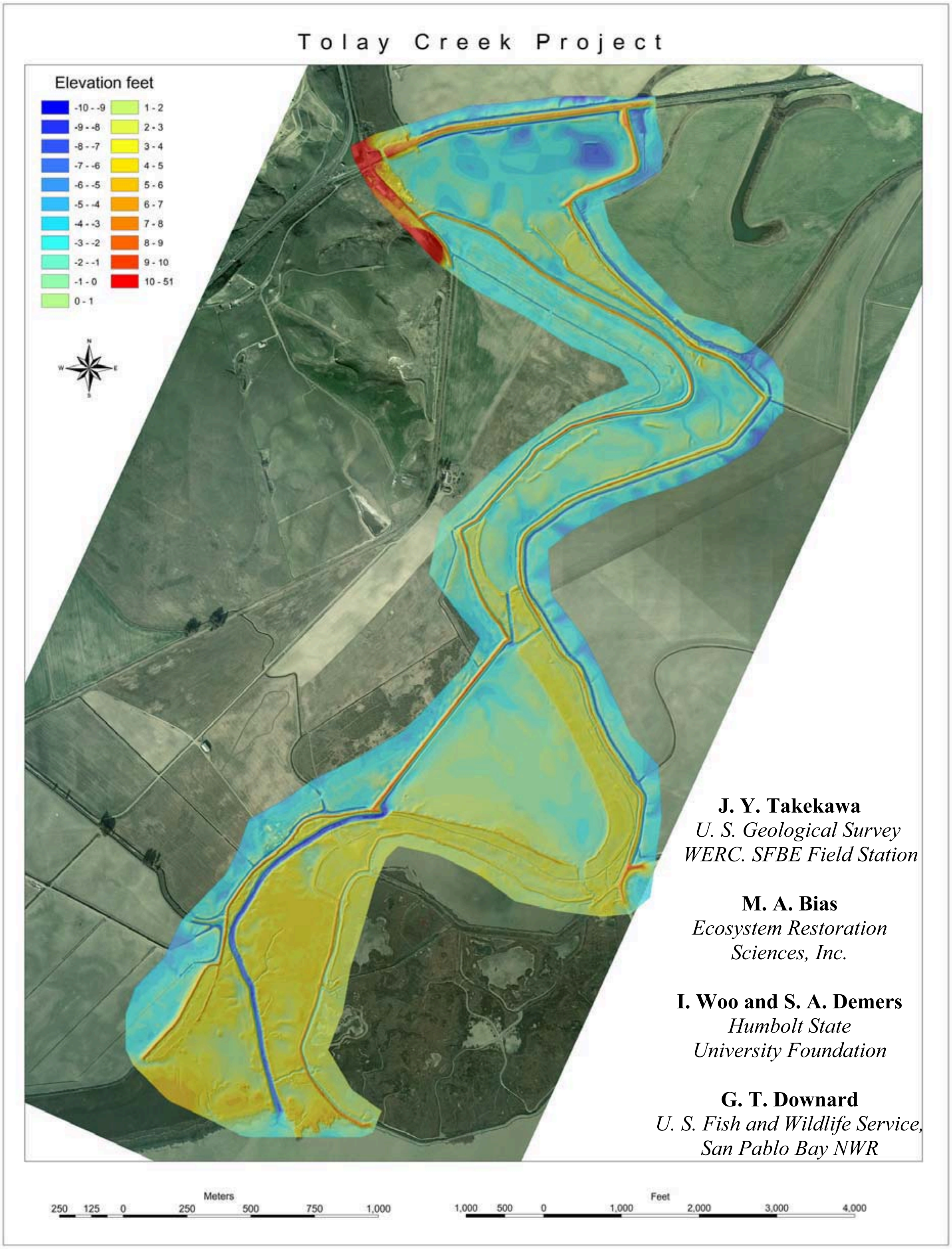
Restoration Research and Monitoring in Bayland Wetlands of the San Francisco Bay Estuary: The Tolay Creek Project

2002 Progress Report



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EXECUTIVE SUMMARY

- Tolay Creek, 17 km in length, flows into San Pablo Bay on the northwest shore between the Petaluma River and Sonoma Creek. The Tolay Creek Restoration Project, managed by San Pablo Bay National Wildlife Refuge and California Department of Fish and Game, was initiated in 1997 to increase tidal flow to 176 ha of the channelized lower creek and improve habitats for endemic tidal marsh species. We developed sampling protocols to monitor biophysical changes from immediately before construction (pre-breach) to after construction (post-breach).

- We distinguished four areas in the Tolay Creek Restoration Project: the Mouth, Lower Lagoon, Mid Channel, and Upper Lagoon. The main channel at the Mouth was widened and deepened to increase tidal flow. Connectivity was increased to the Lower Lagoon (43 ha) with a mitigation pond constructed in the early 1980s. Flow was also increased in the Mid Channel decreasing habitat for breeding mosquitoes. Finally, a levee separating a diked field (22 ha) from the upper drainage was removed to create the Upper Lagoon (28 ha).

- Water quality measurements indicated that pH values increased from a wide range (3.6-7.9) of acidic conditions in 1998 (pre-breach) to a narrower range (8.9 – 9.2) of basic conditions in 2001 (post-breach).

- Initial water levels exceeded predicted values in December 1998, but tidal loggers, installed in late January 1999, verified that corrective channel dredging in the spring of 1999 increased tidal flow and allowed adequate drainage. In the Upper Lagoon, tidal amplitude increased while the tidal lag period decreased.

- An as-built survey detailed the elevation of the site in 2000. Measurement of sediment pins comparing 1999 to 2002 showed an average accumulation of 6.1 cm in the Lower Lagoon but an average sediment loss of 1.2 cm in parts of the Upper Lagoon. Although we measured substrate elevations for 3 years, we were unable to confidently predict the time to marsh plain development.

- Along the 9 vegetation transects, we detected 34 plant species, 14 species were detected during a single pre-breach survey and 27 species were detected subsequently. Pickleweed (*Salicornia virginica*) cover increased from 33% (fall 1998) to 92% (spring 2002). Pickleweed density increased while height decreased since the breach. Gum plant (*Grindelia hirsutula*) was more abundant post-breach, coyote bush (*Baccharis pilularis*) average height increased, while average height of pepperweed (*Lepidium latifolia*) decreased.

- Cover of exotic plants declined from 38% (fall 1998) to 2% (spring 2002), due to the decrease in non-invasive exotic plant cover. Despite volunteer efforts to remove the invasive pepperweed, percent cover of pepperweed persisted. We found no evidence of invasion by smooth cordgrass (*Spartina alterniflora*) or *Spartina* hybrids in the project.

- Amphipods (*Traskorchestia traskiana*) were abundant at Tolay Creek (live biomass ranged from 175 to 500 g/m^2) and are likely a major food item for vertebrates or play a role in pickleweed colonization. We found no relation between amphipod abundance and pickleweed biomass. We suspect our results reflect variation in site conditions.

- We detected 16 species of fish in surveys. From 1999 and 2002, the number of species increased from 6 to 13 in the Upper Lagoon and from 6 to 9 in the Lower Lagoon. Fish species sensitive to suspended sedimentation (Pacific herring) were found in the Upper Lagoon while more tolerant species (bay goby) were found in the Lower Lagoon.

- We recorded 89 species of birds in the project: 43 bird species were detected during a single pre-breach survey and 83 bird species were detected during subsequent seasonal post-breach surveys. The Lower Lagoon and Mouth mud flats were dominated by shorebirds; terns and gulls were dominant in the Mid Channel; and diving ducks occurred predominantly in the Upper Lagoon.

- Shorebird numbers increased from 58% (pre-breach) to 80% (post-breach) in the total bird count. Behavioral observations showed that 68 % of shorebirds counted were foraging followed by dabbling ducks, grebes, and wading birds. Diving ducks were observed foraging only 12% of the time, suggesting that they used this restoration site primarily for roosting.

- We captured 7 small mammal species, 5 pre-breach and 7 post-breach. The numbers of small mammal captures show seasonal fluctuations. Total small mammals captures peaked in spring 2001.

- Salt marsh harvest mice (*Reithrodontomys raviventris*) numbers changed from dominance in the upper reaches (pre-breach) to the lower reaches of Tolay Creek (post-breach) because of the inundation of the Upper Lagoon. Salt marsh harvest mouse abundance was related to areas with greater pickleweed cover and height.

- Tolay Creek provides habitat for state or federally listed species: California clapper rail (*Rallus longirostris obsoletus*), California black rail (*Laterallus jamaicensis coturniculus*), San Pablo song sparrow (*Melospiza melodia samuelis*), common yellowthroat (*Geothlypis trichas sinuosa*), and salt marsh harvest mouse (*Reithrodontomys raviventris halicoetes*). We strive to understand habitat and foraging requirements so that these populations can be properly managed.

- Our management recommendations include continuing careful monitoring of elevations, water levels, sedimentation rates, and levee erosion to determine if corrective actions could improve marsh development.

- Future research and monitoring will include continuous samples of water quality; channel morphology, slough length, and levee erosion; sediment composition and content; and invertebrate food web analyses.

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INTRODUCTION

The northern region of the San Francisco Bay estuary, which includes San Pablo Bay, comprises the largest remaining expanse of undeveloped baylands in the estuary. A large proportion of this undeveloped land is diked baylands that have been converted to agricultural use. Along with urban and agricultural pressure, a rising biological threat to San Francisco baylands is the spread of invasive hybrids of *Spartina alterniflora* (exotic) and *S. foliosa* (native). These hybrids can alter natural biophysical functions and processes by converting mudflats to hybrid *Spartina* meadows, filling tidal sloughs and streams, and by potentially causing the extinction of the native *Spartina foliosa* (Ayres and Strong 2002). These habitat conversions can lead to the cascading loss of habitat for shorebirds that depend on mudflats, California clapper rails that use deep slough channels, and numerous species that are dependent on *S. foliosa* stands. Northern San Pablo Bay represents one of the largest stretches of baylands where the *Spartina* hybrids are currently absent. A 2001 survey of the entire San Francisco Bay estuary revealed heavy *Spartina* hybrid infestations in the Central (22.62%) and South Bay North of Dunbarton Bridge (74.81%), South Bay South of Dunbarton Bridge (2.27%), unlike the North Bay (0.04%) where hybrid *Spartina* occurrences were limited to a few clones in the southern portions near Point Pinole on the east and San Rafael to the west (SFE Invasive Spartina Project, 2001). San Pablo Bay National Wildlife Refuge (NWR) manages more than 5,340 ha of wetlands on San Pablo Bay. The refuge is actively rehabilitating or restoring historic tidal wetlands from previously converted agricultural land. Many endemic species that depend on salt marshes are under state or federal listing (Harvey et al. 1992), such as Mason's lilaeopsis (*Lilaeopsis masonii*), soft bird's beak (*Cordylanthus mollis ssp. mollis*), delta smelt *(Hypomesus transpacificus)*, Sacramento splittail (*Pogonichthys macrolepidotus*), California clapper rail (*Rallus longirostris obsoletus*), California black rail (*Laterallus jamaicensis coturniculus*), San Pablo song sparrow (*Melospiza melodia samuelis*), common yellowthroat (*Geothlypis trichas sinuosa*), salt marsh harvest mouse (*Reithrodontomys raviventris halicoetes*), Suisun shrew (*Sorex ornatus sinuosus*), and the salt marsh wandering shrew (*Sorex vagrans* *halicoetes*) may benefit from the tidal salt marshes restoration projects around the North Bay that focus on native species and vigilant monitoring of invasives.

Tidal wetland restoration projects will increase the extent of saline emergent wetlands on the San Pablo Bay NWR and in the estuary, in accordance with the implementation objective of the CALFED Ecosystem Restoration Program Plan (ERPP). In addition, management for specific elements and structures such as mudflats, islands, or steep-banked channels may enhance the value of tidal marsh restoration projects for migratory shorebirds, waterfowl, and sensitive species by providing roosting and foraging areas. By understanding how physical attributes influence biological organisms, engineering or control measures will be directed towards increasing favorable habitat for target species and decreasing factors that promote the establishment and spread of invasive species.

