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# UTILIZATION BY FISHES OF THE ALVISO ISLAND PONDS AND ADJACENT WATERS IN SOUTH SAN FRANCISCO BAY FOLLOWING RESTORATION TO TIDAL INFLUENCE

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## ABSTRACT

**Earthen levees of three isolated salt ponds known locally as the Alviso Island Ponds were intentionally breached in March 2006 to allow tidal exchange of the ponds with water from Coyote Creek. The water exchange transformed the previously fishless hypersaline ponds into lower salinity habitats suitable for fish life. This study documented fish utilization of the ponds, adjacent reaches of Coyote Creek, and an upstream reach in nearby Artesian Slough during May-July 2006. By the time the study was initiated, water quality conditions in the ponds were similar to conditions in adjacent reaches of Coyote Creek. The only variable exhibiting a strong gradient within the study area was salinity, which increased progressively from upstream to downstream in Coyote Creek. A total of 4,034 fish represented by 18 species from 14 families was caught during the study. Judging from cluster analysis of presence-absence data that excluded rare fish species, the 10 sampling units (3 ponds, 6 reaches in Coyote Creek, and 1 reach in Artesian Slough) formed two clusters or groups, suggesting two species assemblages. The existence of two groups was also suggested by ordination with non-metric multidimensional scaling (NMS). One group, which was composed of the three ponds and four of the lowermost reaches of Coyote Creek, was characterized by mostly estuarine or marine species (e.g., topsmelt,** ***Atherinops affinis*****; northern anchovy,** ***Engraulis mordax*****; and longjaw mudsucker,** ***Gillichthys mirabilis*****). The second group, which was composed of the two uppermost reaches of Coyote Creek and the one reach of Artesian Slough, was characterized by freshwater species (e.g., Sacramento sucker,** ***Catostomus occidentalis*****) and by an absence of the estuarine/marine species noted in the first assemblage. Judging from a joint plot of selected water quality variables overlaying the ordination results, salinity was the only important variable associated with spatial distribution of fish species. Water temperature, dissolved oxygen, and pH had little influence on fish distribution during this study.**

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## INTRODUCTION

Over the past 200 years, as much as 90% of natural tidal marsh and mudflat acreages in San Francisco Bay were lost from a combination of diking, draining, and filling to accommodate the needs of a rapidly growing human population center (Nichols et al. 1986). A portion of the lost tidal marshes and mudflats was converted into salt evaporation pond systems such as those found in the southern portion of the bay (South Bay). Although commercial salt production in the Alviso vicinity began in 1929, diking of marshes to create salt ponds occurred as recently as the early 1950s (Goals Project[2] 2000). In February 2003, about 6,111 ha of salt ponds were purchased from Cargill, Inc., for the South Bay Salt Pond Restoration Project (USFWS et al.[3] 2007). The goals of the South Bay Salt Pond Restoration Project, which involves collaboration among several federal, state, and local agencies, include restoring and enhancing a mix of wetland habitats, providing for flood management, and providing wildlife-oriented public access and recreation opportunities.

Earthen levees of three ponds (Ponds A19, A20, and A21) known locally as the Alviso Island Ponds were intentionally breached in 2006 (Fig. 1). Two trenches were dug across the levees at Pond A19 on 7 March and at Pond A20 on 12 March, and one trench was dug across the levee at Pond A21 on 29 March. These breaches opened the previously isolated ponds to tidal exchange.

Prior to breaching, the Alviso Island Ponds exhibited salinities of 92‰ to 456‰ (N.D. Athearn, U.S. Geological Survey, unpublished data). At salinities of 70‰ to 200‰, Franciscan brine shrimp, *Artemia franciscana*, dominate the macroinvertebrate community, and fish are absent (Goals Project[2] 2000). However, even brine shrimp may not occur when salinities exceed 200‰. Now that levees are breached, water from Coyote Creek enters the ponds on rising tides, and exits on ebbing tides. This water exchange has transformed the previously fishless high salinity ponds into lower salinity habitats potentially suitable for fish life.

The purpose of this study was to document the effects of levee breaching on fish utilization of the Alviso Island Ponds and adjacent reaches of Coyote Creek and the nearby Artesian Slough. Specific objectives were as follows: 1) conduct an inventory of fish species shortly after the levees were breached; 2) monitor selected water quality variables; and 3) determine if the distribution of fish species was associated with water quality conditions.

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[2]Goals Project. 2000. Baylands ecosystem species and community profiles: life histories and environmental requirements by key plants, fish and wildlife. Prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. P.R. Olofson, editor. San Francisco Bay Regional Water Quality Control Board, Oakland, California, USA.

[3]USFWS et al. (U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, and California Department of Fish and Game). 2007. South Bay Salt Pond Restoration Project; draft environmental impact statement/environmental impact report. U.S. Fish and Wildlife Service, Don Edwards San Francisco Bay National Wildlife Refuge, Newark, California, USA. (Accessed from *http://www.southbayrestoration.org/EIR/downloads.html* on 24 October 2007.)

