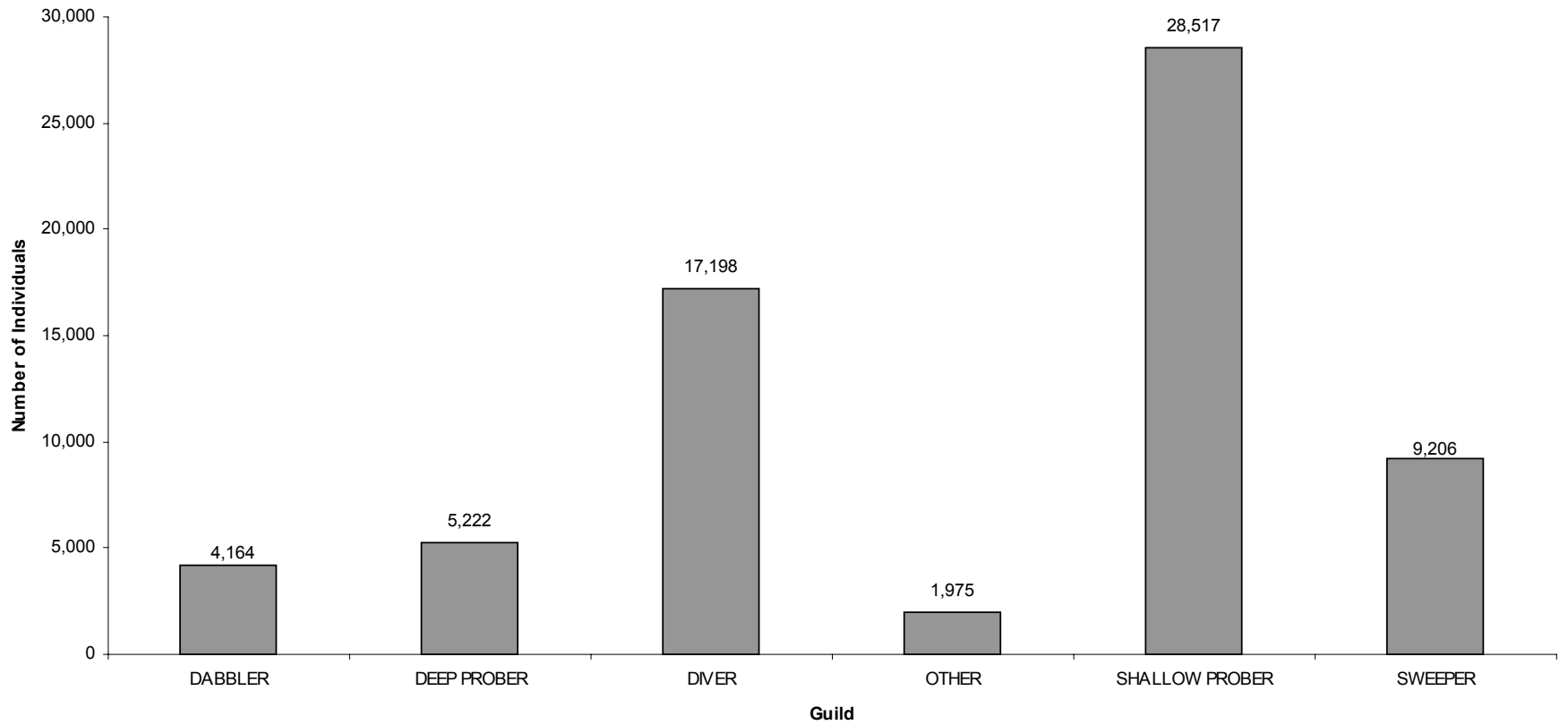


Figure 4b. Number of individuals per guild counted in pond 2 from Jan 1999 to Nov 2000.

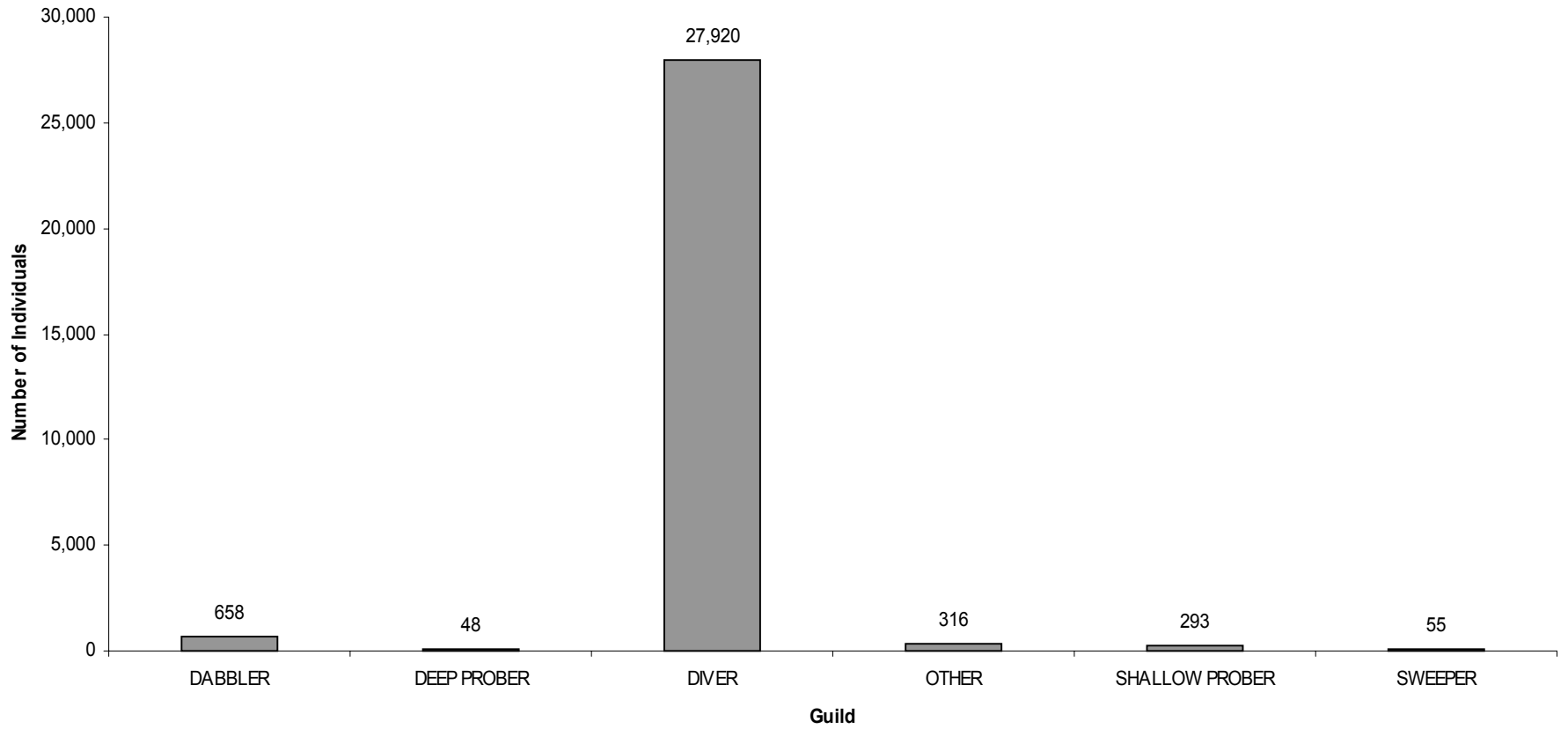


Figure 4c. Number of individuals per guild counted in pond 3 from Jan 1999 to Nov 2000.

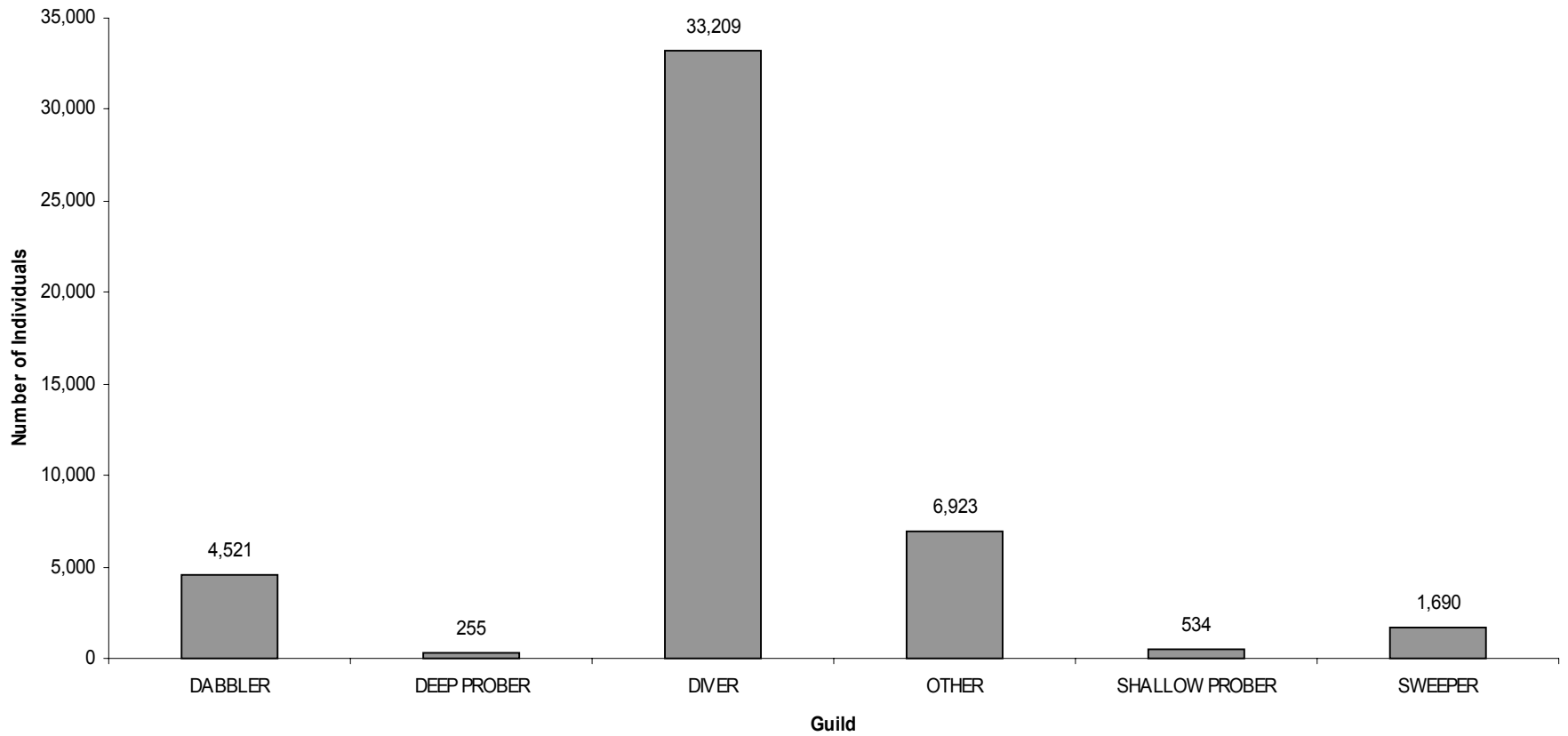


Figure 4d. Number of Individuals per guild counted in Pond 4 from Jan 1999 to Nov 2000.