Monitoring biophysical parameters is a critical component for wetland restoration and rehabilitation projects (CALFED 1997). Documentation and quantification of environmental change, and the progression of wetland restoration actions is necessary to assess restoration techniques and develop adaptive management strategies. Adaptive management can provide guidelines for fine tuning the design and engineering of projects as needed to achieve an objective. Despite its vital role, monitoring has traditionally received little attention in pre- or post-project planning, field efforts, and funding support. Although many wetland restoration projects have been initiated in the estuary, none have included standardized biophysical monitoring. Wetland restoration projects are unpredictable (Race 1985, Zedler 2001) perhaps owing to a lack of comprehensive information of the progression of wetland restoration projects through project completion. Restoration and rehabilitation of diked baylands is a new science. Careful monitoring of the changes occurring during restoration efforts can help advance ecological theory of how wetland processes work and lessons learned can benefit managers and new restoration projects. The Tolay Creek Restoration Project highlights adaptive monitoring and the benefits towards management.

Historically a lake and a web of streams drained into Tolay Creek and tidal linkage existed between Tolay and Sonoma Creeks (Fig.1). Today, Tolay Creek flows for 17 km from the Sonoma Mountains and enters San Pablo Bay on the northwest shore between the Petaluma River and Sonoma Creek, 16 km west of Vallejo on the south side of Highway 37 (Fig.1). The Tolay Creek Restoration Project, managed by San Pablo Bay NWR and California Department of Fish and Game, was initiated in 1997 to increase tidal flow to 176 ha of the channelized lower creek and improve habitats for endemic tidal marsh species (USFWS 1997). The restoration project included rehabilitation of tidal flow to four areas: the Mouth, Lower Lagoon, Mid Channel, and Upper Lagoon. The main channel at the Mouth was widened to increase flow. Connectivity was increased to the Lower Lagoon (43 ha) – a mitigation pond constructed in the early 1980s restricted tidal flow. The Mid Channel received little tidal flow before the restoration. Cracks in the sediment filled with stagnant water filled and created mosquito habitat. In December 1998, the Upper Lagoon (28 ha) was created by removing a levee separating a 22 ha diked agricultural field from the upper drainage (Fig. 2).

The San Pablo Bay NWR restoration project at Tolay Creek provided an opportunity to develop a general framework for wetland monitoring and detailed plans specific to certain rehabilitation or restoration efforts. Monitoring and evaluation to determine the effects of restoration on endangered species was established as a required element of the restoration work for 10 years (1998-2008) following project development (USFWS 1997). Thus, we initiated work in 1998 to develop and undertake biophysical monitoring and evaluation. We developed sampling protocols to monitor biophysical changes from immediately before construction (pre-breach) to after construction (post-breach).

METHODS

Sampling Framework

Biological monitoring and evaluation of Tolay Creek was based on transects running perpendicular from the creek edge out to the project boundary levee (USFWS 1997). A series of 9 transects were established at regular intervals (approximately 500 m apart) from the mouth of Tolay Creek to the northern boundary of Hwy 37 (Fig. 3). A sampling plan was developed for initial surveys (Takekawa et al. 1999a). Water quality and sedimentation rates were sampled throughout the project and water level meters were located at the mouth of Tolay Creek and at the upper lagoon. Vegetation surveys were conducted at each of the sampling transects. Fish were sampled in the lagoon and open water areas. Large birds were recorded in complete area counts while small passerines were surveyed in point counts on the transects. Small mammals were live-trapped for at least 3 nights in 5x5 grids located near the transects.

Water Quality

Water quality data was collected with a Horiba or Hydrolab water quality multi-probe along the study transects (Fig. 32) at Tolay Creek. Water quality parameters included: depth (cm), pH (0.1 pH), conductivity (0.01 mS/cm), dissolved oxygen (0.1 mg/l), temperature (1∀C) and salinity (0.1%). In the summer of 2002, the water quality multi-probe was upgraded to include a turbidity meter (10 NTU) and internal memory for deployment in the field for up to 30 days at a time.

Hydrology

Data loggers were initially installed in 1999 to assess water levels. Five loggers were installed initially at several areas of the project, but initial results suggested that stations at the Mouth and Upper Lagoon (Fig. 3) were sufficient to track tidal changes. We used Global and Telog water loggers initially, but found the Global water loggers unreliable. Telog loggers incorporate pressure transducers and convert water pressure to distance from the water surface (water depth). The loggers were programmed to take readings every 15 minutes and were corrected with an adjacent staff gauge referenced to NGVD 29. Tidal readings were downloaded every 60 days, at which time current logger readings were recorded and referenced against the staff gauge and real time. Data were then corrected to NGVD 29 and corrected. Unfortunately, errors in staff gauge elevation surveys precluded rigorous comparisons to true NGVD water levels and direct comparisons between logger stations were not possible. Thus we present relative water levels in this report.

Geomorphology

Digital ground photographs were taken of the entire site from 14 photo points (Fig. 3) located with GPS at strategic locations, beginning in 2000. At each photo point, a panorama was taken encompassing the site with the frame including 50% of the sky. Aerial photographs were taken of Tolay Creek to assess pre- and post- breach differences (Fig. 2). Aerials were rectified and mapped as Arcview (ESRI, Inc.) coverages in NAD 27. A topographical as-built survey was conducted in 2000 by Ducks Unlimited to determine elevation of the site. A grid was developed from a series of 1:1,200 aerial photographs, ground-truthed to determine elevation, and rectified into an Arcview coverage (Fig. 4).

Sedimentation

Twenty-five sediment pins (5-cm schedule-40 PVC, extending above the water surface to at least 1 m into the sediment) were installed throughout Tolay Creek in late 1998. In December 2000, 4 more sediment pins were installed in the lower lagoon (sediment pin numbers 26-29). Sediment pins were measured three times per year with a graduated rod (sediment pole). A flat disk was attached to the bottom of the sediment pole to minimize the effect of the pole sinking into soft substrates. The average of two readings taken at opposite sides of the sediment pin was reported. A shorter sediment pin indicated sediment accumulation, while a longer sediment pin indicated sediment loss. The top of the pin was surveyed to estimate height in NGVD 88 and was later converted to NGVD 29. However, survey inconsistencies preclude analysis of sediment accumulation to NGVD, and values are reported as sediment accumulation or loss or rates without reference to NGVD.

Vegetation

A combination of point intercept and 0.25-m^2 quadrats was used to monitor plant establishment and to evaluate vegetation changes over time (Fig. 3). Initial plant sampling consisted of 15-m, random direction, continuous line transects, located throughout the length of Tolay Creek (9 transects). A 0.25-m^2 quadrat was used at the beginning (0m), middle (7m), and end of each transect (9.5m). Quadrat measurements consisted of species identification, ocular estimates of percent cover (total $\geq$ 100%), maximum height, and density (stems/m^2).

In 2000, permanent transects that spanned the distance from the levee to Tolay Creek were established to provide a more detailed comparison between species and their cover (Fig. 3). The permanent transects were sampled using continuous line intercept and were roughly spaced 500 meters apart throughout Tolay Creek. We continued to sample the 15-m transects and quadrats, placing the starting point of the 15-m transects along the permanent transects. The direction for the 15-m transects were randomized for each sample. Vegetation sampling occurred twice a year (early and late season) along nine permanent and nine 15-m random direction transects. Transect sampling provided information on species identification and canopy cover. Canopy cover was calculated by adding the length for which a species intersects the line divided by the total length of the line (total = 100%). Because salt marsh vegetation typically grows in monospecific patches, only the uppermost canopy layer was considered for the line transect.

Invertebrate amphipods

The study of invertebrate abundance and their interrelationships has been generally neglected in wetland restoration projects (Maffei 2000). Beach hoppers (*Traskorchestia traskiana*) are euryhaline detritivores that tolerate salinities of 2.5 to 50 ppt (Koch 1989) and are one of the only invertebrates known to consume pickleweed (Page 1997). Increased numbers of beach hoppers enhanced the growth and flowering of pickleweed (Obrebski *et al.* 2000) in studies of the Muzzi Marsh restoration site in the Central Bay. A mutualistic interaction may exist between pickleweed and the beach hopper, where nutrient availability is enhanced by the beach hopper activity and suitable moist habitat is provided for the beach hopper.

Four 1m x 1m enclosures (n = 8) were located in low, mid, and high marsh sites for a total of 32 enclosures in Tolay Creek (Fig. 3). The four treatments included depleted (amphipods removed from mesh cage), enhanced (amphipods added to mesh cage), neutral (mesh cage only), and open (no mesh cage). Each treatment was sampled 1-3 times weekly from March through August in 2001. Amphipods were captured, counted, and moved from depleted to enhanced treatment plots. New growth and flowers were monitored, and at the end of the growing season, above- and belowground biomass was collected. Soil nutrient levels (nitrogen and phosphorus) were determined from monthly soil samples taken in each treatment.

Fish

Open water beach seining was conducted in Tolay Creek in the fall of 1999 and in the late spring of 2002. The 1999 fish survey was sampled using a 35-ft beach seine at the Upper (3 hauls) and Lower Lagoon (5 hauls). In May 2002, a fish were sampled at Tolay Creek with an 80-ft beach seine. Sampling occurred at the Upper Lagoon (2 hauls), Lower Lagoon (4 hauls) and Mid Channel adjacent to the farm access road (1 haul). One end of the line was anchored onshore while the seine was deployed by boat. The seine was deployed perpendicular and parallel to the shore so that the seine formed 3 sides of a rectangle, with the shore forming the 4^{th} side. The two ends of the seine were pulled onshore so that fish species were captured in the net and pulled ashore. All fish, shrimp, and crab species were sorted and counted, with the first 30 specimen of each species measured for total length. Crab species were measured using carapace width. All fish were released back into the creek, except for unknown and voucher specimen, which were preserved in 10% formalin for later identification.

Birds

Two methods were used to survey birds. Area surveys were used for visual sightings of birds within areas defined as the Upper Lagoon, Middle Channel, Lower Lagoon and Mouth. The observer visually surveyed an area and recorded all species along with habitat (mud flat, open water, etc.) and behavior (roosting, foraging, etc.). Area counts were initially conducted seasonally regardless of tide. In 2000, observations that bird numbers varied with tide prompted area surveys to be conducted during both high and low tide for each season. Variable circular plot surveys (point counts) were conducted seasonally and included visual and auditory detection of birds at study transects. The observers walked to the center of the plot and waited for 2 minutes to allow birds to settle, followed by an 8-minute survey period. Observers counted all birds seen or heard within a 150-m radius. Point counts were designed to detect passerines and more secretive birds that may not be seen in tall, structurally complex vegetation, such as rail species. Point counts were conducted along vegetation transects (Fig. 3) within 2.5 to 3 hours after sunrise.

Small Mammals

Permanent grids (5x5) of 25 Sherman live traps were set 10 m apart near transects on Tolay Creek (Fig. 3). A single transect of 10 traps was set out on an island in the upper Mid Channel. Areas were trapped in the fall of 1998 prior to completing construction; subsequent sampling was conducted in the winter 1998, summer and winter of 1999, summer and winter of 2000, spring 2001, and spring 2002. In 2001, small mammal sampling was changed to occur annually in the spring to maximize the likelihood of capturing shrews as well as mice, and voles and in the fall. Trapping occurred for three consecutive nights led by individuals permitted to handle salt marsh harvest mice (*Reithrodontomys raviventris*). Each captured animal was identified, sexed, weighed, and examined for reproductive status. A small area of fur was clipped on the right (first day) or left flank (second day) of each mammal to identify recaptures. Additional measurements were taken for captured harvest mice to distinguish the salt marsh harvest mice from western harvest mice including: body length, ventral pattern, tail length, tail diameter, tail color, ear length, and behavior. Live trapping results were reported as animals (new captures) per 100 trap nights.

RESULTS AND DISCUSSION

Water Quality

Pre-beach tidal flow was restricted in sections of the Mid Channel area of the Tolay Creek Project, an area that had formerly been farmed and was subsided. Initial conditions were highly acidic in the upper reach of the creek (Fig. 5), potentially limiting marsh development. The pH values increased from a wide range of 3.6-7.9 of acidic conditions in 1998 (pre-breach) to a narrower range of 6.79 – 7.93 seven months after the breach, and more recently to 8.9 – 9.2 of basic conditions in 2001 (post-breach). pH samples in the upper reaches of the creek had equalized with those in the lower reaches. The pre-breach pH compared closely with our initial pH readings of 3.3 in the subsided farmlands and oxidized peat soils of the Cullinan Ranch unit (Takekawa et al. 1999b).