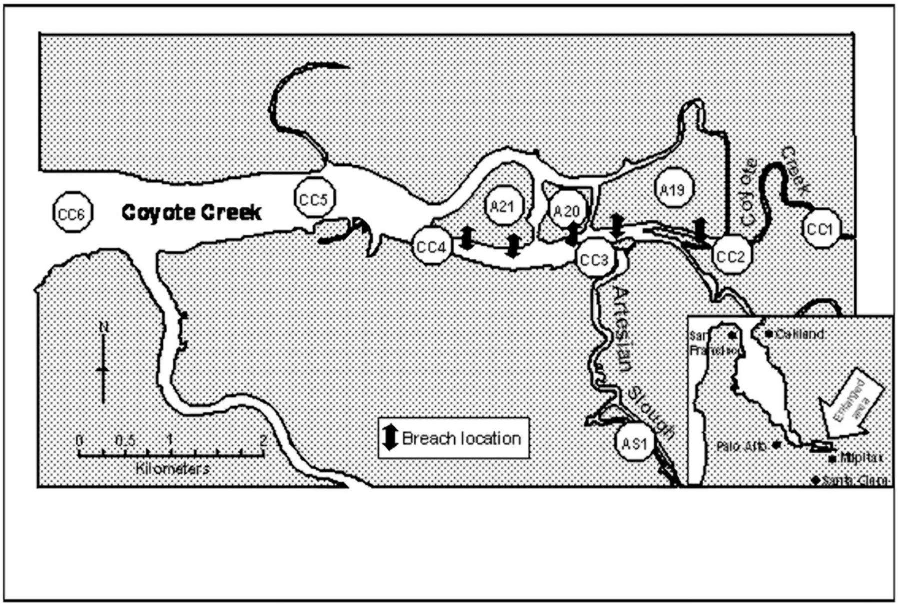


**Figure 1.** Map of the study area showing locations of the Alviso Island Ponds (A19, A20, and A21), six reaches of Coyote Creek (CC1 to CC6), and Artesian Slough (AS1). Each pond or reach constitutes a sampling unit.

## STUDY AREA

The study area encompassed the three Alviso Island Ponds (A19, A20, and A21) and a roughly 10-km reach of Coyote Creek adjacent to the ponds (Fig. 1). The Alviso Island Ponds are located in Alameda County whereas Coyote Creek within the study area roughly follows the dividing line between Alameda and Santa Clara counties. In addition, a 3-km reach of Artesian Slough in Santa Clara County was included in the study area because it feeds into Coyote Creek immediately south of Ponds A19 and A20. Coyote Creek drains approximately 830 km$^2$ and constitutes the largest watershed in Santa Clara County (USFWS and SCVWD[4] 2006). Artesian Slough receives over 378.5 X 10$^6$ liters of treated wastewater daily from the San Jose/Santa Clara Water Pollution Control Plant.

Pond A19 has a surface area of 107 ha, Pond A20 has a surface area of 25.5 ha, and Pond A21 has a surface area of 59.5 ha. The bottom topography of each pond was relatively flat, with borrow ditches located roughly parallel to the levees. The ditches

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[4]USFWS and SCVWD (U.S. Fish and Wildlife Service and Santa Clara Valley Water District). 2006. Final restoration and mitigation monitoring plan for the Island Ponds Restoration Project. U.S. Fish and Wildlife Service, Don Edwards San Francisco Bay National Wildlife Refuge, Newark, California, USA. (Accessed from *http://www.valleywater.org/media/pdf/SPEC%20PROJ/5-06-Island%20Ponds%20Final%20RMMP.pdf* on 24 October 2007.)

were created by excavating sediments during levee construction and maintenance. During our study, a layer of gypsum (calcium sulfate) blanketed the entire bottom of each pond, including the borrow ditches. Gypsum is a natural precipitate that forms during salt production when brines exceed 147‰ (Ver Planck 1958).

Water depths in the Alviso Island Ponds averaged <1 m during high tide, although the deepest portions of borrow ditches occasionally measured as much as 2 m in depth. During low tide, large expanses of pond bottom were above water, with only the borrow ditches remaining wet. By comparison, maximum depths in Coyote Creek varied from <1 m upstream from the ponds to as much as 5 m downstream, whereas maximum depths in Artesian Slough varied from 2 m to >3 m.

According to compliance regulations ordered by the San Francisco Regional Water Quality Control Board, brines exceeding salinities of 135‰ cannot be discharged into receiving waters such as San Francisco Bay (USFWS and SCVWD[4] 2006). To comply with these regulations, excess brine from the Alviso Island Ponds was pumped to a nearby pond for temporary storage. Thus, at the time of levee breaching, brine covering the floor of the Alviso Island Ponds was less than 15 cm deep. Moreover, precipitation during winter 2005 had diluted the brine to an average salinity of 75‰ (range, 56-101‰; N.D. Athearn, unpublished data).

## MATERIALS AND METHODS

Field work was conducted during daylight hours on three occasions as follows: 22-26 May, 19-29 June, and 9-21 July 2006. Sampling occurred at 1-3 randomly selected sites within each pond, 6 reaches in Coyote Creek, and 1 reach in Artesian Slough. In Coyote Creek, the reaches were arranged in a longitudinal (upstream-downstream) pattern, with two reaches located upstream from the ponds, two reaches located adjacent to the ponds, and two reaches located downstream from the ponds. The reach in Artesian Slough was located upstream from the confluence with Coyote Creek. (Note: hereinafter, the ponds and reaches will be referred to as "sampling units.")

Grab measurements of water quality were taken just beneath the surface in the Alviso Island Ponds, and from surface to bottom at 1-m intervals in Coyote Creek and Artesian Slough. The measurements were made with a Hydrolab DataSonde 3 multiprobe (Hach Environmental, Loveland, Colorado; *http://www.hydrolab.com/*).