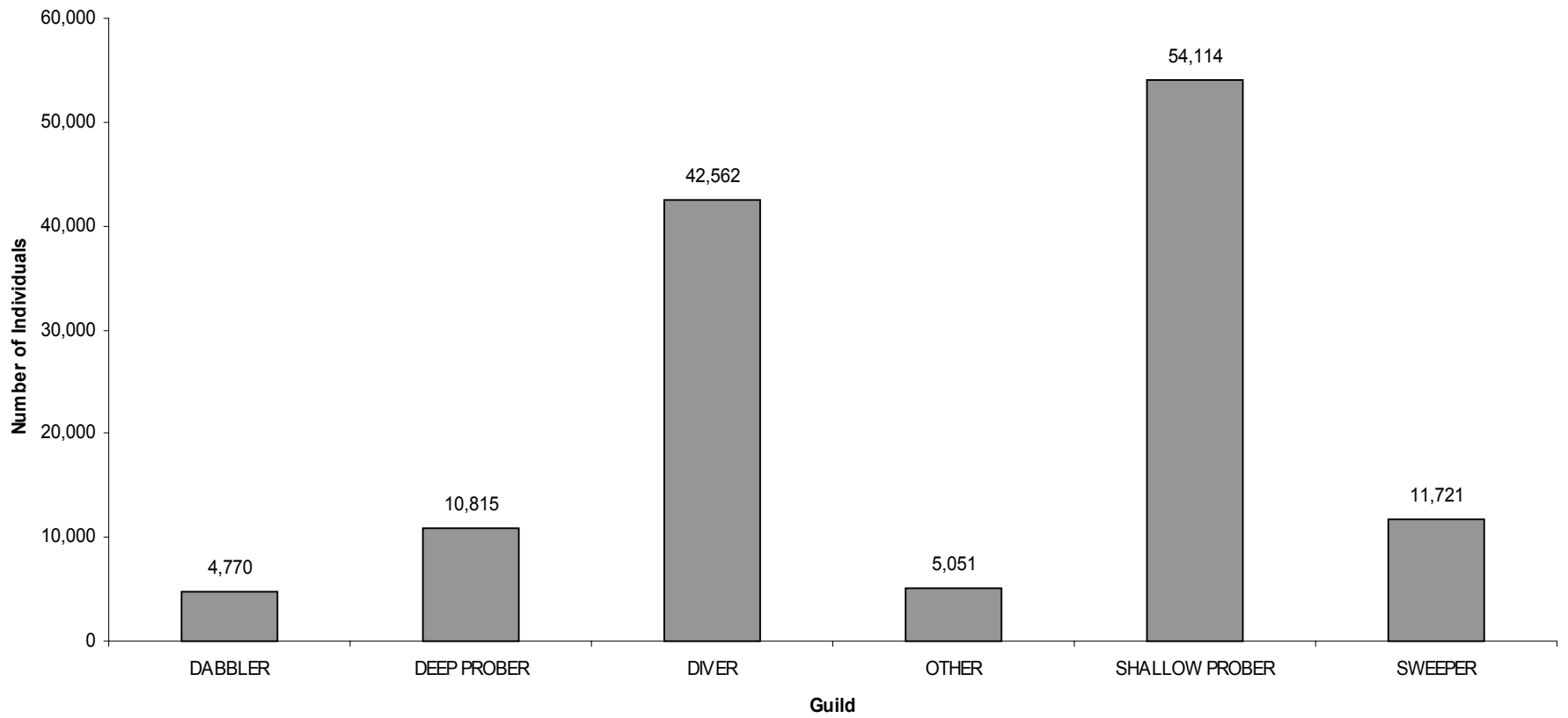


Figure 4e. Number of individuals per guild counted in Pond 2A from Jan 1999 to Nov 2000.

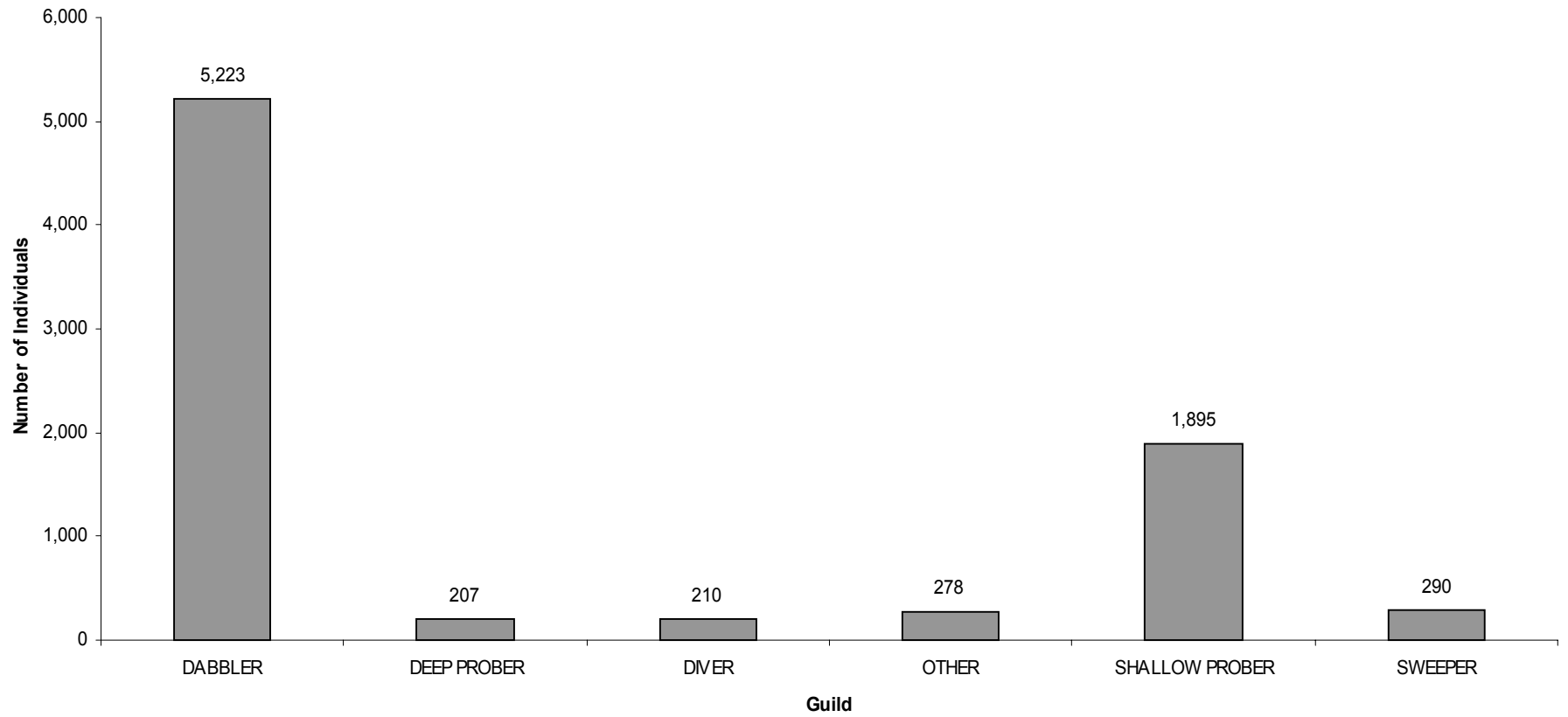
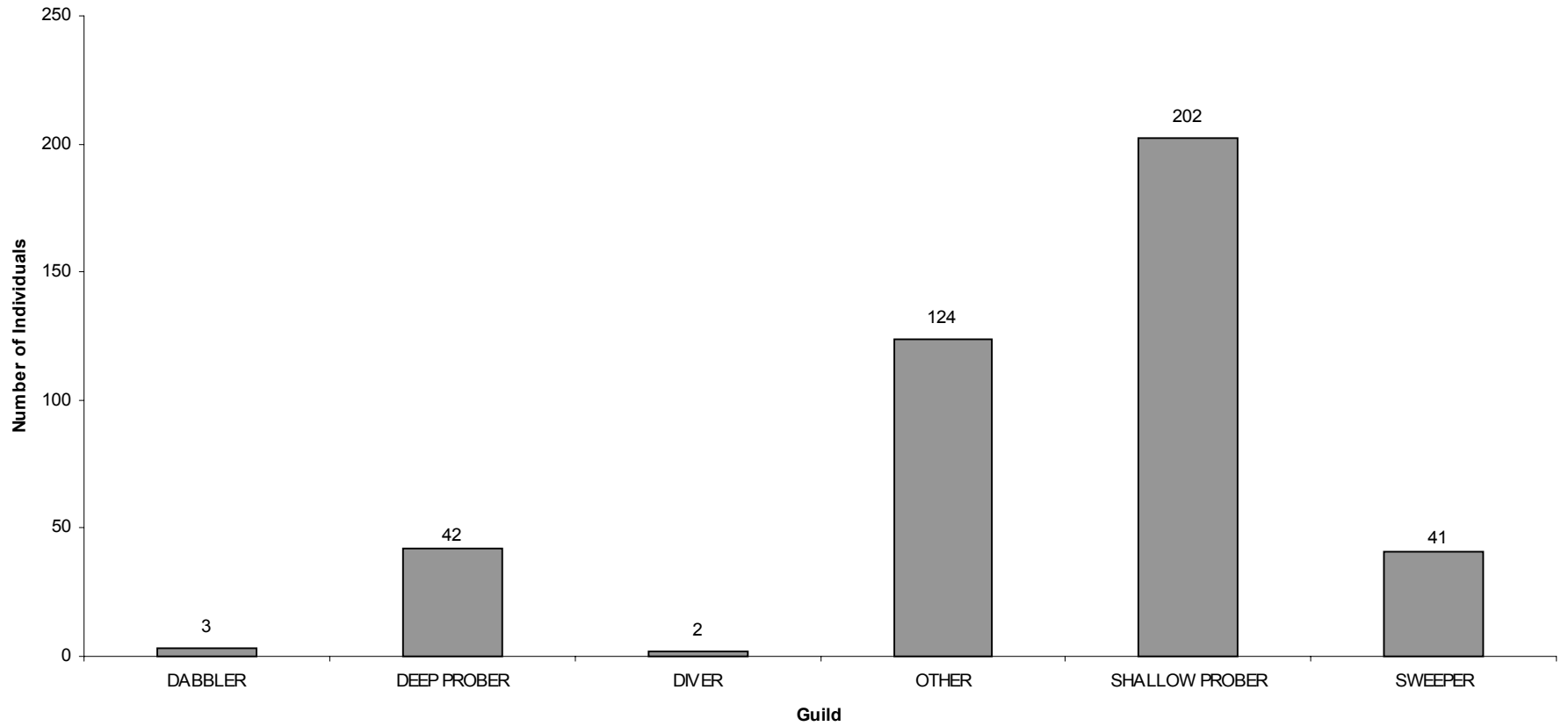
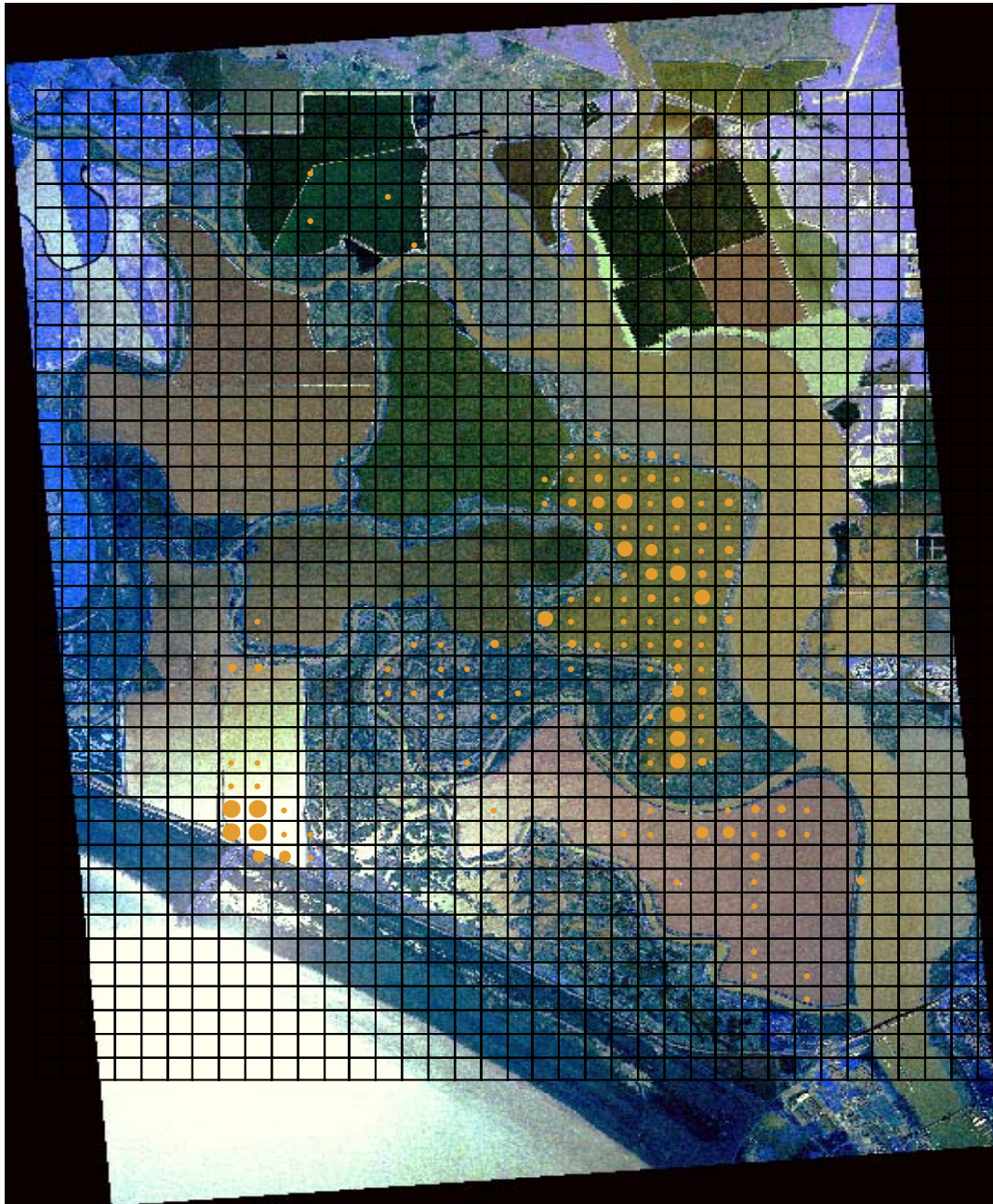


Figure 4f. Number of Individuals per guild counted in Pond 7 from Jan 1999 to Nov 2000.