Hydrology

The water levels discussed here are relative values because elevation surveys for staff gauges used to correct the readings to NGVD29 were not consistent. Thus, the readings at a site should correctly reflect the tidal range, but are not statistically comparable between sites. Survey inconsistencies point to the need for trusted benchmarks along Tolay Creek. Initial water levels exceeded predicted values in December 1998, but tidal loggers, installed in late January 1999, verified that corrective channel dredging in the spring of 1999 increased tidal flow and stabilized water levels. In January 1999, the estimated tidal range at Sonoma Creek (estimated from the Richmond Station with Tide Log corrections of 94% of high tide and 72% of low tide levels) spanned nearly 2.4 m (Fig. 6). The tidal range in the Mouth was less, at roughly 1.8 m. However, tidal amplitude at the Upper Lagoon was only 0.6 m (33%). In January 2002, the estimated tidal range at Sonoma Creek was 2.0 m, 1.7 m at the Mouth, and 1.2 m (71%) in the Upper Lagoon (Fig. 7). Thus, on the highest spring tide, tidal amplitude increased greatly in the Upper Lagoon three years after corrective channel dredging.

Similarly, the tidal period observed at the Mouth of Tolay was very similar to that predicted in the Tide Log for Sonoma Creek for January 1999 (Fig. 8). The gradual slope at the bottom of the falling tide at the Mouth showed that the tidal range was slightly muted. However, the Upper Lagoon logger showed high tides were substantially muted and were delayed by roughly 3 h, and low tide was delayed by 2 h. In 2002, tides in the Upper Lagoon reflected those measured in the Mouth (Fig. 9), and delay in high tide from the lower to upper reach had decreased to roughly 1 h.

Over 4 years, we have observed increased equalization of the spring tidal range in the Upper Lagoon (Fig. 10). In 1999, the tidal range was narrow and elevated. Surprisingly, we found that the tidal range in 2000 remained elevated and even exceeded levels of 1999. Tide levels equalized in 2001-2002, perhaps suggesting that changes in the lower reach including sedimentation of the Lower Lagoon were affecting the upper reach of the project. However, we suggest caution in the interpretation of these readings because they may reflect differences between Global and Telog tidal loggers, rather than a real phenomenon. We found much better consistency in readings when compared to staff gauges with Telog water loggers, which were installed in 2001.

Geomorphology

Aerial photographs of Tolay Creek were taken pre- and post- breach (Fig.2). Initial changes in the project included widening of the channel below the Lower Lagoon with suspended sediment visible that extended from San Pablo Bay past the Lower Lagoon. Digital photographs were used throughout the project to track qualitative changes (Fig. 11). These photos were taken after the growing season to provide reference points for levee erosion, channel width changes, and changes in vegetation. Photo points provide evidence of qualitative change. The rapid increase of pickleweed cover is documented after from August 2000 to August 2002 (Fig. 12).

In 2000, an as-built survey was conducted by Ducks Unlimited to determine site elevations (Fig. 4). The pickleweed-covered marsh plain was located up to 1.5 m NGVD (5 feet) elevation in the Mouth of Tolay. Pickleweed typically grows from 1.3 to 2.8 m MLLW or 0.5 to 2.0 m NGVD (Sullivan and Noe 2001). *Spartina foliosa* establishes on mudflats with elevations around 0.5 – 0.6 m NGVD (1.7 to 2.0 feet) for the Petaluma River Marsh located in San Pablo Bay (Siegel 1998) and is colonizing the banks of sloughs and the Lower Lagoon at Tolay around 0.6 to 0.9 m NGVD (2 to 3 feet). Parts of the Lower Lagoon had already changed from a pond and had begun to reach marsh plain elevation levels. Indeed, there were a few young *S. foliosa* ramets in the southern edge of the lower lagoon where the elevations are slightly higher. Sediment accretion of the Mid Channel was not as rapid, but several areas had increased to 1.1 m NGVD (3.5 feet) with a few transverse channels developing. *Spartina* is also colonizing the edges of channels and creeks throughout Tolay Creek. The Upper Lagoon remained below –1.2 m NGVD (–4 feet) with no channel development.

Sedimentation

Sediment pins were distributed throughout the length of Tolay Creek (Fig. 13). The sediment readings discussed here are relative values because elevation surveys of sediment pins used to correct the readings to NGVD 29 were not consistent. Thus, the readings at each pin should correctly reflect changes in elevation and rate differences, but are not comparable to a vertical datum. Cumulative measurements in 2002 indicated that only half of the 29 sediment pins (hereafter SP) have measured a gain in sediment since 1999 (Fig. 13, 14). In particular, the Lower Lagoon of Tolay had the greatest sediment accumulation and the greatest sediment loss, nearly a 40 cm gain at SP 14 and a 57 cm loss at SP 4. Seven out of 10 pins accumulated sediment and the three pins with sediment loss occurred near areas where new channels might be developing. Measurement of sediment pins comparing 1999 to 2002 showed an average accumulation in the Lower Lagoon of 6.1 cm, but an average loss of 1.2 cm of sediment in the Upper Lagoon.

We expected sediment accumulation rates (Fig. 15) to follow a monotonically declining curve with a large initial accumulation and decreasing accumulation rates through time. Trends in data suggest a seasonal fluctuation of sediment. We were unable to accurately predict time to marsh plain development in only 3 years, because of variations between sediment pins. The sediment pin readings over 4 years suggested little accumulation or loss in the Upper Lagoon, with 0-30 cm annual sediment accumulation rates in the Lower Lagoon. Accumulation in Tolay Creek was less than the 50 cm/year found in 3.5 years at the Petaluma River Marsh (Siegel 1998). With a constant accumulation rate of 15 cm per year and initial elevations of 0.0 - 0.9 m (0-3 feet), pickleweed may colonize the Lower Lagoon in as little as 5 years. However, sediment accumulation is more likely to decrease as elevation increases. At the same time, colonization by *Spartina* may increase sedimentation at the margins. Our sediment measurements suggest that marsh development in the Upper Lagoon is unlikely to occur in the next decade.

Vegetation

Thirty-four plants have been detected on Tolay Creek transects (Table 1). Fourteen species were recorded during a single pre-breach survey and 27 species were reported subsequently (Fig. 13). In comparison, Siegel (1998) reported 7 salt marsh plant species for the Petaluma River Marsh restoration surveys including *Salicornia virginica, Distichlis spicata, Scirpus* spp.*, Grindelia humilis, Frankenia grandifolia*, *Spartina foliosa*, and *Rumex crispus*. While Tolay Creek contains similar dominant species as Petaluma River Marsh, the greater species diversity found at Tolay may reflect differences in the sampling design, the hydrogeomorphic parameters in the two wetlands, the histories, and restoration efforts of the sites.

Tolay Creek comprises of shifting plant mosaics of *Salicornia virginica*, *Frankenia salina*, *Baccharis pilularis*, *Jaumea carnosa*, *Grindelia hirsutula*, *Cuscuta salina*, and *Lepidium latifolia* (Fig. 16). Following the breach of Tolay Creek, *Atriplex triangularis*, sharply decreased, primarily because it was located in transects which are now submerged (Figure 17, pre-breach). The sampling during spring 2001 was conducted early in the season (February) and perhaps underestimates species occurrence of those plants that emerge later in the spring. Subsequent plant surveys were conducted in April. Although species diversity is not necessarily correlated with marsh age, young salt marshes tend to be characterized by low-diversity vegetation dominated by *Salicornia*, while some older marsh remnants may comprise complex and annual variable mosaics of *S. virginica, Distichlis, Cuscuta, Jaumea, Frankenia* and *Atriplex*. However, age and species diversity generalizations cannot be made for all wetlands: old wetlands at China Camp were found to support a low diversity of vegetation dominated by *Salicornia virginica* (Goals Project 2000).

Increasing pickleweed cover is generally a desired outcome of restoration because it functions as a cover and food plant for tidal marsh species. Cover of the 10 most common species groups showed an increasing proportion of pickleweed since 1998 (Fig. 16). Percent cover of pickleweed increased from 33% prior to restoration to72% in less than one year and represented 92% of the total plant cover in 2002 (Fig. 16, 17, 18).

Percent cover of pickleweed increased in transects 1, 4, and 5 and decreased in transects 7, 8, and 9 that became inundated following the breach (Fig. 17, 18). Following restoration activities, pickleweed density increased while average height decreased. Quadrat samples showed that pickleweed density ranged from (mean $\pm$ S.D.) 7.2 $\pm$ 4.4 rooted individuals per m^2 (pre-breach) at transect 1, to 23.6 $\pm$ 7.2 plants/m^2 (post-breach). Post-breach pickleweed height ranged from 63.3 $\pm$ 3.8 cm to 39.3 $\pm$ 6.2 cm at transects 3 and 7, respectively (Fig. 18). There was no correlation between cover and height ($p = 0.329$), cover and density ($p = 0.934$), nor density and height ($p = 0.065$). Gum plant (*Grindelia hirsutula*) was more abundant along transects post-breach (Fig. 17), and the average height of *Baccharis pilularis* increased while pepperweed (*Lepidium latifolium*) height decreased on average (Fig. 19).

Percent cover of exotics have decreased from 38% in Fall 1998 to 8% in Summer 1999 to 2% in Spring 2002 (Fig. 20). Exotic plants were further categorized as non-invasive or invasive based on the California Exotic Pest Plant Council. The decrease in exotic cover mostly consists of the decrease of non-invasive exotic species in the first year after wetland restoration. Invasive exotic cover has slightly decreased from 10% in Fall 1998 to 6.3% in Summer 1999 to 1% in Summer 2000 to 2% in Spring 2002. The decrease in the overall abundance of exotic species predominately is due to the decrease of non-invasive species. Percent cover of invasive species such as pepperweed persists at Tolay Creek. Despite volunteer efforts to remove the invasive pepperweed, percent cover of pepperweed persist along with three other invasive species (Italian rye grass, Ripgut brome, and Starthistle). We found no evidence of invasion by smooth cordgrass (*Spartina alterniflora*) in the project.

Baccharis was the tallest plant at 92 cm, followed by pepperweed at 78 cm, *Grindelia* at 67 cm, and *Salicornia* at 54 cm (Fig. 19). Because plants are distributed along multiple environmental gradients, such as tolerance to salinity, drought, and submergence, further study is needed to assess whether taller foliage may give pepperweed a competitive advantage over *Salicornia* and other native salt marsh species. Pepperweed is an invasive exotic plant of concern. It is perennial and produces dense monospecific stands. Stems can reach up to 1.5 meters in height, almost 1 meter taller than pickleweed canopies (Renz 2000). Dense pepperweed threatens native salt marsh habitat by altering soil salt ions (Blank and Young 1997), displacing native plant species, and threatened species such as the salt marsh harvest mouse (Trumbo 1994), which depends on the native pickleweed. Besides decreasing plant diversity, pepperweed is also believed to reduce nesting frequency of waterfowl in and near wetlands that it invades (Trumbo 1994).

Invertebrate amphipods

Biomass of amphipods (*Traskorchestia traskiana*) was ~200 g/m^2 in Tolay Creek (Fig. 21) suggesting a large number of amphipods existed in the marsh plain. Open and neutral enclosures had similar biomass. Biomass of amphipods was similar in depleted enclosures where amphipods were removed and placed into enhanced enclosures. Biomass increased as pickleweed grew during the season (Fig. 22), but again, depleted enclosures had similar cumulative numbers as did open and neutral enclosures. Unlike results from the restored Muzzi Marsh in the Central Bay (S. Obrebski, unpubl. data), we found no relation between amphipod abundance and pickleweed biomass (Fig. 23). Biomass of pickleweed in enhanced enclosures was not greater than biomass of pickleweed in depleted exclosures. Our results may have been confounded by wide variation in site conditions in the restoration project and by herbivore activity. Amphipods are likely a major food item for vertebrates such as the song sparrow (J. L. Grenier, unpubl. data) and fish species that forage in the marsh plain during high tides.

Fish

We detected 16 species of fish during surveys (Table 2) in 1999 and 2002. In 1999 six species were detected in the Upper and Lower Lagoon of Tolay. In 2002 the number of fish species detected increased to 13 in the Upper Lagoon and from to 9 in the Lower Lagoon. No special status fish species were captured, but incidental observations of carcasses on banks included a few sturgeon sp. and salmon sp.

Fish abundance and distributions vary with season, salinity, and tide among other factors. Fish sampling in April 2002 was performed throughout the day without standardization of tide. The comparison of fish found in the Upper and Lower Lagoon with respect to habitat requirements is a preliminary sketch of the aquatic biota and merits further attention. Sampling occurred in open water areas and in channels. Fourteen species were observed throughout Tolay Creek: 11, 10 and 8 species were captured in the Upper Lagoon, Lower Lagoon, and Mid Channel, respectively (Fig. 24). The 5 most abundant species were bay goby (*Lepidogobius lepidus*), shrimp (*Crangon* and *Palaemon* species), Pacific staghorn sculpin (*Leptottus armatus*), topsmelt (*Atherinops affinis*), and Pacific herring (*Clupea pallasi*).