Fish were sampled with two floating variable-mesh monofilament gill nets fished for 2 hours and five baited minnow traps fished for 1 hour. These standard levels of fishing effort were used to compare catches over sampling units (ponds and reaches) and dates (months). Gill nets were 38 m long by 1.8 m deep, and consisted of five 7.6-m-long panels containing square-mesh of 12.7 mm, 15.4 mm, 38.1 mm, 50.8 mm, and 63.5 mm (Nylon Net Company, Memphis, Tennessee). Minnow traps were 25.4 cm high, 25.4 cm wide, and 43.2 cm long, with 3.2-mm square mesh (Netco, Memphis, Tennessee). Each minnow trap was baited with about 57 g of fish-flavored canned cat food (Special Kitty® "Tuna Dinner" Premium Cat Food, marketed by WalMart Stores, Inc., Bentonville, Arkansas) held in perforated plastic snap-top containers. All fish sampling occurred during slack high tide when water covered the pond bottoms and current flow was negligible. Captured fish were identified to species, counted, then either released alive or sacrificed by preservation in 99% isopropyl alcohol for species verification.

## Statistical Analyses

Chi-square analysis of fish counts was used to determine if proportions of captured fish species differed between gill nets and minnow traps. To compare the catches, we used counts of common and abundant species, plus an additional category consisting of all rare species combined. The rare species, which were arbitrarily defined as taxa represented by 15 or fewer individuals, included Mississippi silverside, *Menidia audens*, threadfin shad, *Dorosoma petenense*, prickly sculpin, *Cottus asper*, rainwater killifish, *Lucania parva*, arrow goby, *Clevelandia ios*, bat ray, *Myliobatis californica*, starry flounder, *Platichthys stellatus*, western mosquitofish, *Gambusia affinis*, and white croaker, *Genyonemus lineatus*.

The combined counts of common and abundant fish species captured with gill nets and minnow traps were converted to presence-absence to examine spatial distribution patterns. According to Jackson and Harvey (1997), presence-absence data obtained with multiple gears fished in a variety of habitats is more likely to yield unbiased information on the structure of fish communities than relative abundance data obtained with a single gear. Ward's minimum-variance method of cluster analysis was performed with presence-absence data to determine if two or more species assemblages were present (McCune and Grace 2002). The number of "significant" clusters was determined by plotting semi-partial $R^2$ values with their corresponding cluster numbers, where the number of significant clusters corresponded to the largest observed reduction in semi-partial $R^2$ values (Khattree and Naik 2000).

A joint plot of non-metric multidimensional scaling (NMS) ordination scores was used to corroborate findings from cluster analysis for grouping the sampling units and to examine relations between fish species and water quality variables. The NMS ordination was performed with a main data matrix consisting of species presence-absence at various sampling units, and a second data matrix consisting of selected water quality variables (temperature, dissolved oxygen, pH, and salinity; McCune and Mefford 1999). Prior to conducting the ordination, all water quality variables were subjected to a "general relativization" procedure so that values varied between 0 and 1. The NMS was conducted in autopilot mode with the following settings: a 6-dimensional solution as a starting point based on Sorensen (Bray-Curtis) distance measurements with slow and thorough speed, 250 runs with real data and 250 runs with randomized data, a stability criterion of 0.00001, and 20 runs to evaluate stability. In addition, as recommended by McCune and Grace (2002), we chose to accept the NMS ordination solution only if it resulted in a computed stress value <20. After achieving an acceptable 2-dimensional solution, we constructed a joint plot of ordination results overlaid by water quality variables. For a given water quality variable, the length of the arrow (vector) constitutes the hypotenuse of a right triangle, with the two other sides corresponding to Pearson correlation coefficients (r values) between the variable and the two axes of the joint plot.

With one exception, all statistical computations were conducted with SAS software for Windows, version 9.1 (SAS Institute Inc., Cary, North Carolina). The NMS analysis was exceptional because it was computed with PC-ORD, version 5.2 for Windows (MjM Software Design, Gleneden Beach, Oregon). Unless indicated otherwise, results of statistical tests were deemed significant when $P \leq 0.05$.

## RESULTS

### Water Quality Characteristics

Water quality in the Alviso Island Ponds, Coyote Creek, and Artesian Slough exhibited temporal and spatial variations during the 3-month period covered by this study. In general, temperature and salinity increased from May to July, whereas dissolved oxygen and pH decreased over the same time interval (Fig. 2). Spatial patterns were not clearly discernible for water temperature, dissolved oxygen, and pH (Fig. 2). By comparison, salinity exhibited a distinct longitudinal (upstream-downstream) pattern especially in Coyote Creek, with relatively low salinities at the uppermost reach and progressively higher salinities in downstream reaches. Although salinities in ponds were slightly higher than in adjacent reaches of Coyote Creek, they were generally lower than in the two lowermost reaches of the creek. By comparison, salinities in Artesian Slough were similar to those in the uppermost reach of Coyote Creek.

### Abundance and Distribution of Fish Species

A total of 4,034 fish represented by 18 species from 14 families was caught during this study (Table 1). Although gill nets accounted for only slightly more than one-third of the total catch, this gear captured 11 species. By comparison, almost twice as many fish were caught with minnow traps, but the catch was represented by only nine species. In addition, the proportions of captured species varied significantly between gill nets and minnow traps ($\chi^2 = 3{,}900$ df = 9, $P < 0.0001$), with gill nets catching mostly topsmelt, *Atherinops affinis* (68.7%), striped bass, *Morone saxatilis* (14.7%), and northern anchovy, *Engraulis mordax* (7.3%), and minnow traps catching mostly threespine stickleback, *Gasterosteus aculeatus* (96.5%).

The numbers of fish captured with gill nets and minnow traps exhibited considerable variation, with no consistent temporal or spatial patterns (Table 2). When fishing effort was standardized for gill nets, 7% of the catch occurred in May, 20% occurred in June, and 72% occurred in July (Table 2). By comparison, for minnow traps, 22% of the catch occurred in May, 74% occurred in June, and 4% occurred in July. Catch rates fluctuated considerably among the Alviso Island Ponds, Coyote Creek, and Artesian Slough (Table 2). Even among the six reaches of Coyote Creek, no longitudinal pattern in numbers of fish caught was evident.