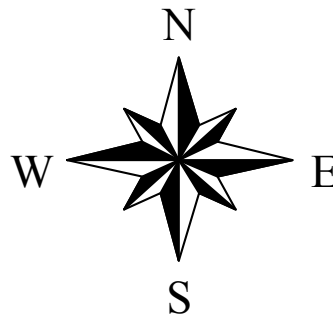
**Figure 5a. Distribution of sweepers by grid in the Napa-Sonoma salt ponds from Jan 1999 to Nov 2000.**



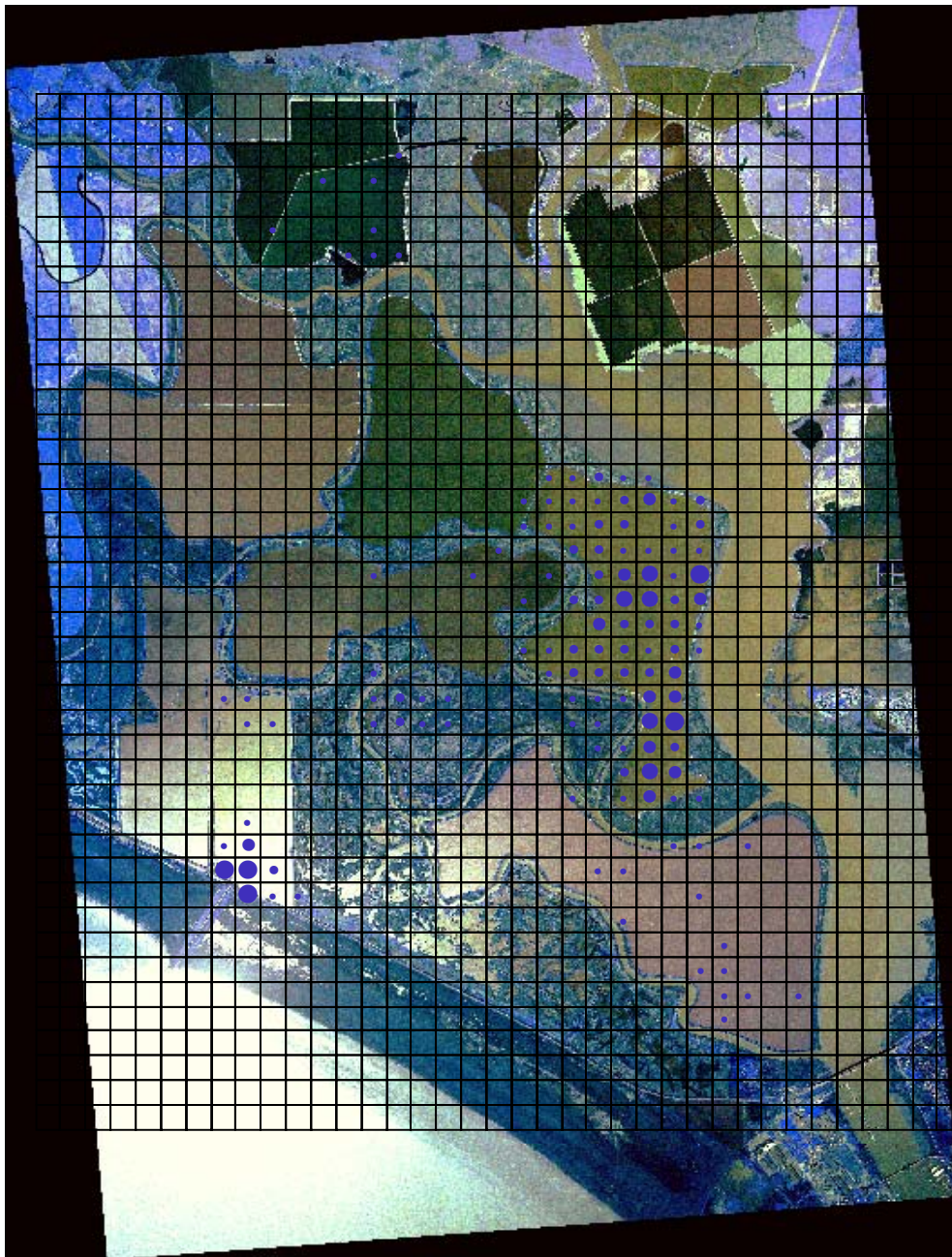
5000 0 5000 Meters

**Legend**

- 1 - 85
- 86 - 232
- 233 - 429
- 430 - 1012
- 1013 - 3168
- 250m sq grids

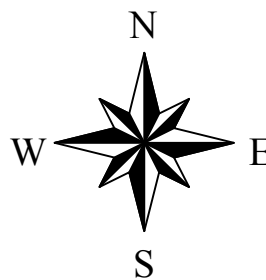


**Figure 5b. Distribution of shallow probers by grid in the Napa-Sonoma salt ponds from Jan 1999 to Nov 2000.**

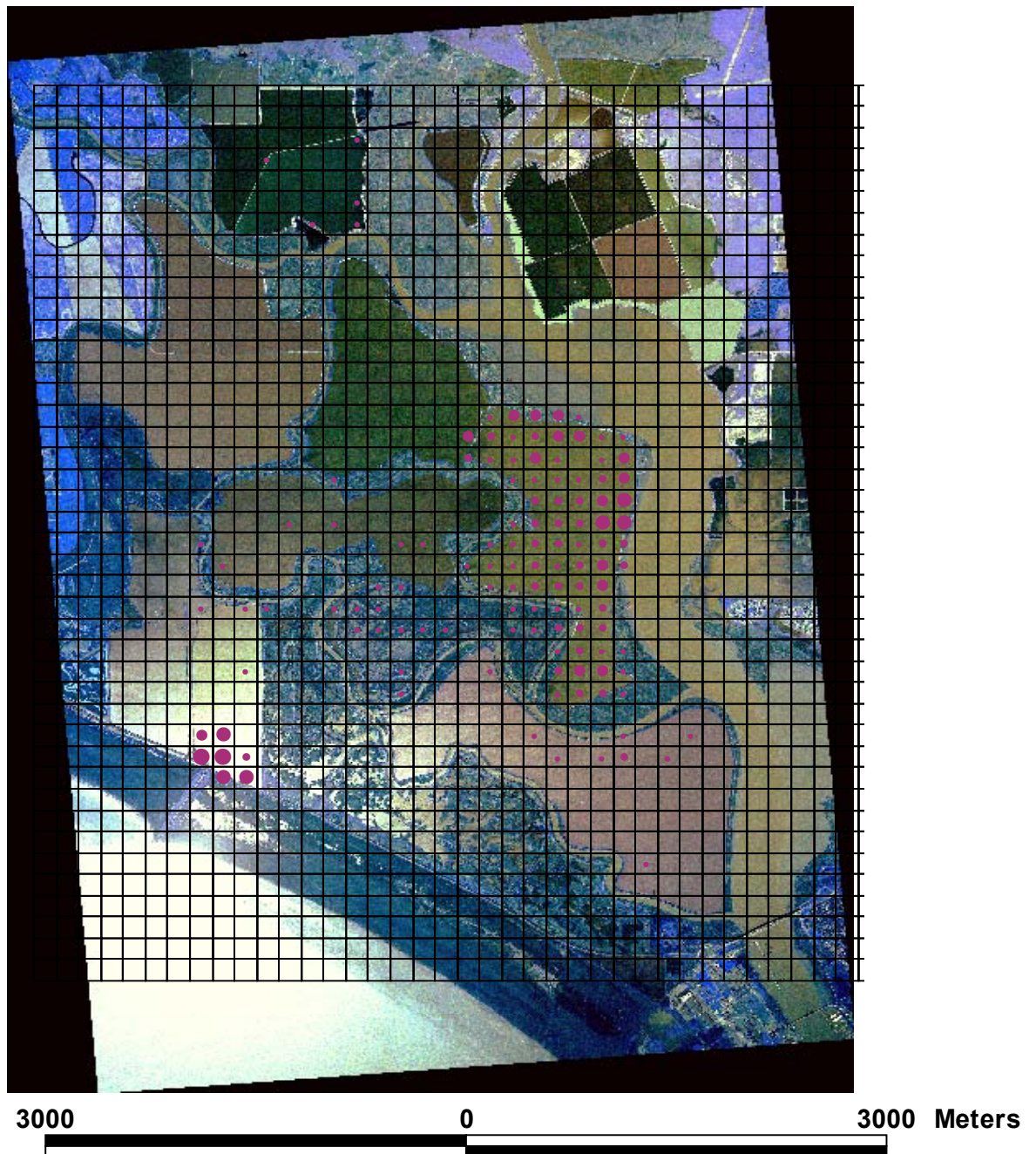


**Legend**

- 1 - 293
- 294 - 840
- 841 - 1733
- 1734 - 4541
- 4542 - 13736
- 250m sq grids

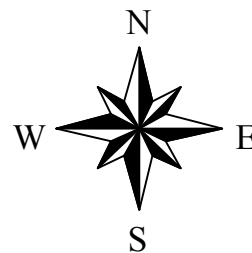


**Figure 5c. Distribution of deep probers by grid in the Napa-Sonoma salt ponds from Jan 1999 to Nov 2000.**

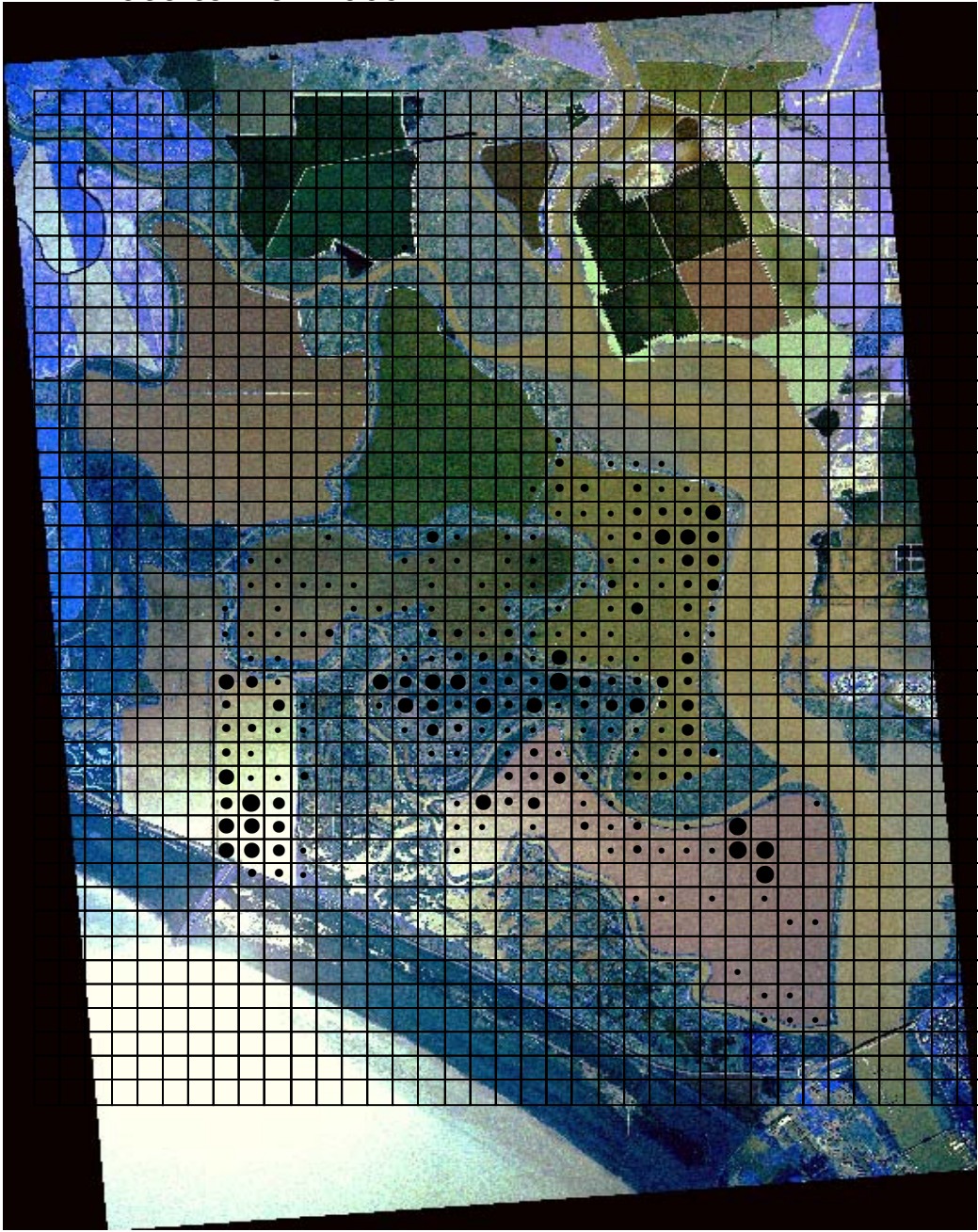


**Legend**

- 1 - 67
- 68 - 189
- 190 - 434