The common aquatic species found in the Upper Lagoon includes shrimp species, bay goby, Pacific staghorn sculpin, topsmelt, and Pacific herring. Shrimp of *Crangon* species was the most abundant specimen collected in the Upper Lagoon. *Crangon* shrimp has the important ecological role as a prey item for many estuarine fishes. Pacific herring prefer sea grass habitats or substrates that are rigid that lack sediment. They spawn in the shallow waters of California bays in January and February. Juveniles migrate out to deeper waters in the fall, returning to estuaries during spring and summer (April-August).

Certain fish species are found along environmental gradients and the presence (or absence) and abundance may convey information about their habitat. The common species found in the Lower Lagoon are bottom dwellers that can tolerate sediment loads, while fish found in the Upper Lagoon species with stricter habitats requirements, such as the Pacific herring that is sensitive to high sedimentat loads. Common species found in the Lower Lagoon include bay goby, Pacific staghorn sculpin, yellowfin goby (*Acanthogobius flavimanus*), and shrimp species. Bay goby is a benthic dwelling fish with high tolerance to environmental changes. For the bay goby the abundance of predators (such as Pacific staghorn sculpin) may influence populations. Bay goby is abundant in the San Francisco Bay estuary and young of the year densities are usually highest in South or San Pablo Bays, while densities of older bay goby are usually highest in Central Bay. Like the bay goby, Pacific staghorn sculpin is a bottom dweller with a high tolerance to changing environments and is considered an indicator of stress in estuarine environments (Goals Project 2000). They primarily prey upon grass shrimp and are a food source for diving ducks, gulls, great blue heron, and Caspian terns. The yellowfin goby is another benthic dwelling fish that prefers muddy and sandy bottoms along the shores of bays and estuaries but also migrates regularly into freshwater. As an introduced species it competes with native gobies and sculpins.

Birds

Tolay Creek lies along the Pacific flyway and provides habitat for migratory waterbirds and shorebirds. We recorded 89 species of birds in the project: 43 bird species were detected during a single pre-breach survey and 83 bird species were detected during subsequent seasonal post-breach surveys (Table 3). Overall percent of dabbling ducks, diving ducks, and passerines have declined while percent of shorebirds have increased from pre-breach 58% to post-breach 80% of the total bird count (Fig. 25, 26). Shorebird counts in the Lower Lagoon has increased significantly since 1998 (Fig. 26), presumably because of increased sedimentation, creating favorable foraging habitat. After the breach of Tolay Creek, shorebirds made up the majority (80%) of the birds observed, followed by diving ducks, terns or gulls, coots, dabbling ducks, passerines, wading birds, cormorants, raptors, grebes, geese, and gamebirds (Fig. 23).

Surveys detected differences in the spatial and temporal occurrences of birds. The Lower Lagoon and Mouth channel mud flats were dominated by shorebirds; terns and gulls were found in the Mid Channel; and diving ducks were primarily found in the Upper Lagoon (Fig. 27). Habitat occurrences showed that the majority of birds were observed using open water and mud flat habitats. Area surveys have documented a change in bird numbers according to tide: more birds were observed during low tide than at high tide (Fig. 28), largely due to the high influx of shorebirds during low tide (Fig. 26). Birds that use open water habitat such as diving ducks did not show any pattern associated with tide.

Observation of bird behavior was also conducted during surveys and included foraging occurrence (Fig. 29). Shorebirds were using Tolay Creek predominately for foraging (68%), followed by dabbling ducks (43%), grebes (32%), and wading birds (32%). In contrast, diving ducks were observed foraging only 12% of the time, suggesting that the restoration site was used by this guild primarily for roosting.

Point counts have detected the state threatened California black rail (*Laterallus jamaicensis coturniculus*) and the federally and state endangered California clapper rail (*Rallus longirostris obsoletus*) at Tolay Creek (Table 4). The California black rail has been detected near the Lower Lagoon and Mouth of Tolay since 1999; while the California clapper rail was first detected near the Mouth of Tolay in spring 2002. Abundance indices of tidal marsh passerines were calculated from point count bird surveys (Fig. 30). The San Pablo song sparrow (*Melospiza melodia samuelis,* a state species of concern) was the most common species recorded in point count surveys, followed by the marsh wren (*Cistothorus palustris*) and the common yellowthroat (*Geothlypis trichas sinuosa,* a state species of concern). Song sparrow, marsh wrens, and common yellowthroat occurrences vary seasonally with low numbers detected in the fall and winter, compared to spring and summer surveys. This might reflect migration patterns or difficulty in detecting short winter calls, which for common yellowthroat, consists of a single low note. In addition we detected annual variations in numbers. In 2002, common yellowthroat numbers have been consistently low across seasons.

Small Mammals

We live-trapped 7 small mammal species: 5 pre-breach and 7 post-breach (Table 5). Comparing the 1998 winter population (pre-breach) with spring 2001 (post-breach), total numbers increased 2 fold (Fig. 31). Seasonally, we found decreased numbers of California voles (*Microtus californicus*) with increased numbers of deer mice. The salt marsh harvest mouse (*Reithrodontomys raviventris*) is a state and federally listed as endangered. The greatest numbers of salt marsh harvest mice were detected in the upper reaches during pre-breach surveys, unlike post-breach surveys where the Upper Lagoon was inundated and subsequently, the majority of salt marsh harvest mice were captured at the lower reaches of Tolay Creek (Fig. 32). Salt marsh harvest mouse abundance might be related to areas of greater pickleweed density and height.

New small mammal captures per 100 trap nights ranged from 61 in the spring 2001 to 20 in spring 2002 for grids that have been sampled repeatedly (Fig. 31). The large numbers were captured in 2001 may reflect a spike in small mammal populations. Numbers of new salt marsh harvest mice captures are highest in spring and summer, lowest in winter (Fig. 31). Salt marsh harvest mouse numbers varied also by grid (Fig. 32); however the differences by grid for pre- and post-breach comparisons are widely contributed to the inundation and lack of available habitat to trap on grids 7, 8, and 9 post-breach and grid 1 was not surveyed pre-breach. Small mammal surveys in grid 2 found no salt marsh harvest mouse captures before the breach, and 46 new captures in the 5 surveys conducted since the breach. Salt marsh harvest mice are dependent on thick, perennial cover of salt marshes, in particular pickleweed (Bias 1994). Our data suggested a relationship between salt marsh harvest mouse abundance and pickleweed height, cover, and density (Fig. 33). Salt marsh harvest mice were trapped at sites with higher vegetation, denser cover, and intermediate stem densities. They also may be found in adjacent upland habitats (Botti et al.1986, Bias 1994, Hulst et al. 2002).

Conflicting results exist regarding the interactions of salt marsh harvest mice with other species. Geissel et al. (1988) suggested seasonal displacement of salt marsh harvest mice from optimal habitat by California voles; however, Bias (1994) demonstrated that this pattern is not substantiated with greater number of trap nights. At Tolay Creek, voles have been the dominant small mammal captured. Shrews comprise a small percentage of small mammal captures. Shrew habitat preference appears to be more strongly associated with vegetation structure rather than species composition. Shrews (*Sorex* sp) are found in areas with dense vegetation cover, abundant food source (invertebrates) and fairly continuous ground moisture, while salt marsh harvest mouse habitat consists of thick perennial cover (GOALS Project 2000).

ASSESSMENT OF RESTORATION GOALS

The ultimate goal of the Tolay Creek Restoration Project is to restore and enhance tidal salt marsh habitat in Tolay Creek to benefit endangered and threatened species (USFWS 1997). Specific objectives were to: 1) restore tidal flows to Tolay Creek from Highway

37 to San Pablo Bay, 2) restore two former farm fields to tidal marsh habitat, 3) enhance existing tidal marsh habitat in the Tolay Creek flood plain south of Highway 37, 4) restore the property in a manner that will require minimal maintenance, 5) create habitat that minimizes mosquito production, and 6) monitor and evaluate the results for its effects on endangered species.

Our monitoring and evaluation results suggest that the Tolay Creek Restoration Project has been highly successful in reaching its goals, despite difficulties with adjacent areas in the floodplain. Restoration activities transformed what was a choked, narrow drainage with limited tidal flow into a developing tidal marsh with increased diversity. A primary lesson of this restoration has been that dealing with small remnant wetland fragments is difficult and engineering predictions are not always correct. This is especially true when restoration projects extend across decades (nearly 30 years have elapsed since the Tolay Creek acquisition in 1974) with several groups involved. A restored, “maintenance-free” habitat fragment is not the norm, but an exception and has become a more unrealistic management goal as we have learned more about the restoration process. Adaptive management actions should be expected for problems that arise. Monitoring protocols should also be adaptive to be more inclusive. For example, the observation that different birds were using parts of the project at different times prompted area bird surveys to be done during both high and low tide. We have learned that restoration monitoring must include not only the ultimate target species and characteristics of the ecosystem, but the relevant physical parameters for management actions including geomorphology, elevation, levee erosion, sedimentation, water levels, and water quality.

(1) Restore tidal flows to Tolay Creek from Highway 37 to San Pablo Bay.-- Flows have been restored at Tolay Creek from San Pablo Bay to Highway 37. Dredging channels and creating new areas at the upper reach of the project have been beneficial. However, tidal flow remains constricted between the Lower Lagoon and Upper Lagoon. As the marsh plain develops in the project, these constricted areas may require dredging. Alternatively, it may be possible to increase tidal prism by reconnecting the upper portions of Tolay Creek to historic channels. Historically, Tolay Creek may have

received extensive run-off from the upstream watershed that included a small lake to the northwest in the Sonoma Mountains (Goals Report 1999), as well as from a tidal connection to Sonoma Creek. Increasing flow from the drainage or dredging the connection to Sonoma Creek above Highway 37 may maintain channels and improve flow and sedimentation to the Upper Lagoon. Opening Tolay Creek to tidal flushing on both ends may improve tidal flushing and sedimentation dynamics. We recommend a formal analysis by a professional hydrologist or engineer to examine and model the effects of connecting Tolay Creek to Sonoma Creek, north of Highway 37.

(2) Restore tidal marsh habitat to two former farm fields.-- Our results from monitoring sedimentation suggest that the Lower Lagoon and the Mid Channel are accumulating sediment. Tidal marsh vegetation has colonized in the Lower Lagoon and we expect increased colonization and establishment in the next 5 years assuming relatively constant sedimentation rates. However, little sediment is reaching the Upper Lagoon. Once sediment accumulates in the Lower Lagoon, it may result in less suspended sediment moving to the Upper Lagoon. Dredging of channels in the constricted areas may be required to maintain the necessary flows to carry the suspended sediments to the upper reaches. An alternative may be to model effects of dredging Tolay Creek the connection to Sonoma Creek above Highway 37.

(3) Enhance existing tidal marsh habitat in the Tolay Creek flood plain south of Highway 37.-- We found improvements in the existing tidal marsh habitat with increased pickleweed cover and density. Height of pickleweed decreased, but other native species increased. Many of the exotic invasive species were removed through inundation, but a few including pepperweed persist, and should be carefully monitored to consider control if they begin to spread widely. We found improvements in the Mid Channel and the marsh edge surrounding the Lower Lagoon. Near the Lower Lagoon, improved drainage has resulted in less inundated areas of dead pickleweed. *Spartina foliosa* has colonized the Lower Lagoon and gentle-sloped banks throughout Tolay Creek. We have found no evidence of the invasive *Spartina alterniflora* and its hybrids at Tolay Creek.

4) Restore the property in a manner that will require minimal maintenance.-- Significant maintenance has been required to strengthen the levees surrounding Tolay Creek. However, as the tidal marsh plain rises and channels develop, it is likely that less maintenance will be required. Wind and tidal action are erosive forces on channels; however, plant establishment may reduce erosive effects on levees. Along the Upper Lagoon, protection of the highway has been completed, but with limited sedimentation, the deeper areas of water along the fetch (Fig. 4, southwest of the parking lot) may result in higher energy waves and continued erosion. Although marsh development may be very slow, the Upper Lagoon is likely critical in maintaining the tidal prism in the project.