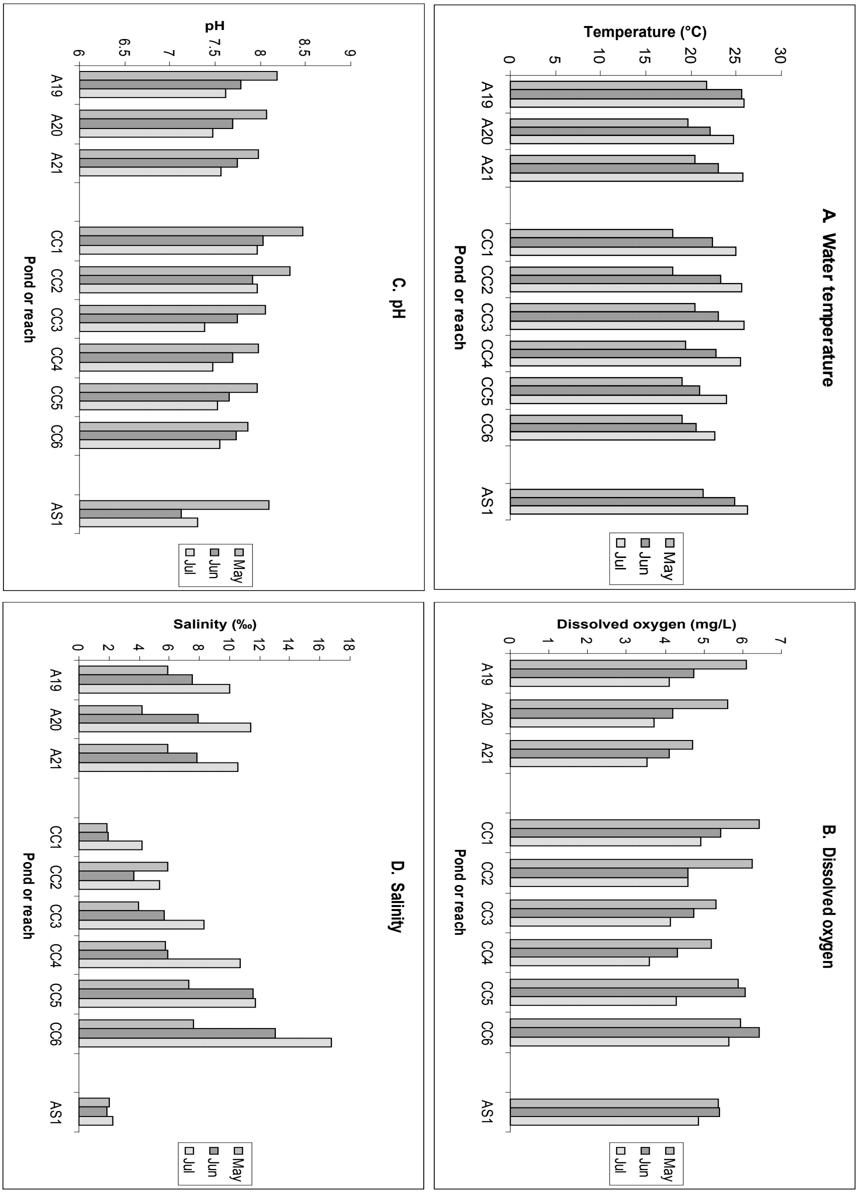


**Figure 2.** Summary of water temperature, dissolved oxygen, pH, and salinity in the Alviso Island Ponds (A19, A20, A21), six reaches of Coyote Creek (CC1 to CC6), and Artesian Slough (AS1) during May, June, and July 2006. Values depicted by bar heights are geometric means.

Table 1. Numbers (N) and percent (%) of fish captured with gill nets and minnow traps from the Alviso Island Ponds, Coyote Creek, and Artesian Slough during May-July 2006.

| Family | Species | Common name | Code | Gill net | | Minnow trap | |
|---|---|---|---|---|---|---|---|
| | | | | N | % | N | % |
| Atherinidae | *Atherinops affinis* | Topsmelt | TPS | 988 | 68.66 | 12 | 0.46 |
| Atherinidae | *Menidia audens* | Mississippi silverside | MSS | 0 | 0.00 | 2 | 0.08 |
| Catostomidae | *Catostomus occidentalis* | Sacramento sucker | SSU | 20 | 1.39 | 0 | 0.00 |
| Clupeidae | *Alosa sapidissima* | American shad | AMS | 29 | 2.02 | 0 | 0.00 |
| Clupeidae | *Dorosoma petenense* | Threadfin shad | TFS | 15 | 1.04 | 0 | 0.00 |
| Cottidae | *Cottus asper* | Prickly sculpin | PSP | 0 | 0.00 | 3 | 0.12 |
| Cyprinidae | *Cyprinus carpio* | Common carp | CCP | 48 | 3.34 | 0 | 0.00 |
| Engraulidae | *Engraulis mordax* | Northern anchovy | NAN | 105 | 7.30 | 0 | 0.00 |
| Fundulidae | *Lucania parva* | Rainwater killifish | RKF | 0 | 0.00 | 3 | 0.12 |
| Gasterosteidae | *Gasterosteus aculeatus* | Threespine stickleback | TSB | 0 | 0.00 | 2504 | 96.49 |
| Gobiidae | *Acanthogobius flavimanus* | Yellowfin goby | YGB | 17 | 1.18 | 44 | 1.70 |
| Gobiidae | *Clevelandia ios* | Arrow goby | AGB | 0 | 0.00 | 1 | 0.04 |
| Gobiidae | *Gillichthys mirabilis* | Longjaw mudsucker | LMS | 0 | 0.00 | 25 | 0.96 |
| Moronidae | *Morone saxatilis* | Striped bass | SBA | 212 | 14.73 | 0 | 0.00 |
| Myliobatidae | *Myliobatis californica* | Bat ray | BRA | 1 | 0.07 | 0 | 0.00 |
| Pleuronectidae | *Platichthys stellatus* | Starry flounder | SFD | 2 | 0.14 | 0 | 0.00 |
| Poeciliidae | *Gambusia affinis* | Western mosquitofish | WMF | 0 | 0.00 | 1 | 0.04 |
| Sciaenidae | *Genyonemus lineatus* | White croaker | WCK | 2 | 0.14 | 0 | 0.00 |
| Totals | | | | 1439 | 100.00 | 2595 | 100.00 |