- 435 - 852
- 853 - 1476
- 250m sq grids

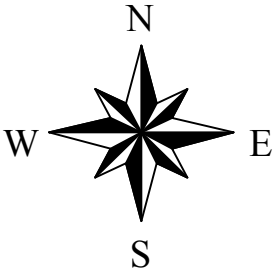


**Figure 5d. Distribution of dabblers by grid in the Napa-Sonoma salt ponds from Jan 1999 to Nov 2000.**

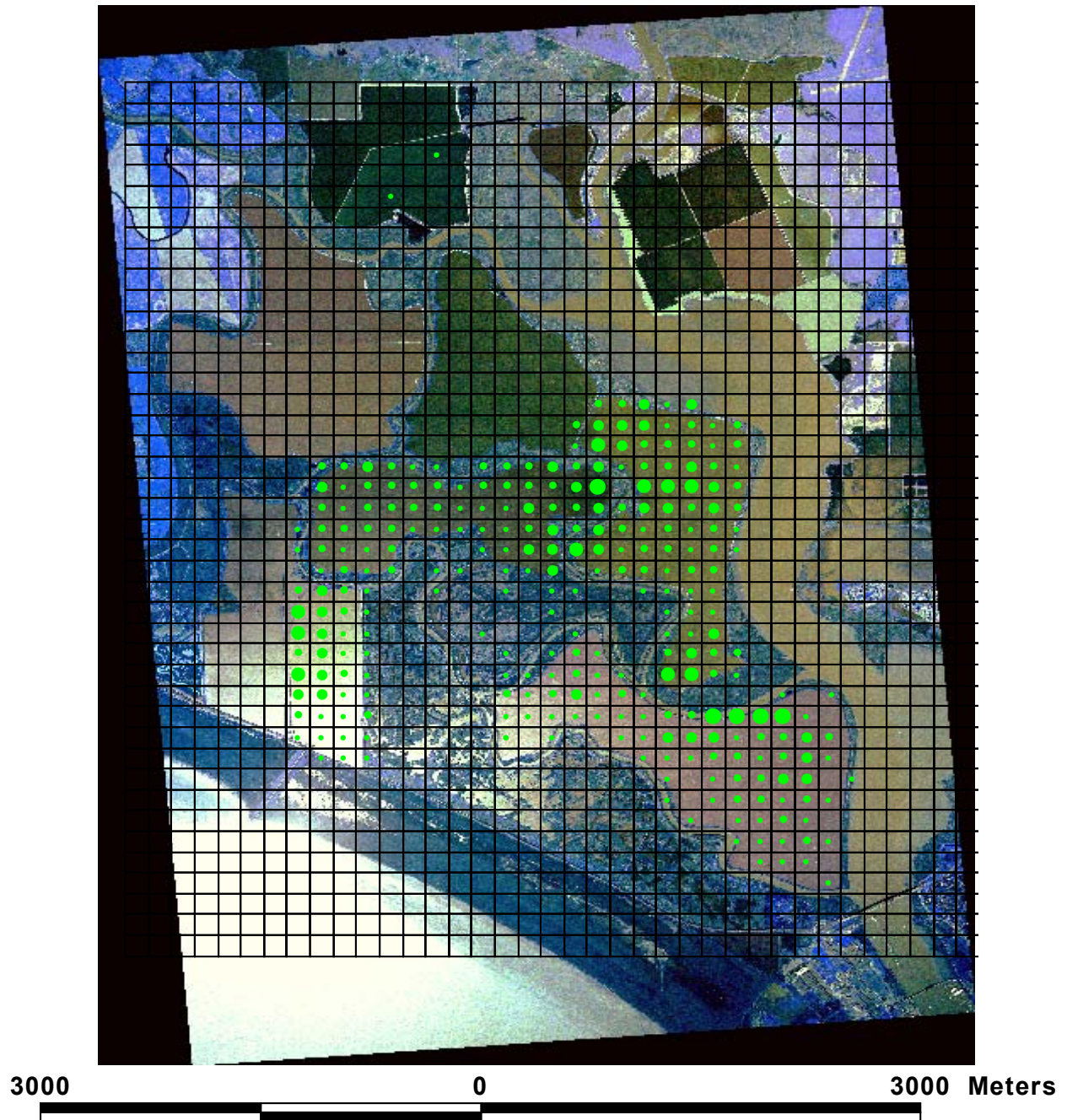


5000 0 5000 Meters

- Legend**
- 1 - 39
  - 40 - 123
  - 124 - 247
  - 248 - 476
  - 477 - 750
  - 250m sq grids



**Figure 5e. Distribution of diving benthivores by grid in the Napa-Sonoma salt ponds from Jan 1999 to Nov 2000.**



**Legend**

- 1 - 228
- 229 - 632
- 633 - 1341
- 1342 - 2337
- 2338 - 3966
- 250m sq grids

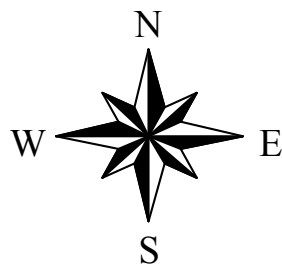


Figure 6. North Bay locations for Black-necked Stilts banded at Skaggs Island Road, Mare Island, and American Canyon.

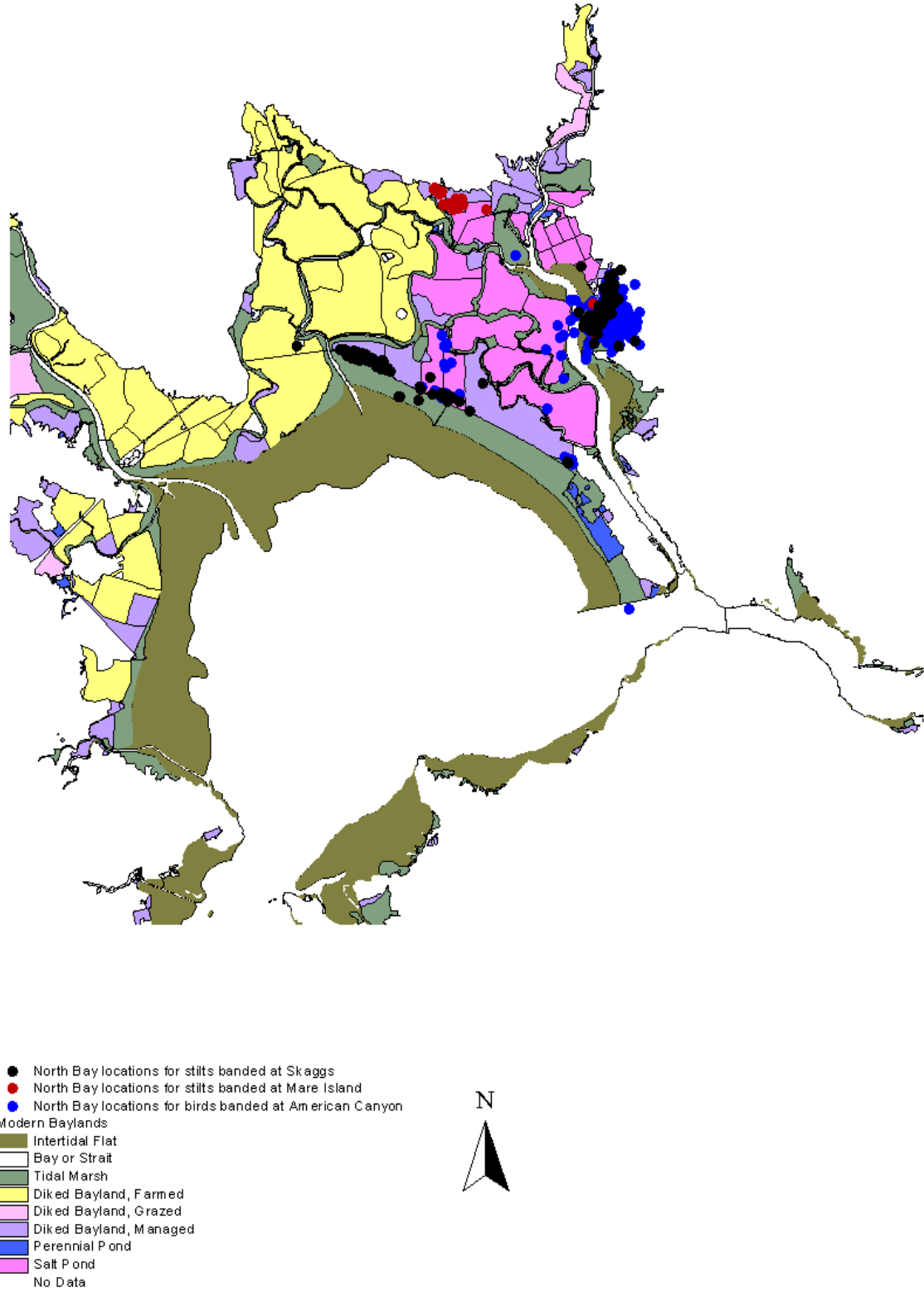


Figure 7. Long-billed dowitcher locations for the Northern San Pablo Bay.