(5) Create habitat that minimizes mosquito production.-- The cracked sediments in the Upper Lagoon and Mid Channel were eliminated with disking and inundation. Areas surrounding the Lower Lagoon have improved in tidal flow, which has reduced breeding habitat for mosquitoes, decreasing control efforts.

(6) Monitor and evaluate the results for its effects on endangered species.-- Our monitoring showed immediate increases in salt marsh harvest mice post-breach in 1999, but seasonal variation precluded rigorous comparisons. In post-breach surveys of different seasons, indices of salt marsh harvest mice populations generally increased. San Pablo song sparrow numbers increased in 1999-2001, but decreased in 2002. We have had consistent detections of the California black rail since 1999 (post-breach) and the first detection of a California clapper rail in 2002, suggesting that habitats in the Mouth have improved. Population trends of endangered species may be more easily established with more years of data, but this question clearly shows the importance of conducting surveys well-before projects are completed, to develop a baseline for comparison. We continue to monitor trends in state and federally listed species (and others) in relation to habitat so that we can better understand their requirements.

We have learned that restoring small remnant wetland fragments is difficult and engineering predictions are not always correct. This is especially true when restoration projects extend across decades (nearly 30 years have elapsed since the Tolay Creek acquisition in 1974) with several groups involved. It is not realistic to consider that management of such restored habitat fragments can be "maintenance-free," and adaptive management actions should be expected for problems that arise. We have learned that restoration monitoring must include not only the ultimate target species and characteristics of the ecosystem, but the relevant physical parameters including elevations, geomorphology, levee erosion, sedimentation, water levels, and water quality.

MANAGEMENT RECOMMENDATIONS

The Tolay Creek restoration project remains a valuable model to learn about processes in restoration management. There are few restoration projects in this area that include a continuous dataset started before construction was completed. Thus, it would be valuable to continue extensive monitoring on this site for as long as possible. Our monitoring and evaluation detected constrictions to the tidal prism of the Upper Lagoon. Future action may be necessary to prevent the Lower Lagoon from restricting tidal flow to the Upper Lagoon. We suggest an assessment to maintain and increase tidal prism in the Upper Lagoon, including modeling the effects of connecting Tolay Creek to Sonoma Creek north of Highway 37. Sixty restoration projects are ongoing or proposed for the North Bay, and Tolay Creek may provide a model for other restoration projects in the region. Our management recommendations include continuing monitoring of water levels, sedimentation rates, and levee erosion to determine if corrective actions would improve marsh development. Monitoring funding should be obtained for this effort and built into all future projects as an integral component of the design (Block et al. 2001).

FUTURE RESEARCH

Our USGS study plan (USGS 2002) includes continued monitoring through the next 5 years. We are improving measurements of tidal levels and sedimentation rates to reference them with elevation benchmarks. Our work will include measurements of other monitoring parameters for salt marshes recommended by Zedler (2001) including soil composition, organic matter, and salinity; invertebrate abundance; and channel length and cross-sections. We will continue to incorporate recent findings on the genetic subdivisions of the San Pablo song sparrow (*Melospiza melodia samuelis,* Chan and Arcese 2002) and the ornate shrew (*Sorex ornatus*, Maldonado et al. 2001). A major focus of our research work will be on the tidal marsh food web, vertebrate colonization and habitat use, and the distribution and abundance of invertebrate prey. We will examine benefits of tidal marsh restoration results at this site in light of regional habitat goals, including proposed conversion of salt evaporation ponds in the estuary.

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Table 1. List of plant species, species code, native and invasive status for pre-breach (September 1998) and post-breach (1999-2002) surveys.

Common Name	Scientific Name	Code	Native	Invasive *	Pre-breach	Post-breach
Alkali heath	*Frankenia salina*	FRSA	Y	N	X	X
American bulrush	*Scirpus americanus*	SCAM	Y	N		X
Beeplant	*Scrophularia californica*	SCCA2	Y	N		X
Bentgrass	*Agrostis avenacea*	AGAV	N	N	X	
Brass buttons	*Cotula coronipifolia*	COCO	N	N		X
Coast fiddlehead	*Amsinckia menziesii*	AMME	Y	N		X
Common pickleweed	*Salicornia virginica*	SAVI	Y	N	X	X
Common wild radish	*Raphanus sativus*	RASA	N	N		X
Common yarrow	*Achillea millefolium*	ACMI	Y	N		X
Cordgrass	*Spartina foliosa*	SPFO	Y	N		X
Coyotebush	*Baccharis pilularis*	BAPI	Y	N	X	X
Curly dock	*Rumex crispus*	RUCR	N	N	X	
Ditch grass	*Ruppia maritima*	RUMA	Y	N		X
Dodder	*Cuscuta salina*	CUSA	Y	N		X
Fat hen	*Atriplex triangularis*	ATTR	Y	N	X	X
Fleshy jaumea	*Jaumea carnosa*	JACA	Y	N	X	X
Gum plant	*Grindelia hirsutula*	GRHI	Y	N	X	X
Italian rye grass	*Lolium multiflorum*	LOMU	N	Y		X
Mediterranean barley	*Hordeum marinum*	HOMA	N	N		X
Perennial pepperweed	*Lepidium latifolium*	LELA	N	Y	X	X
Perennial rye grass	*Lolium perenne*	LOPE	N	N	X	
Prickly lettuce	*Lactuca serriola*	LASE	N	N	X	
Prostrate knotweed	*Polygonum arenastrum*	POAR	N	N	X	
Rabbitfoot beardgrass	*Polypogon monspeliensis*	POMO	N	N	X	
Ripgut brome	*Bromus diandrus*	BRDI	N	Y		X
Salt grass	*Distichlis spicata*	DISP	Y	N		X
Saltmarsh bulrush	*Scirpus maritimus*	SCMA	Y	N		X
Sand spurry	*Spergularia rubra*	SPRU	Y	N		X
Sea lavender	*Limonium californicum*	LICA	Y	N		X
Sea milkwort	*Glaux maritima*	GLMA	Y	N		X
Soft chess	*Bromus hordeaceous*	BRHO	N	N		X
Wild oats	*Avena fatua*	AVFA	N	N		X
Wild turnip	*Brassica rapa*	BRRA	N	N		X
Yellow Starthistle	*Centaurea solstitialis*	CESO	N	Y	X	
Areas without plants	*Bare*	BARE				
Dead plants	*Litter*	LITR				
Inundated with water	*Open Water*	OPWA				

* Invasive status follows the guidelines of the California Exotic Pest Plant Council

Table 2. List of fish species and location for the surveys conducted in 1999 and 2002.

		1999		2002	
Common Name	**Scientific Name**	**Upper Lagoon**	**Lower Lagoon**	**Upper Lagoon**	**Lower Lagoon**
Arrow goby	*Clevelandia ios*				X
Bay goby	*Lepidogobius lepidus*			X	X
Bay pipefish	*Syngnathus zeptorhynchus*			X	
Crangon spp.	*Crangon spp.*			X	X
Hemigrapsus sp.	*Hemigrapsus sp.*			X	X
Inland silverside	*Menidia beryllina*	X	X		
Mosquito fish	*Gambusia afinis*	X	X		
Pacific herring	*Clupea pallasi*			X	
Pacific staghorn sculpin	*Leptocottus armatus*	X	X	X	X
Palaemon sp.	*Palaemon sp.*			X	X
Rainwater killifish	*Lucania parvu*			X	
Speckled sanddab	*Citharichthys stigmaeus*			X	
Striped bass	*Morone saxatilus*	X	X	X	
Threespine stickleback	*Gasterosteus aculeatus*	X	X	X	
Topsmelt	*Atherinops afinis*			X	X
Yellowfin goby	*Acanthogobius flavimanus*	X	X	X	X

Table 3. List of bird species observed in pre-breach (1998) and post-breach (1999-2002) surveys for area and point count survey methods.

				Survey Method	
Common Name	**Scientific Name**	**Pre-breach**	**Post-breach**	**Area Count**	**Point Count**
American avocet	*Recurvirostra americana*	X	X	X	X
American bittern	*Botaurus lentiginosus*		X		X
American coot	*Fulica americana*	X	X	X	X
American goldfinch	*Carduelis tristis*		X	X	X
American kestrel	*Falco sparverius*	X	X	X	
American white pelican	*Pelecanus occidentalis*	X	X	X	
American wigeon	*Anas americana*	X		X	
Barn swallow	*Hirundo rustica*		X	X	X
Black phoebe	*Sayornis nigricans*	X		X	X
Black-bellied plover	*Pluvialis squatarola*		X	X	
Black-crowned night heron	*Nycticorax nycticorax*	X	X	X	
Black-necked Stilt	*Himantopus mexicanus*	X	X	X	X
Bonaparte's gull	*Larus philadelphia*		X	X	
Brewer's blackbird	*Euphagus cyanocephalus*	X	X		X
Brown-headed cowbird	*Molothrus ater*	X		X	
Bufflehead	*Bucephala albeola*		X	X	X
California black rail	*Laterallus jamaicensis coturniculus*		X	X	X
California clapper rail	*Rallus longirostris obsoletus*		X		X
California gull	*Larus californicus*	X	X	X	X
Canada goose	*Branta canadensis*		X	X	X
Canvasback	*Aythya valisineria*		X	X	X
Caspian tern	*Sterna caspia*		X	X	X
Cinnamon teal	*Anas cyanoptera*		X	X	X
Clark's grebe	*Aechmophorus clarkii*	X	X	X	X
Cliff swallow	*Petrochelidon pyrrhonota*		X	X	X
Common goldeneye	*Bucephala clangula*		X	X	X
Common raven	*Corvus cryptoleucus*	X		X	X
Common snipe	*Gallinago gallinago*	X	X	X	X
Common yellowthroat	*Geothlypis trichas*	X	X	X	X
Double-crested cormorant	*Phalacrocorax auritus*	X	X	X	X
Dowitcher	*Limnodromus spp.*		X	X	
Dunlin	*Calidris alpina*		X	X	X
Forster's tern	*Sterna forsteri*		X	X	X

Table 3. Continued.

				Survey Method	
Common Name	**Scientific Name**	**Pre-breach**	**Post-breach**	**Area Count**	**Point Count**
Gadwall	*Anas strepera*		X	X	X
Golden-crowned sparrow	*Zonotrichia albicollis*		X		X
Great blue heron	*Ardea herodias*		X	X	X
Great egret	*Ardea alba*	X	X	X	X
Greater scaup	*Aythya marila*		X	X	
Greater yellowlegs	*Tringa melanoleuca*		X	X	X
Green-winged teal	*Anas crecca*		X	X	X
Heermann's gull	*Larus heermanni*		X	X	
Horned grebe	*Podiceps auritus*	X	X	X	
Horned lark	*Eremophila alpestris*		X	X	
House finch	*Carpodacus mexicanus*		X	X	X
Killdeer	*Charadrius vociferus*	X	X	X	X
Least sandpiper	*Calidris minutilla*		X	X	X
Least tern	*Sterna antillarum*		X	X	
Lesser scaup	*Aythya affinis*		X	X	
Lesser yellowlegs	*Tringa flavipes*		X	X	
Long-billed curlew	*Numenius americanus*	X	X	X	X
Long-billed dowitcher	*Limnodromus scolopaceus*		X	X	X
Mallard	*Anas platyrhynchos*	X	X	X	X
Marbled godwit	*Limosa fedoa*		X	X	X
Marsh wren	*Cistothorus palustris*	X	X	X	X
Mourning dove	*Zenaida macroura*	X	X	X	X
Northern flicker	*Colaptes auratus*	X		X	
Northern harrier	*Circus cyaneus*	X	X	X	X
Northern pintail	*Anas acuta*	X	X	X	X
Northern rough-winged swallow	*Stelgidopteryx serripennis*		X		X
Northern shoveler	*Anas clypeata*		X	X	X
Peregrine falcon	*Falco peregrinus*	X	X		X
Pied-billed grebe	*Podilymbus podiceps*	X	X	X	X
Red knot	*Calidris canutus*		X	X	
Redhead	*Aythya americana*		X	X	
Red-necked phalarope	*Phalaropus lobatus*	X	X	X	X
Red-tailed hawk	*Buteo jamaicensis*	X	X	X	X
Red-winged blackbird	*Agelaius phoeniceus*	X	X	X	X
Ring-billed gull	*Larus delawarensis*	X	X	X	X
Ring-necked pheasant	*Phasianus colchicus*		X	X	

Table 3. Continued.