Table 2. Numbers of fish (all species combined) captured with gill nets and minnow traps in the Alviso Island Ponds (A19, A20, and A21), six reaches of Coyote Creek (CC1 to CC6), and Artesian Slough (AS1), during May, June, and July 2006. The fish numbers are standardized for fishing effort (two gill nets fished for 2 hours or five minnow traps fished for 1 hour).

| Sampling unit or summary statistic | Gill nets | | | Minnow traps | | |
|---|---|---|---|---|---|---|
| | May | June | July | May | June | July |
| A19 | 2.0 | 2.0 | 18.7 | 181.0 | 410.0 | 6.7 |
| A20 | 2.0 | 1.7 | 10.3 | 8.7 | 14.0 | 2.7 |
| A21 | 2.0 | 25.3 | 282.3 | 10.3 | 7.0 | 3.3 |
| CC1 | 7.0 | 11.0 | 74.0 | 1.0 | 0.0 | 7.0 |
| CC2 | 0.0 | 7.0 | 67.0 | 1.0 | 3.0 | 2.0 |
| CC3 | 0.0 | 4.0 | 7.0 | 16.0 | 1.0 | 3.0 |
| CC4 | 11.0 | 4.0 | 2.0 | 0.0 | 1.0 | 10.0 |
| CC5 | 6.0 | 13.0 | 11.0 | 0.0 | 3.0 | 2.0 |
| CC6 | 7.0 | 59.0 | 13.0 | 0.0 | 0.0 | 2.0 |
| AS1 | 15.0 | 14.0 | 19.5 | 0.5 | 304.0 | 1.5 |
| Sum | 52.0 | 141.0 | 504.8 | 218.5 | 743.0 | 40.2 |
| Percent | 7.5 | 20.2 | 72.3 | 21.8 | 74.2 | 4.0 |

Striped bass was the most ubiquitous species, occurring in all 10 sampling units; followed by threespine stickleback and yellowfin goby, *Acanthogobius flavimanus*, (9 sampling units each); topsmelt and American shad, *Alosa sapidissima*, (7 sampling units each); longjaw mudsucker, *Gillichthys mirabilis*, (6 sampling units); and threadfin shad, common carp, *Cyprinus carpio*, and northern anchovy (5 sampling units each; see Table 3). Four species—Sacramento sucker, *Catostomus occidentalis*,

Table 3. Occurrence of common or abundant fish species (+, present; -, absent) in two groups of sampling units that collectively encompass three Alviso Island ponds (A19, A20, and A21), six reaches of Coyote Creek (CC1 to CC6), and one reach of Artesian Slough (AS1). Nine rare species (i.e., taxa represented by 15 or fewer individuals), which were excluded from cluster analysis and ordination by non-metric multidimensional scaling, are not shown.

| Fish species | Group 1 | | | | | | | Group 2 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A19 | A20 | A21 | CC3 | CC4 | CC5 | CC6 | CC1 | CC2 | AS1 |
| Topsmelt | + | + | + | + | + | + | + | - | - | - |
| Sacramento sucker | - | - | - | - | - | - | - | + | - | + |
| American shad | - | + | + | - | + | + | - | + | + | + |
| Common carp | + | - | + | - | - | - | - | + | + | + |
| Northern anchovy | - | + | + | - | + | + | + | - | - | - |
| Threespine stickleback | + | + | + | + | + | + | - | + | + | + |
| Yellowfin goby | + | + | + | + | + | - | + | + | + | + |
| Longjaw mudsucker | + | + | - | + | + | + | + | - | - | - |
| Striped bass | + | + | + | + | + | + | + | + | + | + |

prickly sculpin, rainwater killifish, and starry flounder—were found at two sampling units each, whereas five species—Mississippi silverside, arrow goby, bat ray, western mosquitofish, and white croaker—occurred at one sampling unit each.

## Fish Species Assemblages

According to results from cluster analysis of presence-absence data for fish species, the 10 sampling units were grouped into two major clusters (Fig. 3). The existence of two clusters (groups) was suggested by a plot of semi-partial $R^2$ values, which exhibited a maximum slope (rate of change) at the two-cluster location (Fig. 4). Group 1 was composed of the three ponds and four of the lowermost reaches (CC3-CC6) of Coyote Creek, whereas Group 2 was composed of the two uppermost reaches (CC1-CC2) of Coyote Creek and Artesian Slough. The existence of two groups was also indicated by NMS analysis of fish presence-absence data, where the 10 sampling units are ordinated in a 2-dimensional joint plot (Fig. 5). The first two axes of the joint plot represented 97.2% of the total variance. The ordination yielded a final stress of 3.70441 after 190 iterations.