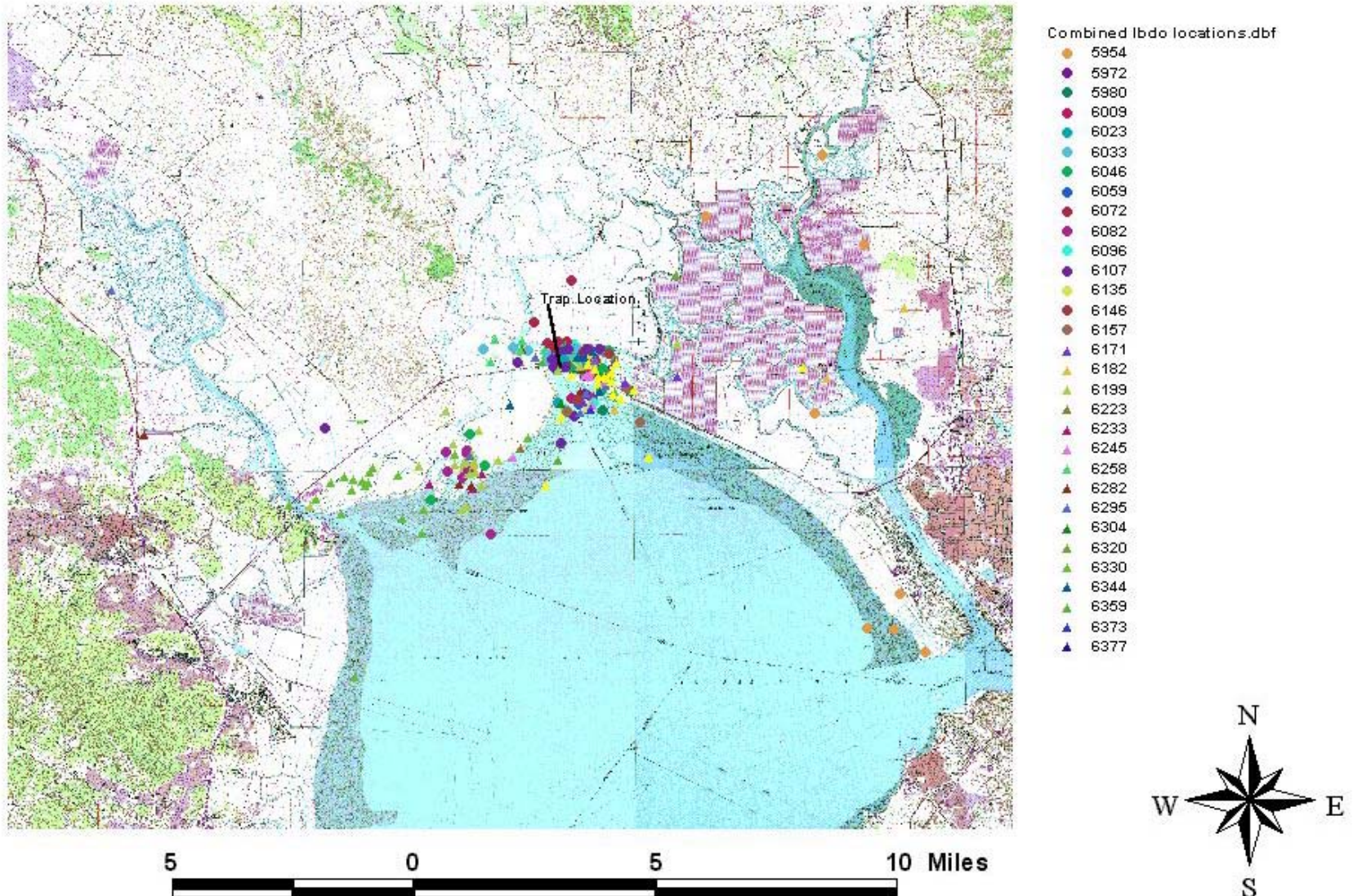


Figure 8. Total Long-billed dowitcher locations for the San Francisco Bay and Central Valley, CA.

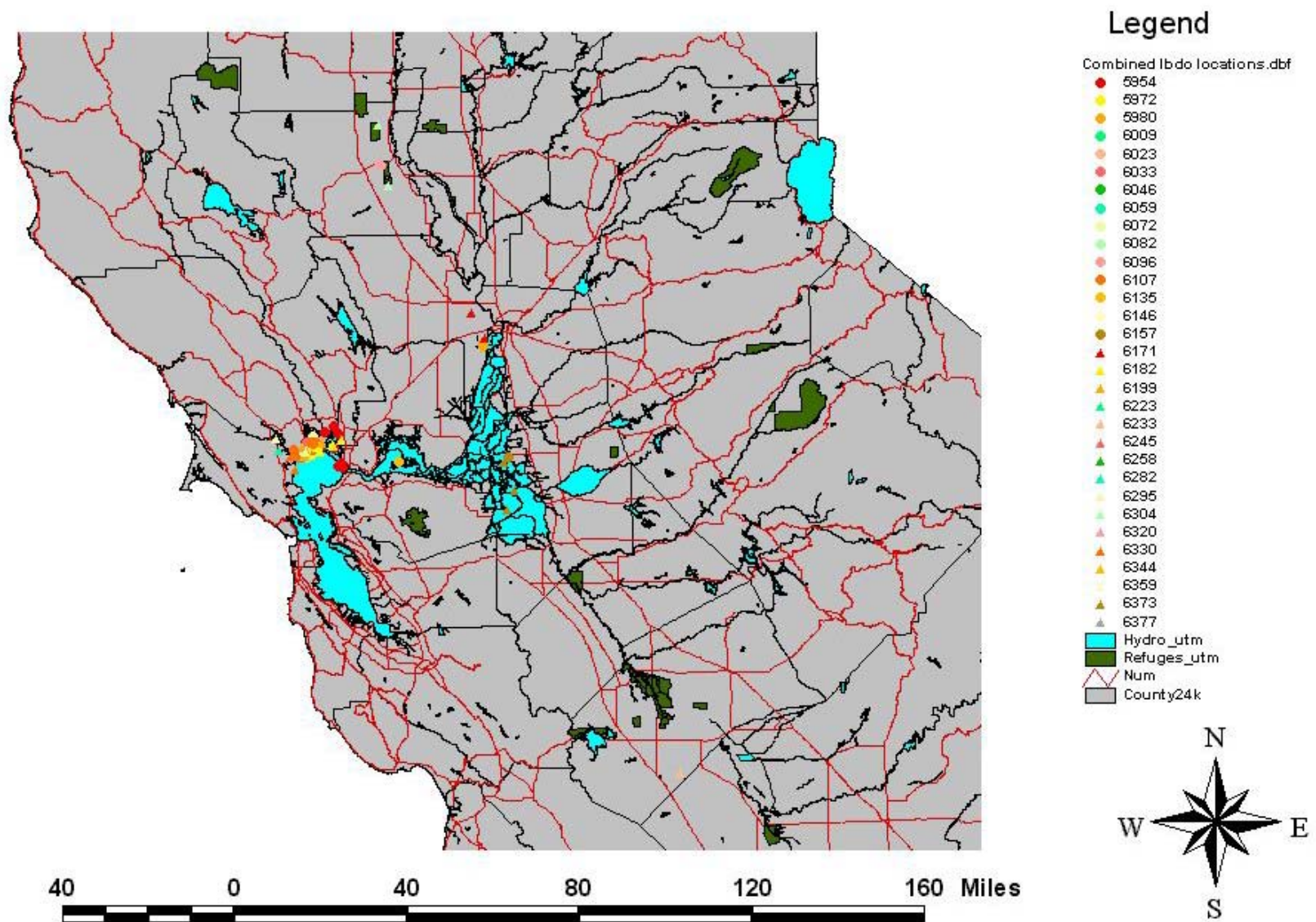




Figure 9a. Average temperature of the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

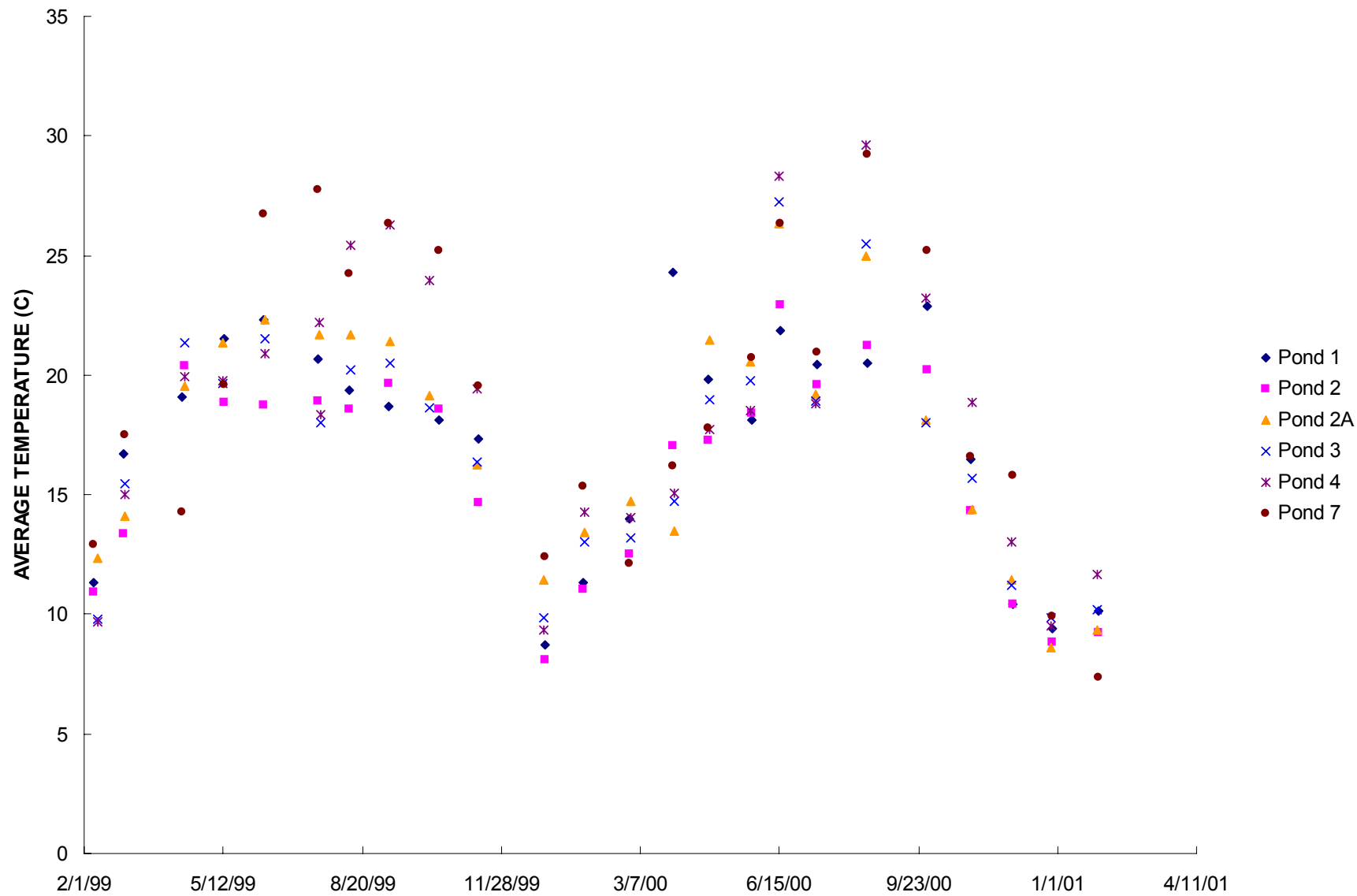


Figure 9b. Standard deviation of average temperature of the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