Common Name	Scientific Name	Pre-breach	Post-breach	Survey Method: Area Count	Survey Method: Point Count
Rough-legged hawk	*Buteo lagopus*		X	X	
Ruddy duck	*Oxyura jamaicensis*	X	X	X	X
San Pablo song sparrow	*Melospiza melodia samuelis*	X	X	X	X
Sanderling	*Calidris alba*		X	X	
Savannah sparrow	*Passerculus sandwichensis*	X	X	X	X
Semipalmated plover	*Charadrius semipalmatus*		X	X	
Short-billed dowitcher	*Limnodromus griseus*		X	X	
Short-eared owl	*Asio flammeus*		X	X	
Snowy egret	*Egretta thula*	X	X	X	X
Sora	*Porzana carolina*	X			X
Turkey vulture	*Cathartes aura*	X	X	X	X
Violet-green swallow	*Tachycineta thalassina*	X	X	X	X
Western grebe	*Aechmophorus occidentalis*		X	X	X
Western gull	*Larus occidentalis*		X	X	X
Western meadowlark	*Sturnella neglecta*	X	X	X	X
Western sandpiper	*Calidris mauri*		X	X	X
Whimbrel	*Numenius phaeopus*		X	X	X
White-crowned sparrow	*Zonotrichia leucophrys*	X	X	X	X
White-tailed kite	*Elanus leucurus*	X	X	X	X
Willet	*Catoptrophorus semipalmatus*	X	X	X	X

Table 4. List of occurrences of California black rail and California clapper rail detected during point count surveys at Tolay Creek from 1999 to 2002.

Common Name	Scientific Name	Month Year	Point	Number
California black rail	*Laterallus jamaicensis coturniculus*	July 2002	1	1
California black rail	*Laterallus jamaicensis coturniculus*	July 2002	2	1
California clapper rail	*Rallus longirostris obsoletus*	April 2002	1	1
California black rail	*Laterallus jamaicensis coturniculus*	February 2002	3	1
California black rail	*Laterallus jamaicensis coturniculus*	October 2001	3	1
California black rail	*Laterallus jamaicensis coturniculus*	March 2000	1	1
California black rail	*Laterallus jamaicensis coturniculus*	March 2000	2	1
California black rail	*Laterallus jamaicensis coturniculus*	March 2000	4	2
California black rail	*Laterallus jamaicensis coturniculus*	June 1999	1	1
California black rail	*Laterallus jamaicensis coturniculus*	June 1999	2	1
California black rail	*Laterallus jamaicensis coturniculus*	June 1999	4	1

Table 5. List of small mammal species and species code found at Tolay Creek during pre- and post-breach surveys.

Common name	**Scientific name**	**Code**	**Pre-breach**	**Post-breach**
Salt marsh harvest mouse	*Reithrodontomys raviventris*	RERA	X	X
Western harvest mouse	*Reithrodontomys megalotis*	REME	X	X
Deer mouse	*Peromyscus maniculatus*	PEMA	X	X
California vole	*Microtus californicus*	MICA	X	X
Shrew [1]	*Sorex* spp.	SORE		X
House mouse	*Mus musculus*	MUMU	X	X
Norway rat	*Rattus norvegicus*	RANO		X

[1]*Sorex ornatus sinuosus* or *Sorex vagrans halicoetes* (but see Maldonado 2001)

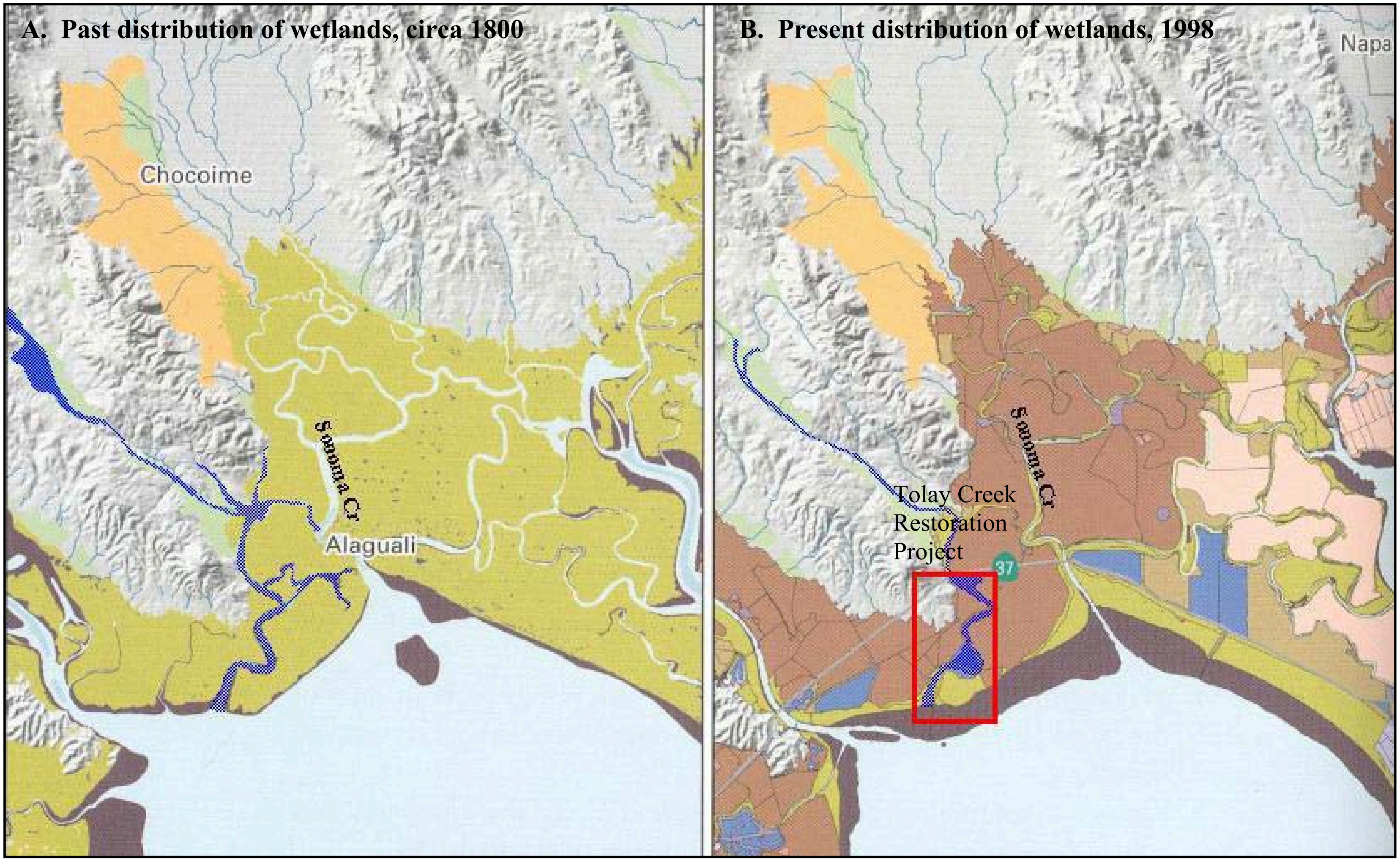


Figure 1. The Tolay Creek drainage (overlayed in dark blue) in historical (A) compared to present (B) times. Present drainage of the Tolay Creek Restoration Project (outlined in red) is much smaller and no longer consists of a lake to the northwest, a network of creeks, nor tidal linkage to Sonoma Creek. (Goals Project 1999)

Figure 2. The 176 ha Tolay Creek Restoration Project, Pre-breach (A), and Post-breach (B). The project extends 5.3 km (3.2 mi) from San Pablo Bay at the bottom left, to Highway 37 in the upper middle of the aerial photographs.

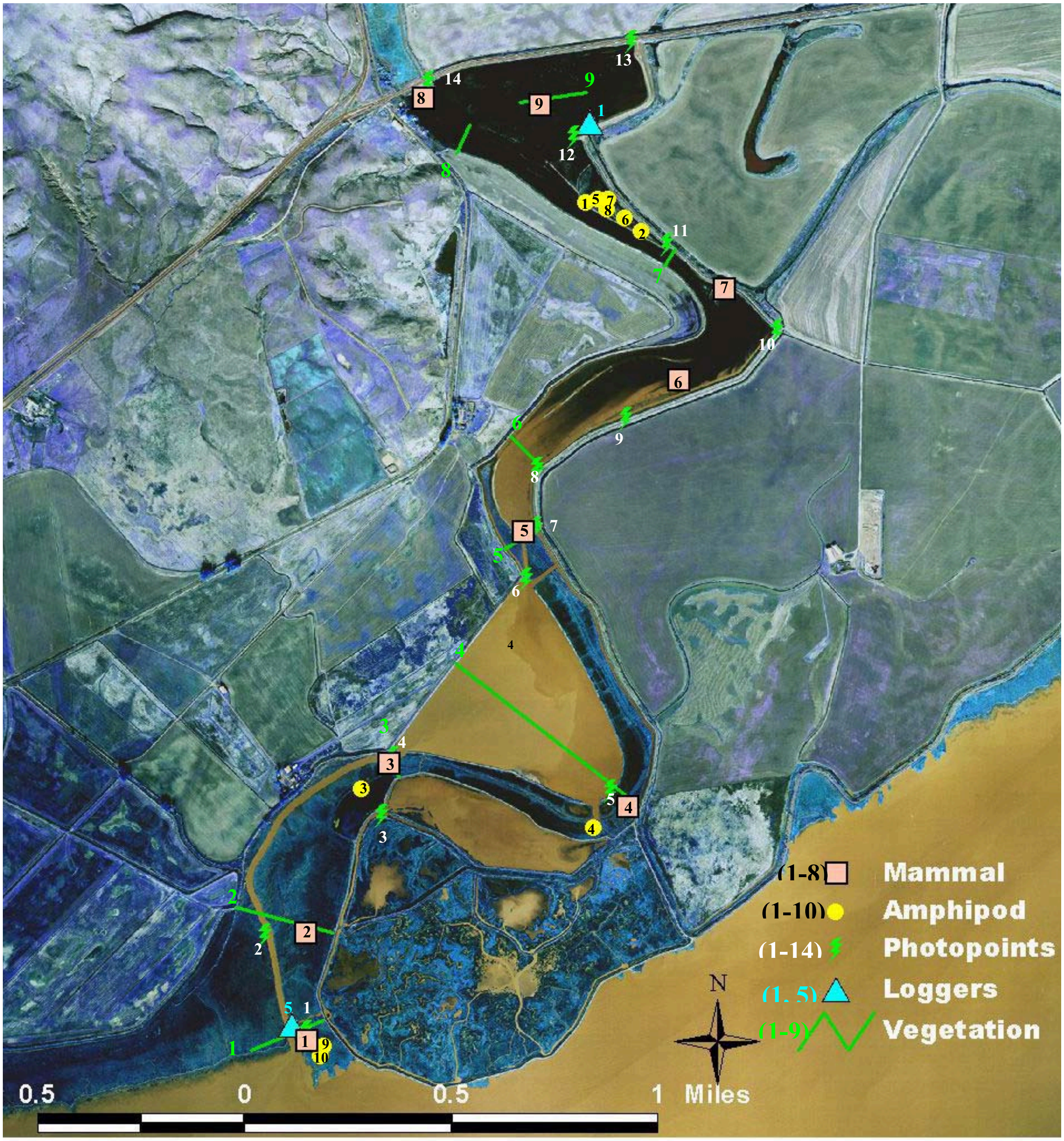


Figure 3. Location and number of sampling transects, water level loggers, photo points, amphipod study enclosures, and mammal trapping grids at the Tolay Creek Restoration Project.