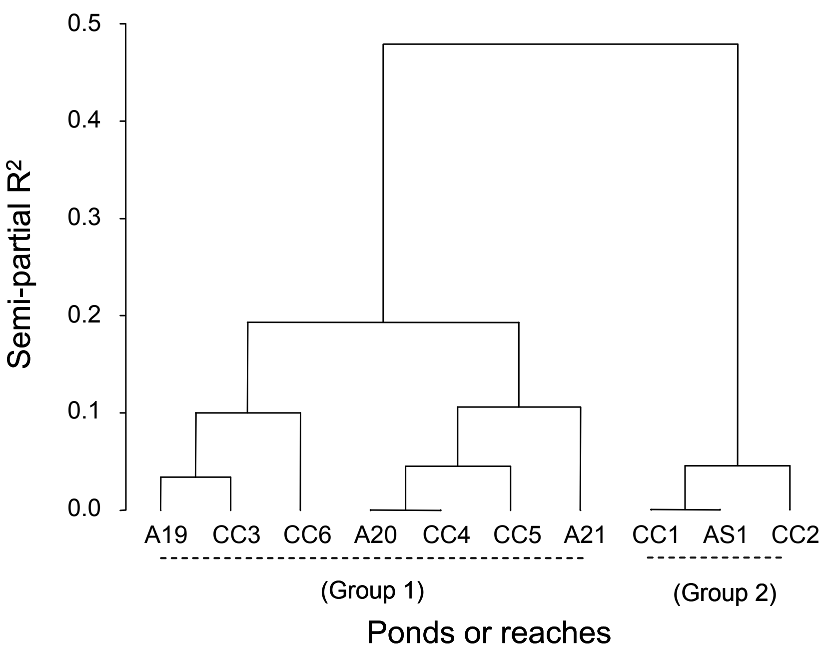


Figure 3. Dendrogram for cluster analysis (Ward's minimum variance method) of three Alviso Island ponds (A19, A20, and A21), five reaches of Coyote Creek (CC1 to CC5), and one reach of Artesian Slough (AS1). Each pond or reach constitutes a sampling unit.

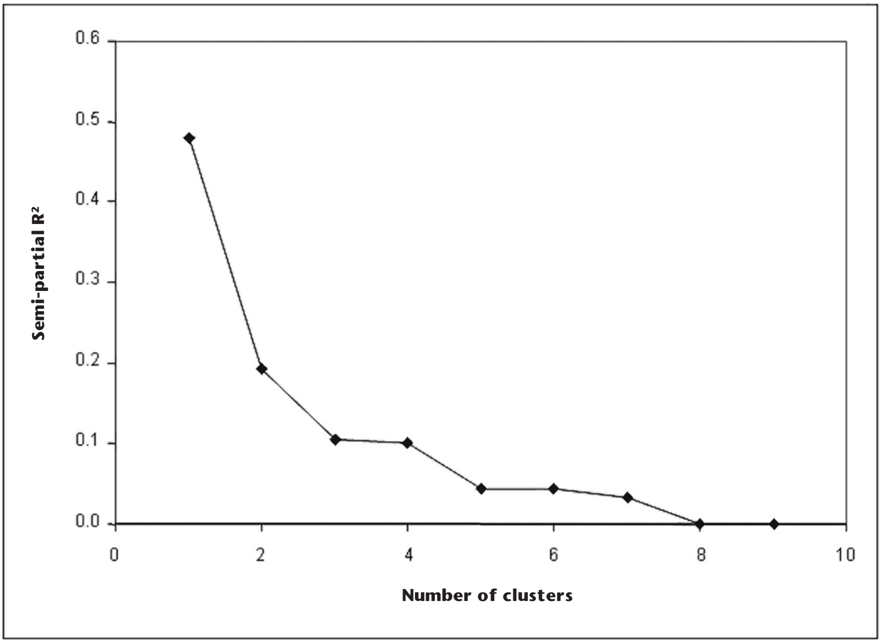


Figure 4. Relation of semi-partial $R^2$ values to the numbers of clusters. The number of "significant" clusters was determined from the largest reduction in semi-partial $R^2$ values that, in this study, corresponded to the two-cluster level.

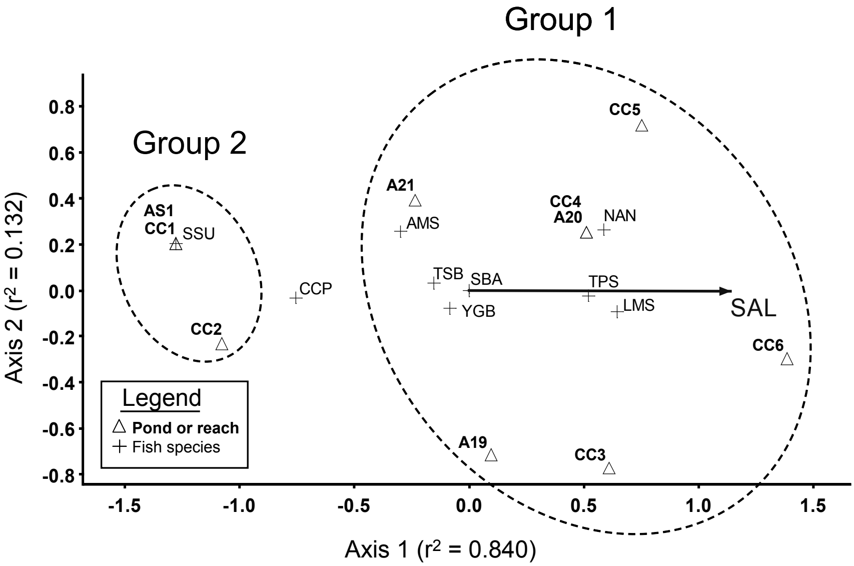


Figure 5. Ordination by non-metric multidimensional scaling of sampling units (Ponds A19, A20, and A21; six reaches of Coyote Creek, CC1 to CC6; and one reach of Artesian Slough, AS1) and fish species (see Table 1 for codes), with an overlay of salinity (SAL). The angle and length of the arrow (vector) representing salinity indicates the direction and strength of this relationship.