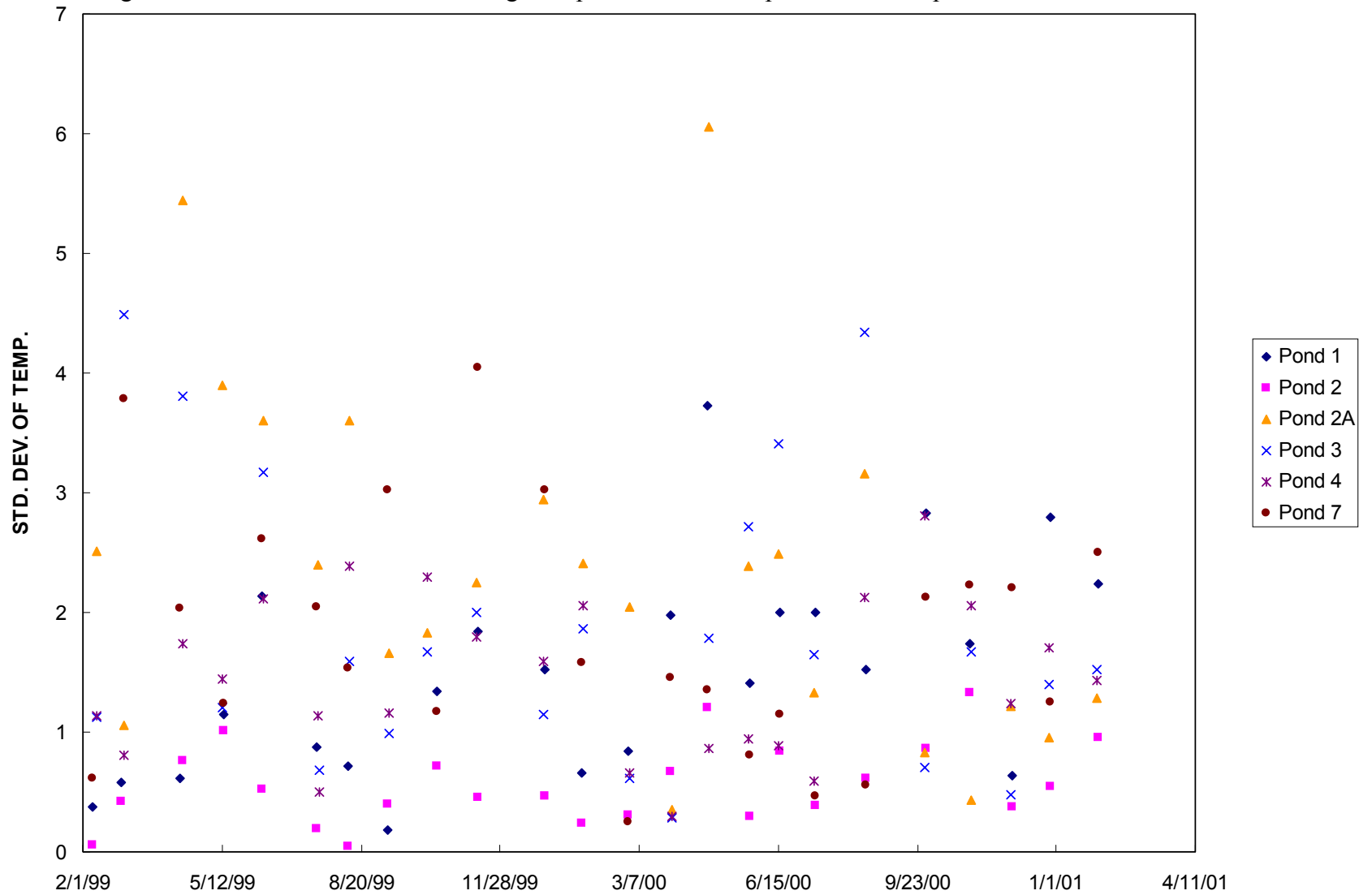


Figure 9c. Average turbidity of the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

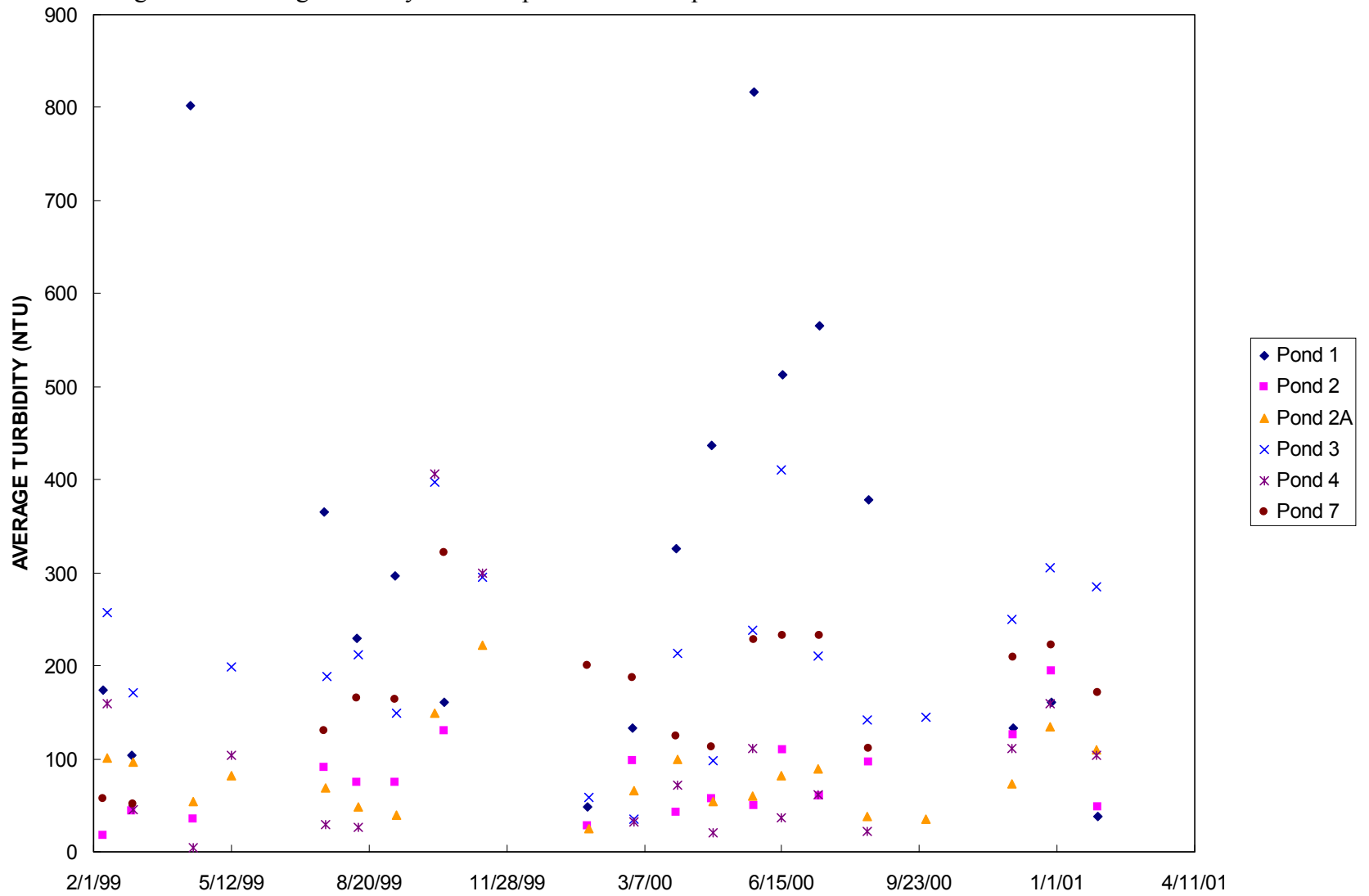


Figure 9d. Standard deviation of average turbidity of the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

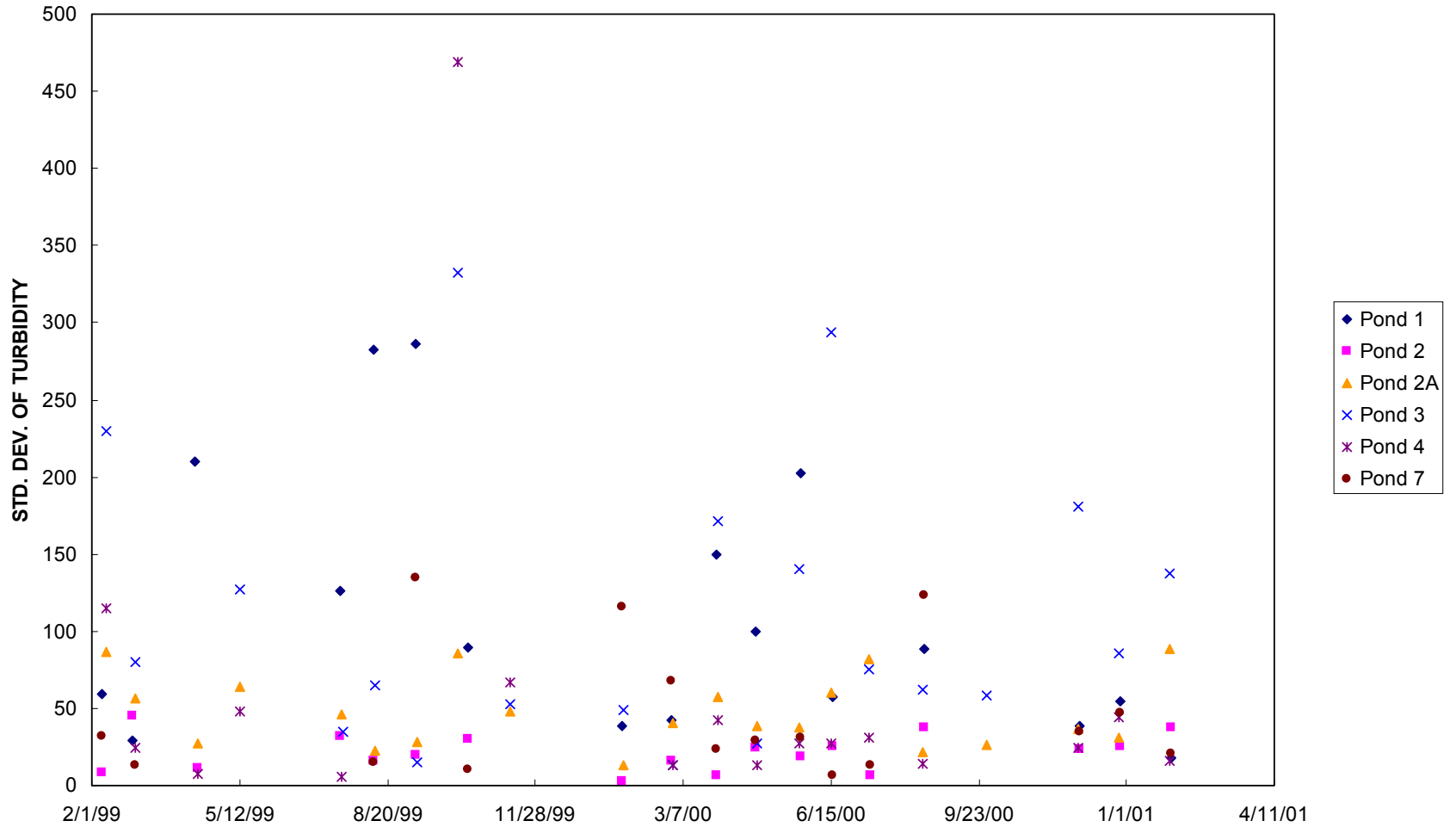


Figure 9e. Average pH of the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

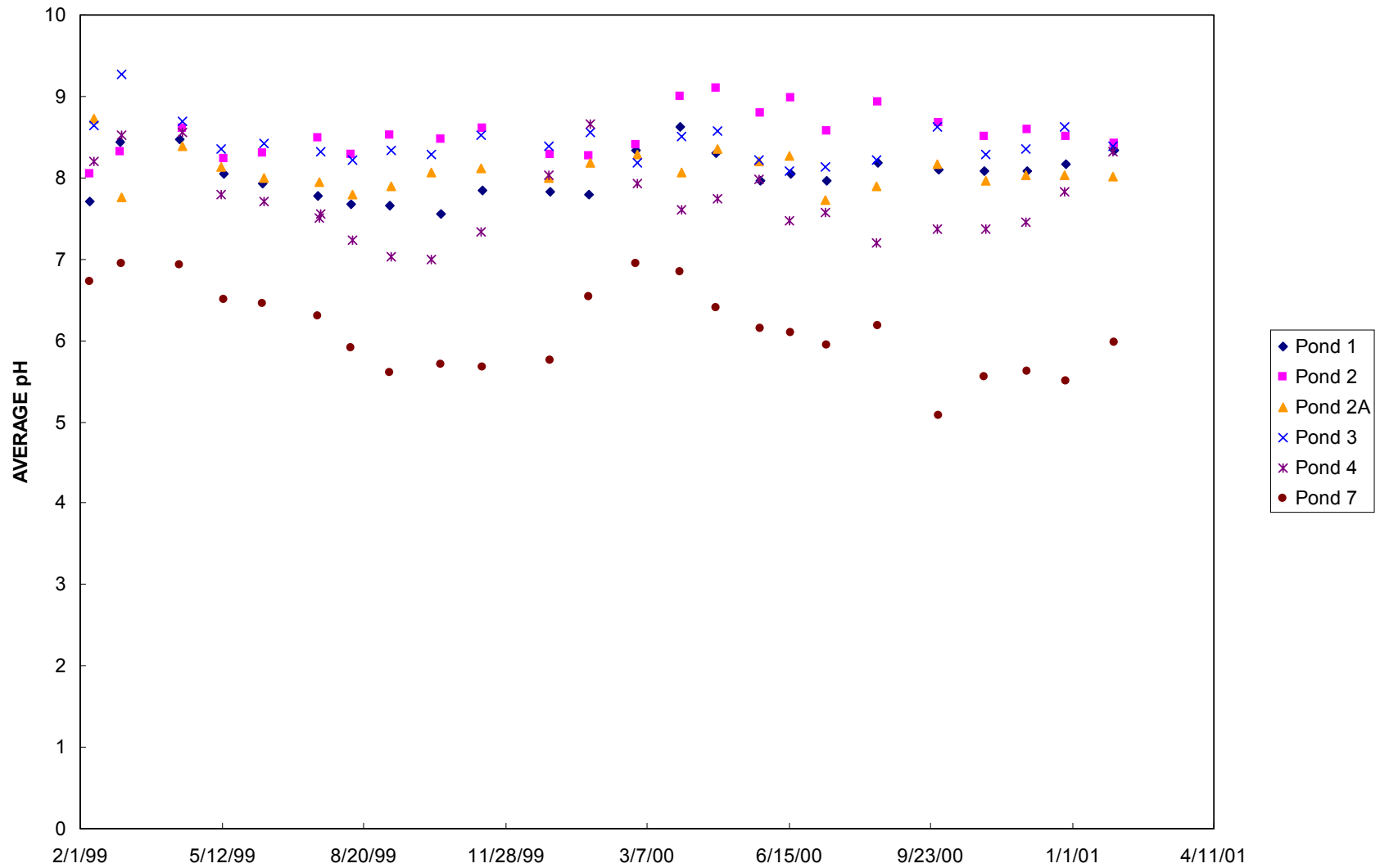


Figure 9f. Standard deviation of average pH of the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