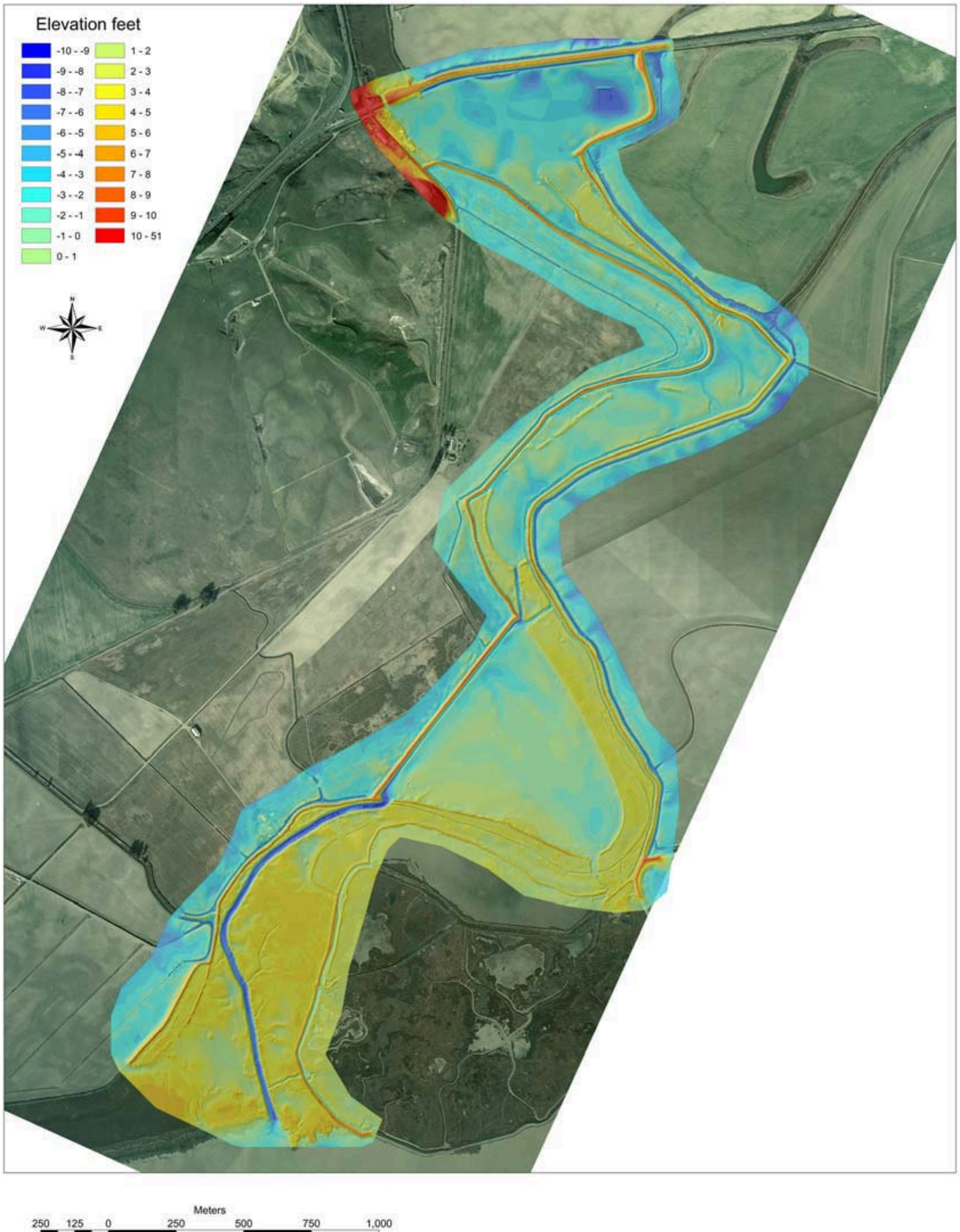


Figure 4. As-built survey created by Ducks Unlimited for the Tolay Creek Restoration Project, 2000. Elevations are presented as 1-foot contours and were determined from aerial photographs, rectified, and mapped as a grid coverage in ArcView

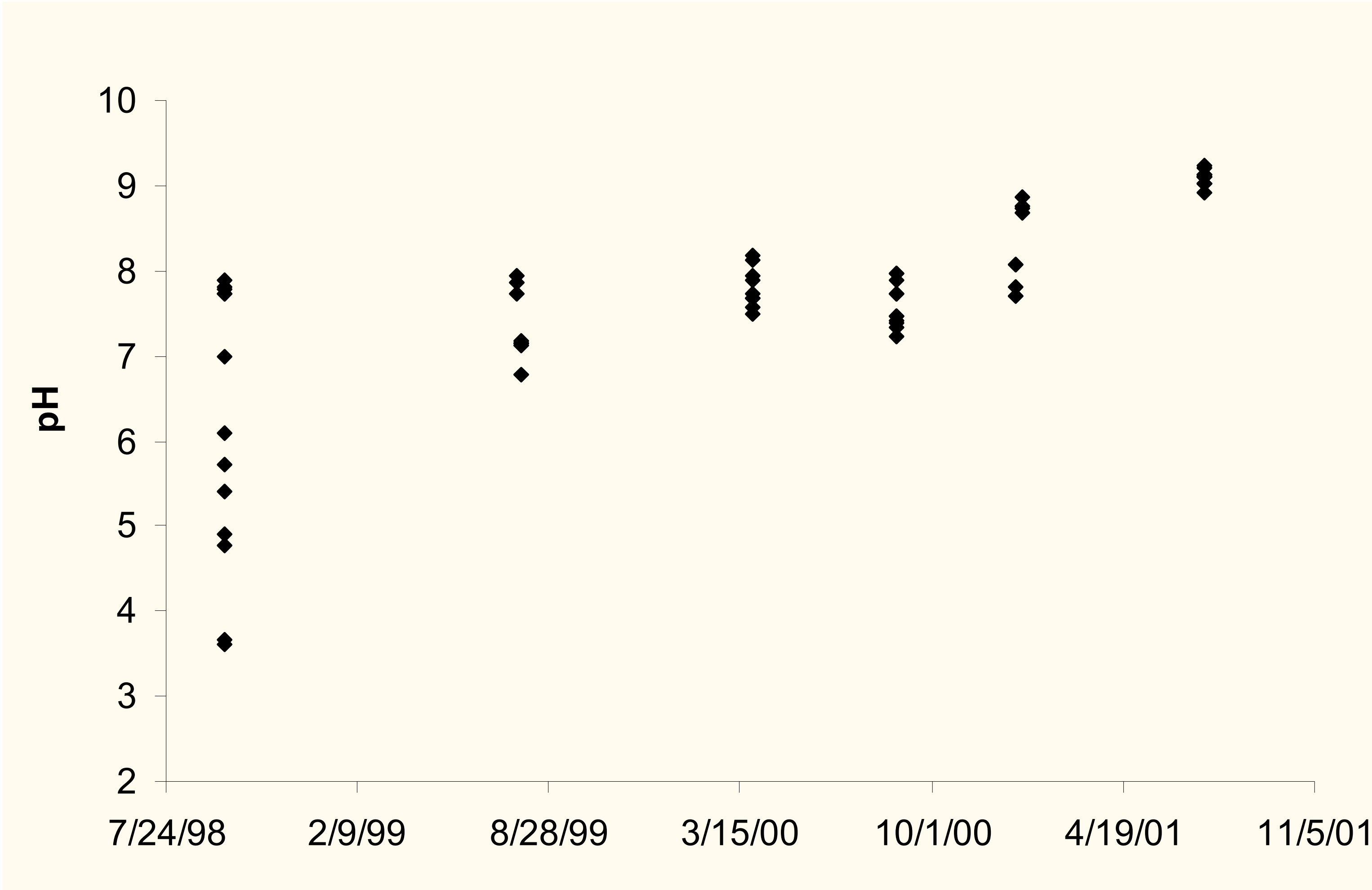


Figure 5. Water quality (pH) readings at 9 transects within the Tolay Creek Restoration Project, 1998-2001. Acidic conditions were evident during the pre-breach period in the upper reach of the project.

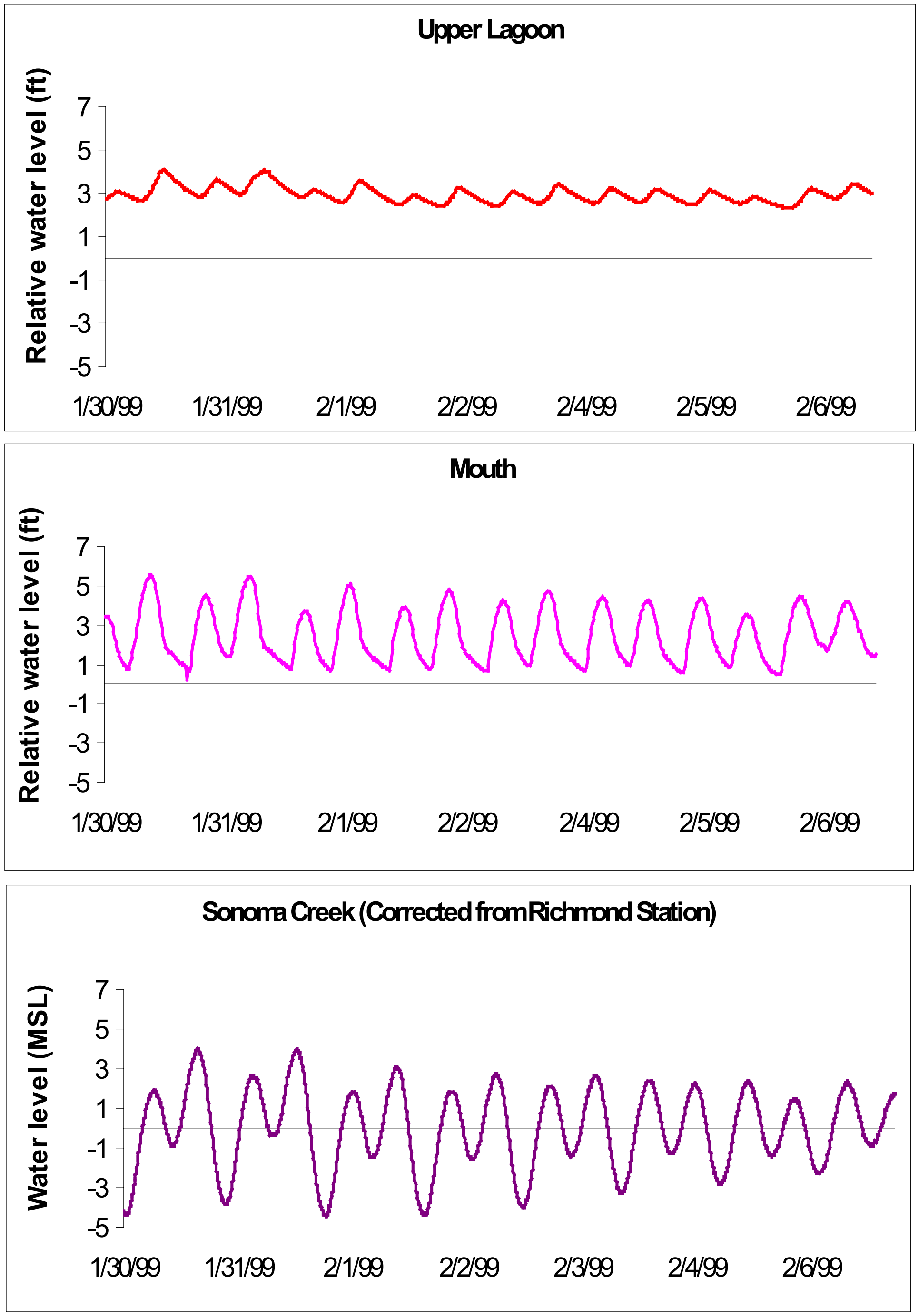


Figure 6. Amplitude and relative water levels of estimated tidal flows at the Upper Lagoon (top), at the Mouth (middle) of Tolay Creek, and at Sonoma Creek (bottom) during a one-week period, Jan 2002. Data loggers at the Tolay Creek Restoration Project measured water levels every 15 min. Water levels at Sonoma Creek were estimated from the Richmond Station with corrections for high tide (94%) and low tide (72%) provided in Tide Logs, but time was not corrected. Water levels are relative depths and were not adjusted to a benchmark.