The fish species assemblage in Group 1 was characterized by mostly estuarine or marine taxa (e.g., topsmelt, northern anchovy, and longjaw mudsucker), although a freshwater species (common carp) occurred in two sampling units (Ponds A19 and A21; Table 3). By comparison, the fish species assemblage in Group 2 was characterized by freshwater species (e.g., Sacramento sucker) and by an absence of the estuarine/marine species noted in Group 1.

## Relation of Fish Species to Water Quality Variables

The relation between fish species and selected water quality variables was assessed from a joint plot of the 2-dimensional NMS solution overlaid by water quality variables. Weak variables (e.g., water temperature, dissolved oxygen, and pH) were omitted if their coefficients of determination ($r^2$ values) with either axis of the joint plot did not exceed a cutoff value of 0.399 (computed from r = 0.632, the correlation coefficient that is statistically significant at P = 0.05 when N = 10; see Table 4). Salinity was the only important variable associated with spatial distribution of fish species (Fig. 5). Water temperature, dissolved oxygen, and pH had little or no influence on fish distribution during this study.

Table 4. Pearson correlation coefficients (r) and coefficients of determination ($r^2$) between selected environmental variables and two axes of the non-metric multidimensional scaling solution, N = 10.[a]

| | Axis 1 | | Axis 2 | |
|---|---|---|---|---|
| Variable | r | $r^2$ | r | $r^2$ |
| Water temperature (°C) | -0.396 | 0.157 | -0.333 | 0.111 |
| Dissolved oxygen (mg/L) | -0.033 | 0.001 | -0.128 | 0.016 |
| pH | -0.399 | 0.159 | -0.154 | 0.024 |
| Salinity (‰) | 0.870* | 0.758 | -0.052 | 0.003 |

[a]Code: *, P<0.010.

# DISCUSSION

The breaching of earthen levees in March 2006 allowed water from Coyote Creek to dilute previously fishless brines in the Alviso Island Ponds, resulting in lower salinities that were tolerated by fish. By the time we began our study about 2 months after breaching had occurred, water quality in the ponds was similar to that in adjacent reaches of Coyote Creek. Moreover, fish species occurring in the ponds were similar to those in the creek. Even though water quality variables (especially temperature) varied over time (May-July 2006), the differences were most likely associated with seasonal changes rather than effects from levee breaching.

Although major changes in water quality (especially salinity reduction) within the Alviso Island Ponds probably occurred during the first few days or weeks following levee breaching, minor changes are still possibly in progress as precipitated salts in sediments are leached into the overlying water. For example, we occasionally observed salinity measurements taken in crevices or fissures within pond bottoms that were higher than in overlying water. The leached salts probably include dissolved gypsum because dissolution of this precipitated material was expected to occur when salinities in the ponds fell below 147‰ (USFWS and SCVWD[4] 2006). The leaching of salts from sediments may also explain why salinity measurements in the ponds were almost always slightly higher than in adjacent reaches of Coyote Creek (see Fig. 2D).

Environmental changes occurring in the Alviso Island Ponds probably began shortly after earthen levees were breached. Presumably, during high tides immediately following the breaches, water from Coyote Creek flooded the ponds where it diluted the brine. Although speculative, fish carried in with the tides possibly experienced osmotic stress as the relatively low-salinity creek water mixed with the brine. However, after several tidal cycles, dilution of the brine was probably sufficient to reduce salinities to levels tolerated by most estuarine fishes, including some species commonly found in freshwater (e.g., Mississippi silversides, threadfin shad, common carp, western mosquitofish).

The post-breach events described above are consistent with observations made by other investigators soon after a similar but unplanned breaching of levees occurred during August 2002 in Pond 3 of the Napa-Sonoma salt pond complex in North San Francisco Bay (Takekawa et al.[5] 2004). Rapid water quality changes occurred immediately following this levee breach as freshwater from the Napa River diluted the previously hypersaline water in Pond 3. The decrease in salinity was followed by transformation of the predominantly salt-tolerant fish species assemblage into an assemblage that included some freshwater species. Prior to breaching, salinity averaged 62.2‰, and the fish species assemblage was dominated by longjaw mudsucker (45% of captured fish), with five other species--Mississippi silverside, rainwater killifish, yellowfin goby, Shimofuri goby, *Tridentiger bifasciatus*, and striped bass--present in low numbers. However, 2 weeks following breaching, salinities in the pond had declined to an average of 59.4‰. By January 2003, salinities had declined even further, averaging 8.4‰ (range, 4.6-13.2‰). In June 2003, the fish species assemblage consisted of at least nine species, with threespine stickleback, yellowfin goby, and Mississippi silverside collectively accounting for 75% of captured fish (longjaw mudsucker was absent from the catch). In addition, freshwater species such as western mosquitofish and goldfish, *Carassius auratus*, were present in Pond 3.