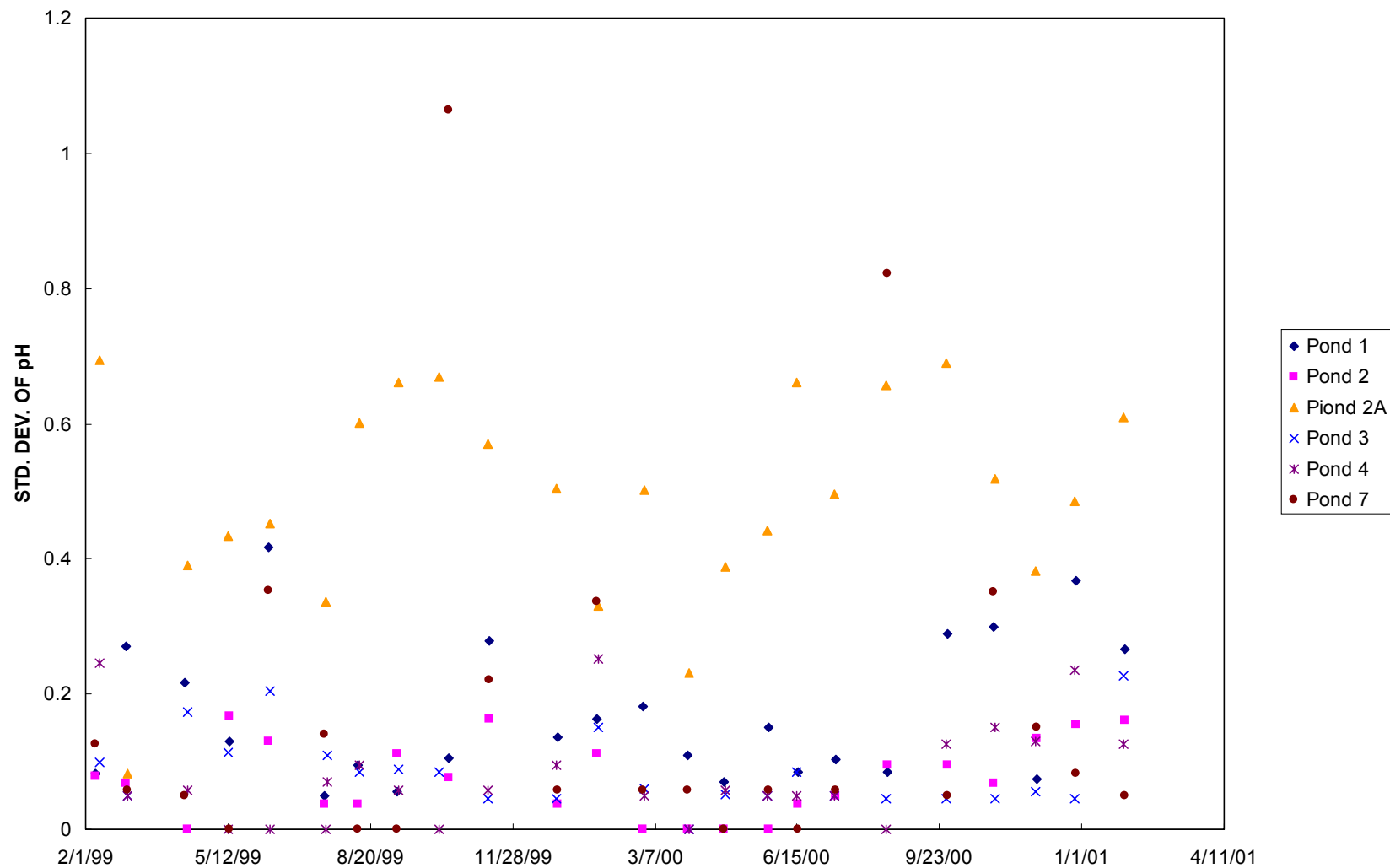


Figure 9g. Average salinity of the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

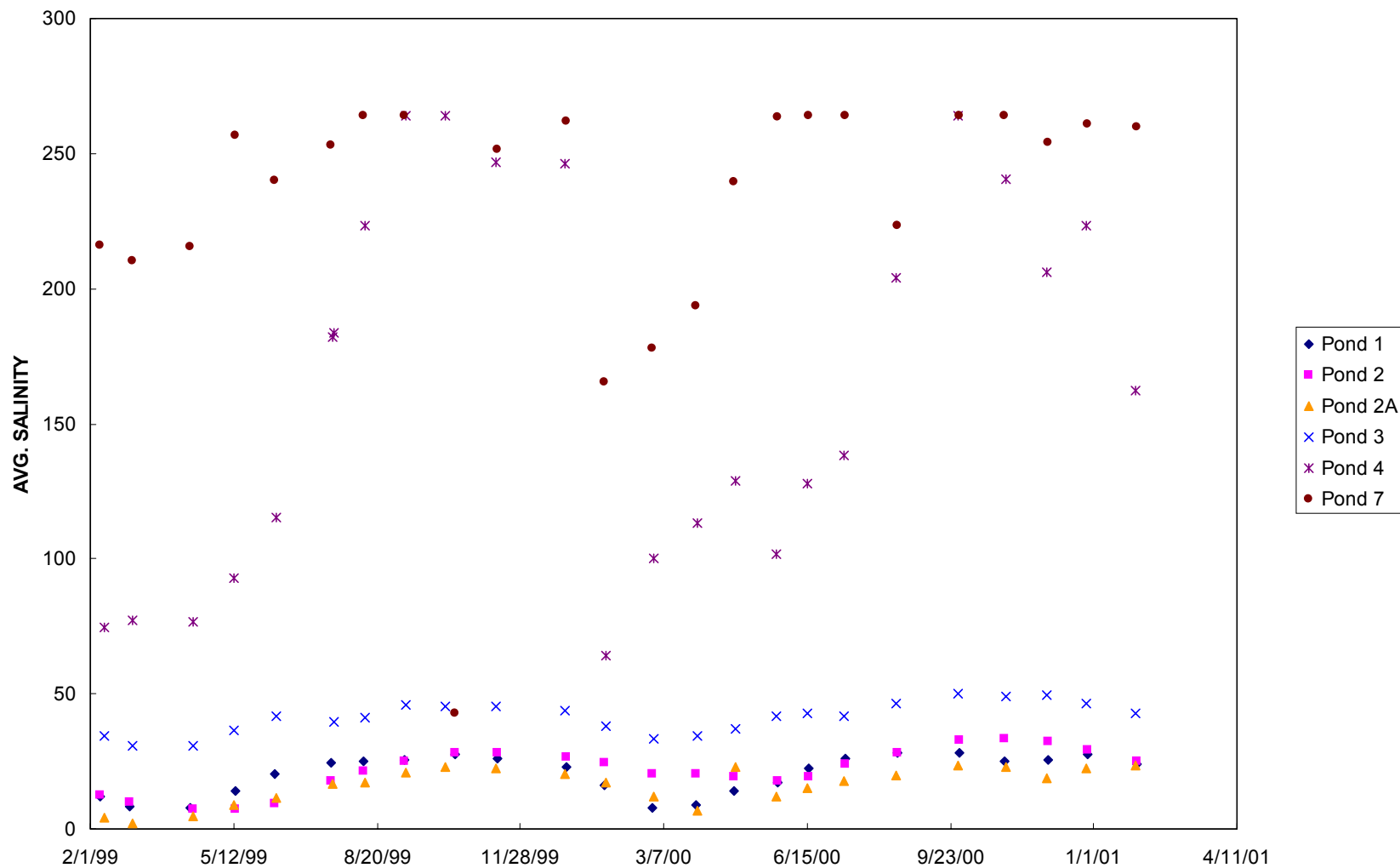


Figure 9h. Standard deviation of average salinity of the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

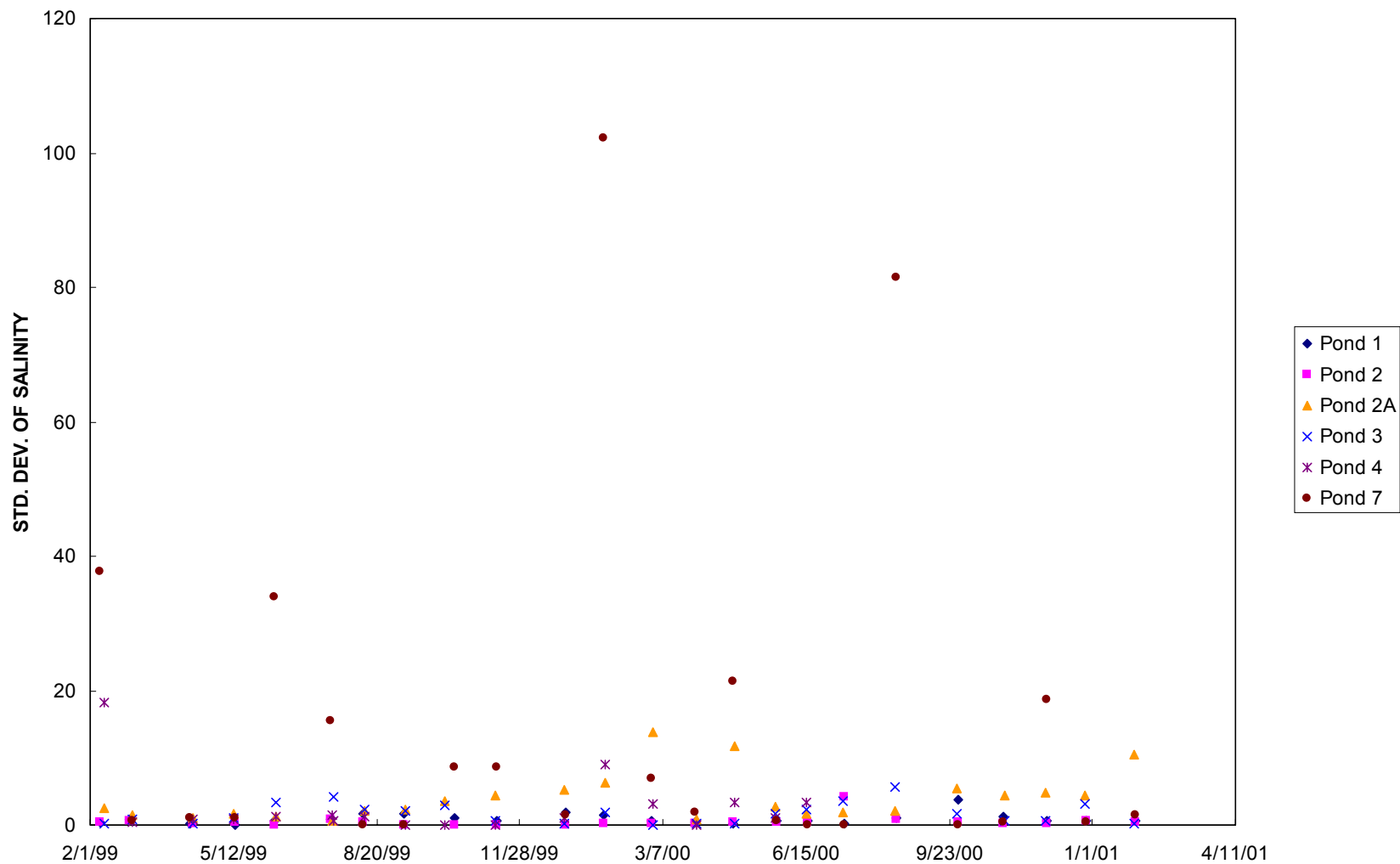




Figure 9i. Average dissolved oxygen of the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