[5]Takekawa, J.Y. , D.H. Schoellhamer, A.K. Miles, G.G. Shellenbarger, N.D. Athearn, S.E. Spring, M.K. Saiki, and C.A. Jannusch. 2004. Initial biophysical changes after breaching a salt pond levee: final report on the Napa-Sonoma Wildlife Area Pond 3 breach. Unpublished Progress Report, U.S. Geological Survey, Vallejo, California, USA. (Accessed from *http://www.napa-sonoma-marsh.org/documents/Pond_3_Final_Report_0604.pdf* on 24 October 2007.)

Although salinity is thought to play a dominant role in determining the distribution of estuarine fishes (Martino and Able 2003, Jaureguizar et al. 2004, Barletta et al. 2005, Pombo et al. 2005), other water quality variables can also be important. According to Moyle and Cech (1988), fish species assemblages in estuaries are often distributed along gradients of salinity, temperature, and dissolved oxygen, with individual fish species distributed according to their physiological tolerance to these variables. In our study area, which exhibited estuarine conditions due to freshwater inflows from Coyote Creek and Artesian Slough, individual fish species were found along a predominantly salt-related gradient (Fig. 5). Thus, Sacramento sucker occurred mostly in fresher waters characteristic of upstream reaches of Coyote Creek and Artesian Slough, whereas topsmelt, northern anchovy, and longjaw mudsucker occurred in saltier waters characteristic of Ponds A19, A20, and A21, and the middle and lowermost reaches of Coyote Creek.

Although beyond the scope of our study, spatial patterns exhibited by estuarine fishes have been linked to other environmental variables, including substrate composition, channel complexity, and predator-prey relations. For example, Visintainer et al. (2006) determined that tidal channel complexity influenced fish species composition, fish abundance, and fish diets in China Camp Marsh, a tidally influenced wetland in North San Francisco Bay. In Western Australia, Molony and Parry (2006) argued that even salt-tolerant predator species can eventually be eliminated from solar salt ponds if they experience starvation following loss of their prey base from high salinities.

Zedler et al. (1997) and Nemerson and Able (2005) indicated that restored marshes may seemingly function like natural marshes, but high sedimentation rates, lack of development of tidal creek networks, and lack of shallow water transitions to the marsh surface can hinder establishment of new fish species. Nevertheless, restoration of former salt ponds to tidal marshes in San Francisco Bay is likely to benefit recreational and commercial fisheries by increasing forage production and providing additional foraging and rearing habitats (Peterson and Turner 1994, West and Zedler 2000). Fish that could especially benefit from an increase in tidal wetlands include obligate estuarine species that spawn or give birth in these habitats and anadromous species that use these habitats to rear their young.

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## LITERATURE CITED

Barletta, M., A. Barletta-Bergan, U. Saint-Paul, and G. Hubold. 2005. The role of salinity in structuring the fish assemblages in a tropical estuary. Journal of Fish Biology 66:45-72.

Jackson, D.A., and H.H. Harvey. 1997. Qualitative and quantitative sampling of lake fish communities. Canadian Journal of Fisheries and Aquatic Sciences 54: 2807-2813.

Jaureguizar, A.J., R. Menni, R. Guerrero, and C. Lasta. 2004. Environmental factors structuring fish communities of the Rio de la Plata estuary. Fisheries Research 66:195-211.

Khattree, R., and D.N. Naik. 2000. Multivariate data reduction and discrimination with SAS software. SAS Institute Inc., Cary, North Carolina.

Martino, E.J., and K.W. Able. 2003. Fish assemblages across the marine to low salinity transition zone of a temperate estuary. Estuarine Coastal and Shelf Science 56:969-987.

McCune, B., and J.B. Grace. 2002. PC-ORD. Analysis of ecological communities. MjM Software Design, Gleneden Beach, Oregon, USA.

McCune, B., and M.J. Medford. 1999. PC-ORD. Multivariate analysis of ecological data, version 4. MjM Software Design, Gleneden Beach, Oregon, USA.

Molony, B.W., and G.O. Parry. 2006. Predicting and managing the effects of hypersalinity on the fish community in solar salt fields in north-western Australia. Journal of Applied Ichthyology 22:109-118.

Moyle, P.B., and J.J. Cech. 1988. Fishes: an introduction to ichthyology, Prentice Hall, Englewood Cliffs, New Jersey, USA.

Nemerson, D.M., and K.W. Able. 2005. Juvenile sciaenid fishes respond favorably to Delaware Bay marsh restoration. Ecological Engineering 25:260-274.

Nichols, F.H., J.E. Cloern, S.N. Luoma, and D.H. Peterson. 1986. The modification of an estuary. Science 231:567-573.

Peterson, G.W., and R.E. Turner. 1994. The value of salt marsh edge vs interior as habitat for fish and decapod crustaceans in a Louisiana tidal marsh. Estuaries 17:235-262.

Pombo, L., M. Elliot, and J.E. Rebelo. 2005. Environmental influences on fish assemblage distribution of an estuarine coastal lagoon, Ria de Aveiro (Portugal). Scientia Marina 69:143-159.

Ver Planck, W.E. 1958. Salt in California. California Division of Mines, Bulletin 175:1-168.

Visintainer, T.A., S.M. Bollens, and C. Simenstad. 2006. Community composition and diet of fishes as a function of tidal channel geomorphology. Marine Ecology Progress Series 321:227-243.

West, J.M., and J.B. Zedler. 2000. Marsh-creek connectivity: fish use of a tidal salt marsh in southern California. Estuaries 23:699-710.

Zedler, J.B., G.D. Williams, and J.S. Desmond. 1997. Wetland mitigation: can fishes distinguish between natural and constructed wetlands? Fisheries 22:26-28.

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