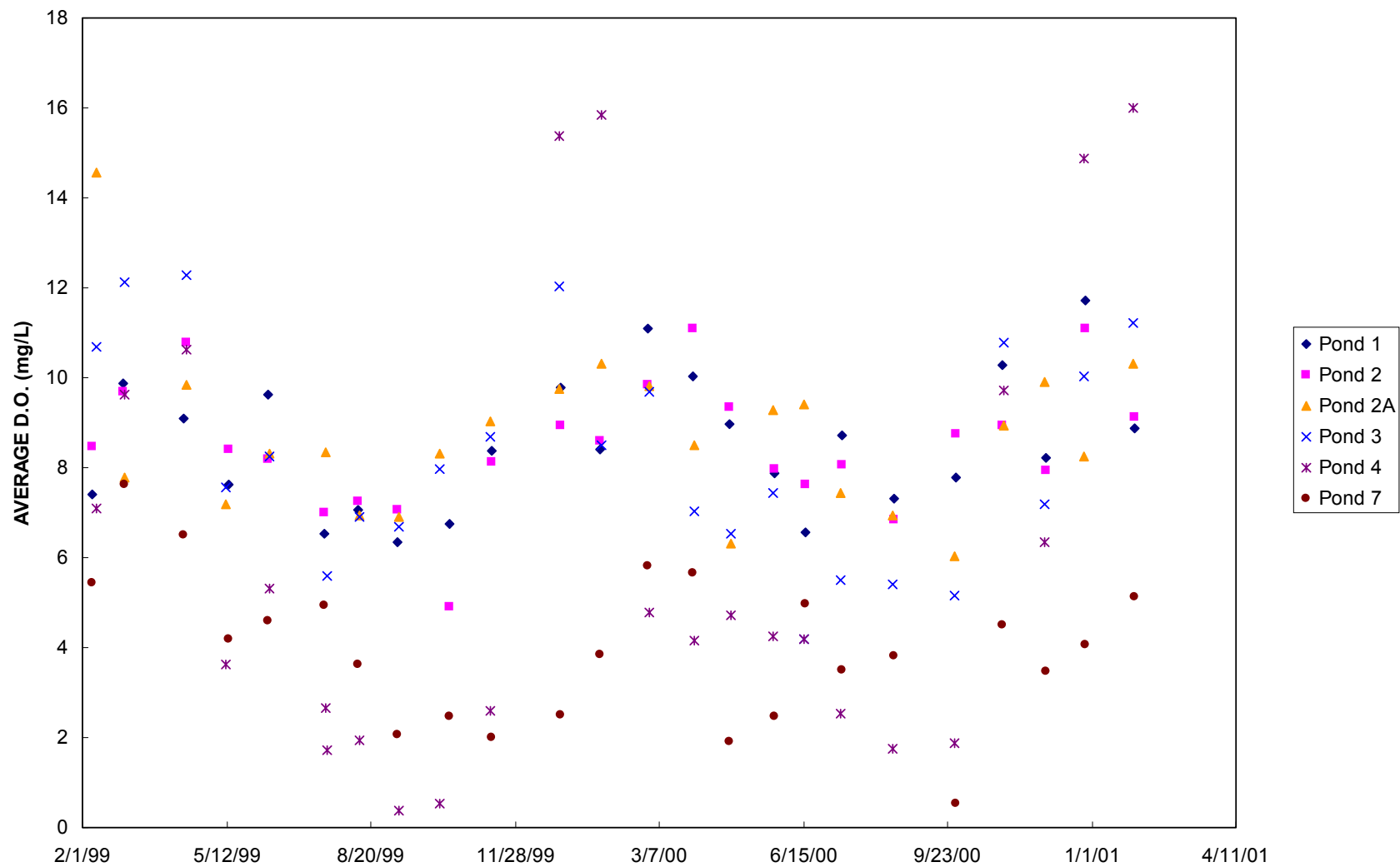


Figure 9j. Standard deviation of average dissolved oxygen of the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

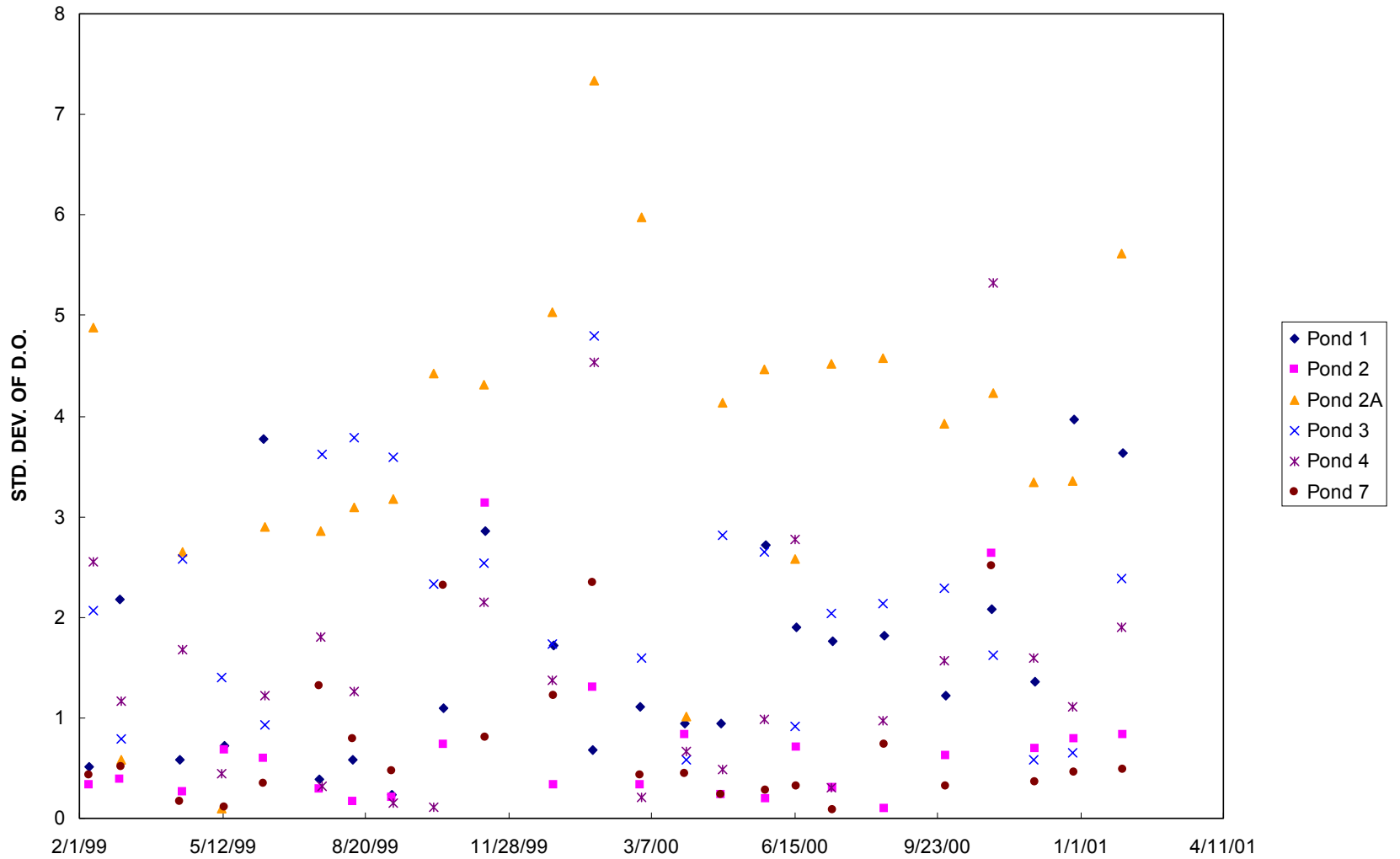


Figure 9k. Average pH vs. average salinity of the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

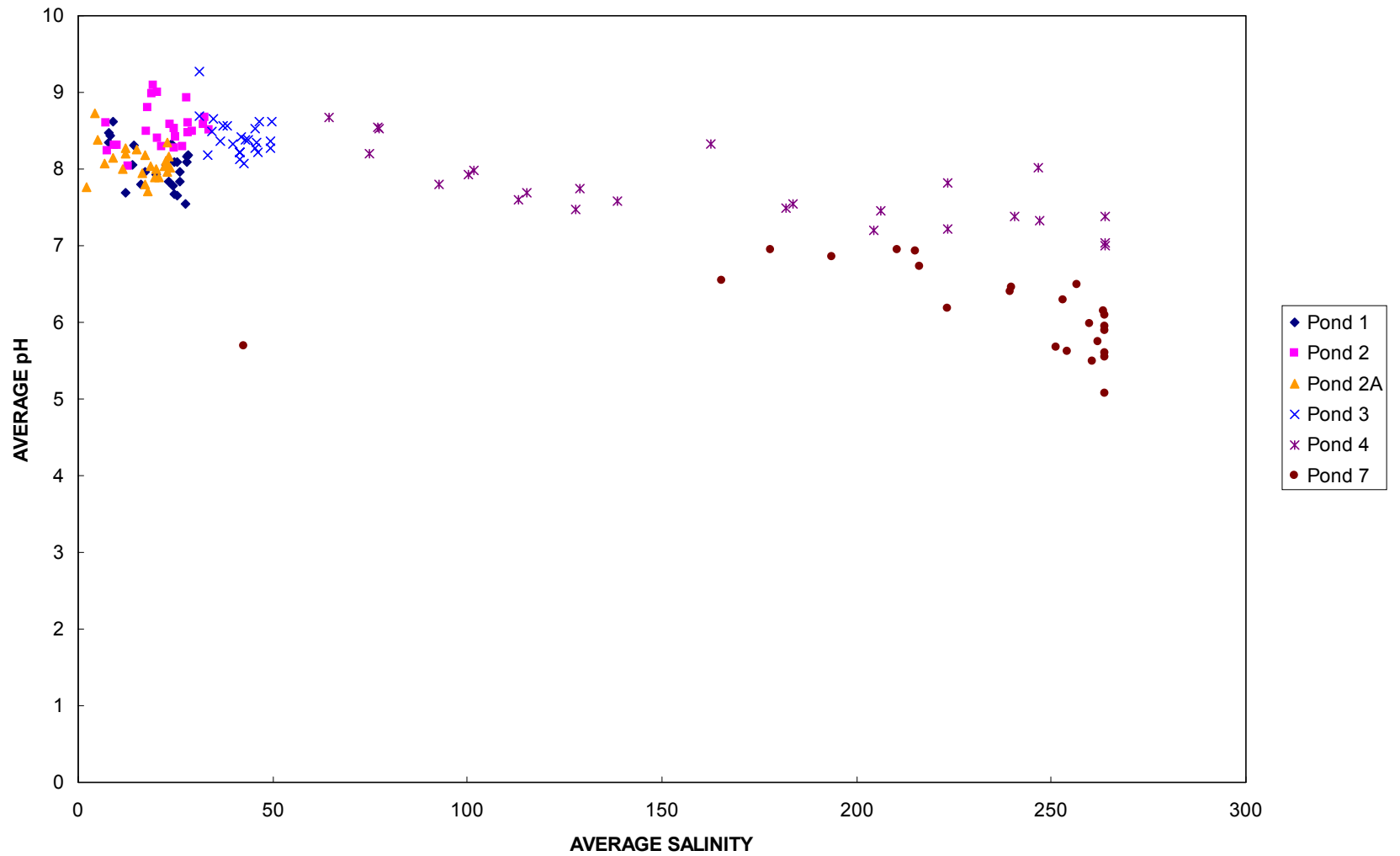


Figure 91. Average dissolved oxygen vs. average salinity of the Napa-Sonoma salt ponds from Feb 1999 to Jan 2001.