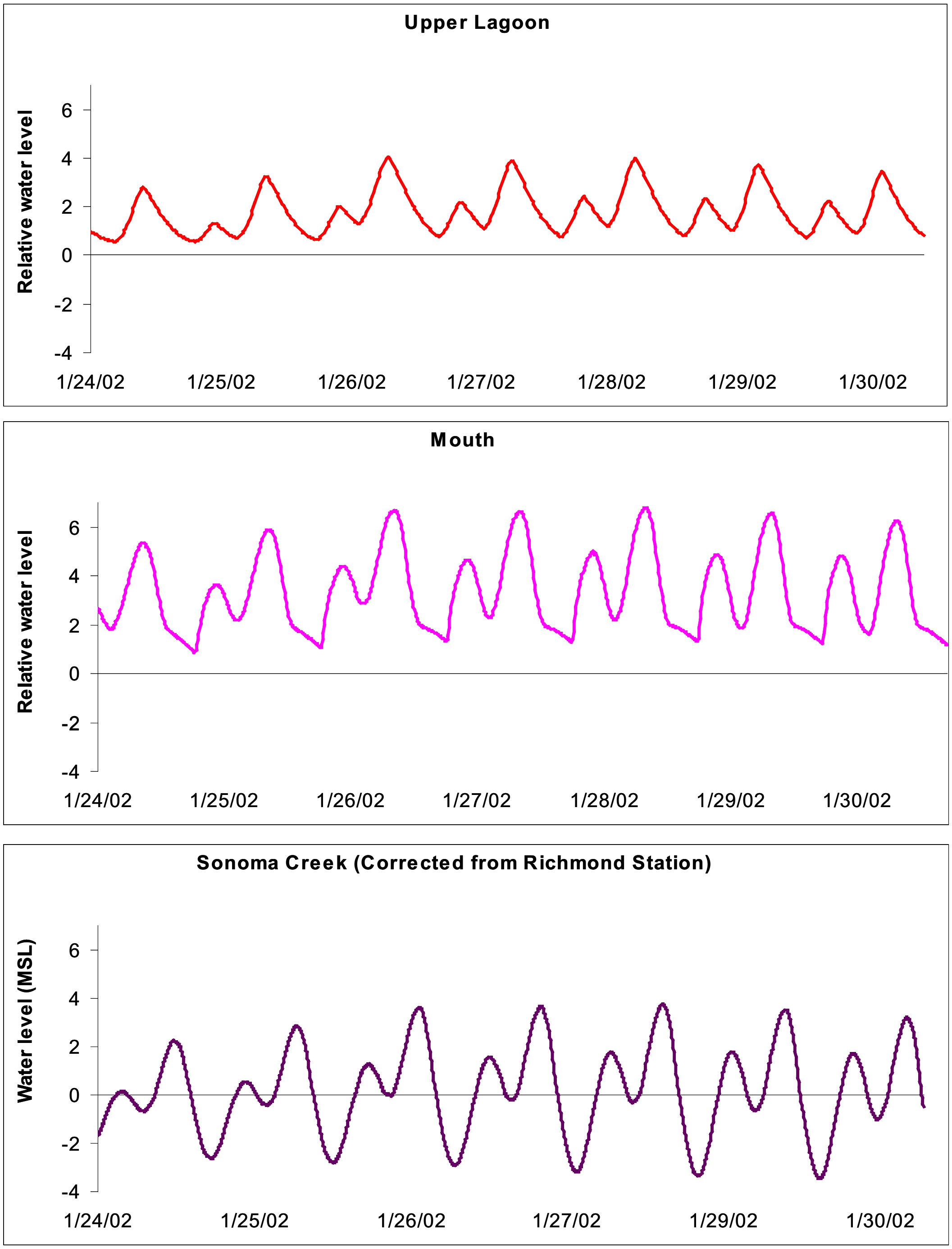
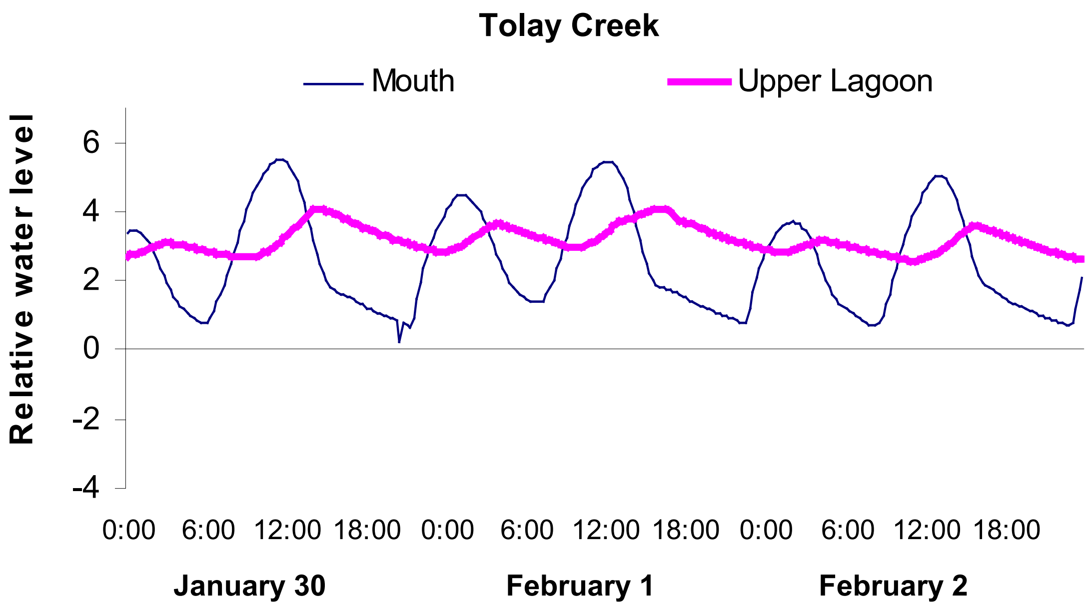


Figure 7. Amplitude and relative water levels of estimated tidal flows at the Upper Lagoon (top), at the Mouth (middle) of Tolay Creek, and at Sonoma Creek (bottom) during a one-week period, Jan 2002. Data loggers at the Tolay Creek Restoration Project measured water levels every 15 min. Water levels at Sonoma Creek were estimated from the Richmond Station with corrections for high tide (94%) and low tide (72%) provided in Tide Logs, but time was not corrected. Water levels are relative depths and were not adjusted to a benchmark.



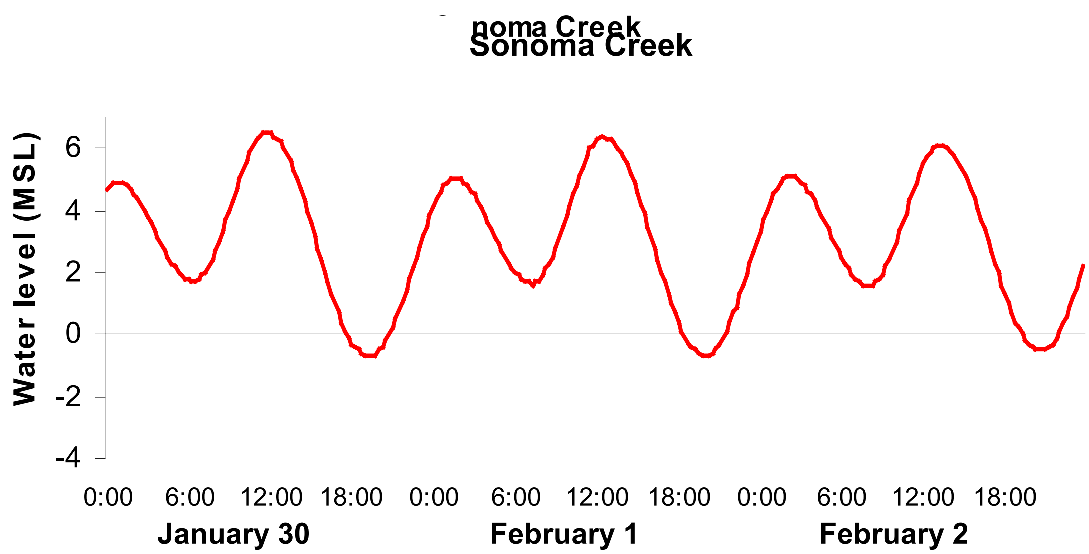
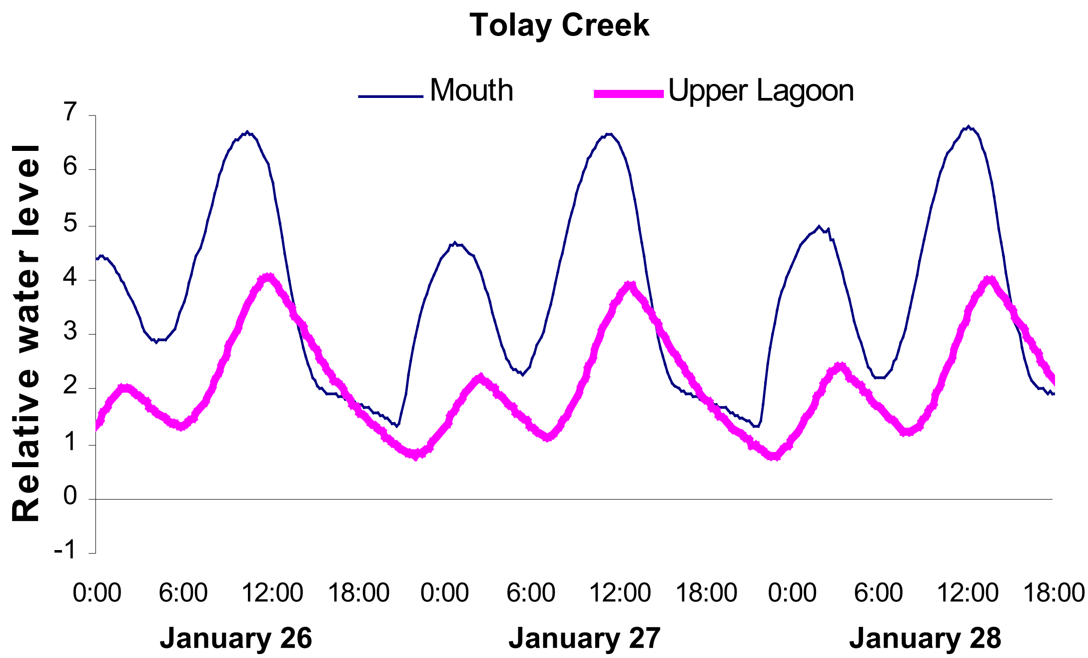


Figure 8. Predicted tidal period at Sonoma Creek (bottom) from a Tide Log and relative water levels at the Mouth (top, thin line) and Upper Lagoon (top, thick line) of the Tolay Creek Restoration Project from data loggers collecting measurements each 15 min during a 3-day period, January 30 to February1, 1999. Time period, but not water levels, are directly comparable for the Mouth and Upper Lagoon.



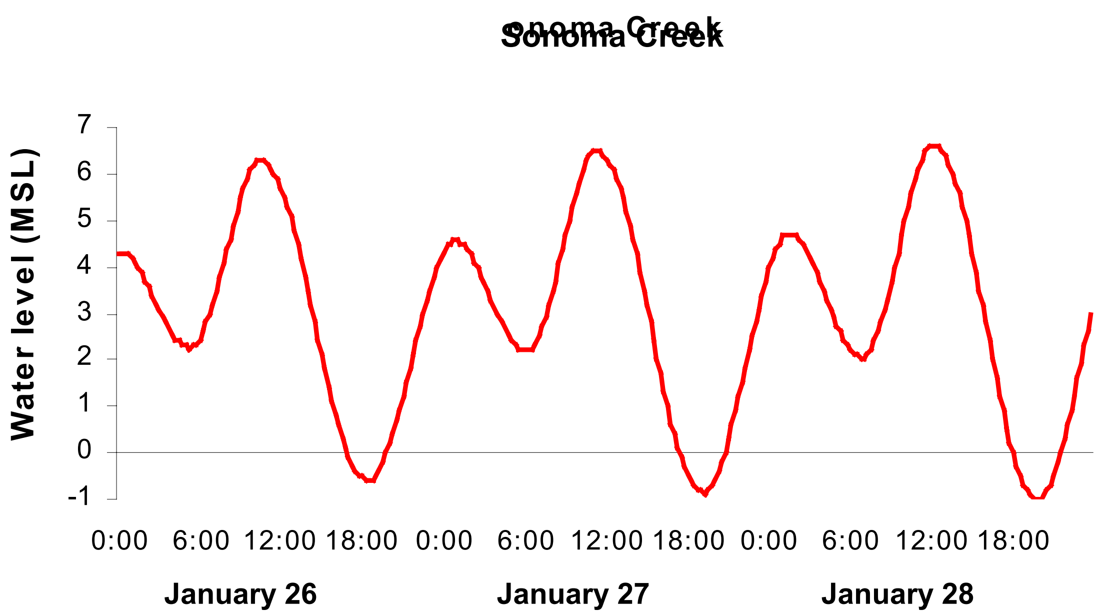


Figure 9. Predicted tidal period at Sonoma Creek (bottom) from a Tide Log and relative water levels at the Mouth (top, thin line) and Upper Lagoon (top, thick line) of the Tolay Creek Restoration Project from data loggers collecting measurements each 15 min during a 3-day period, January 26 to January 28, 2002. Time period, but not water levels, are directly comparable for the Mouth and Upper Lagoon.

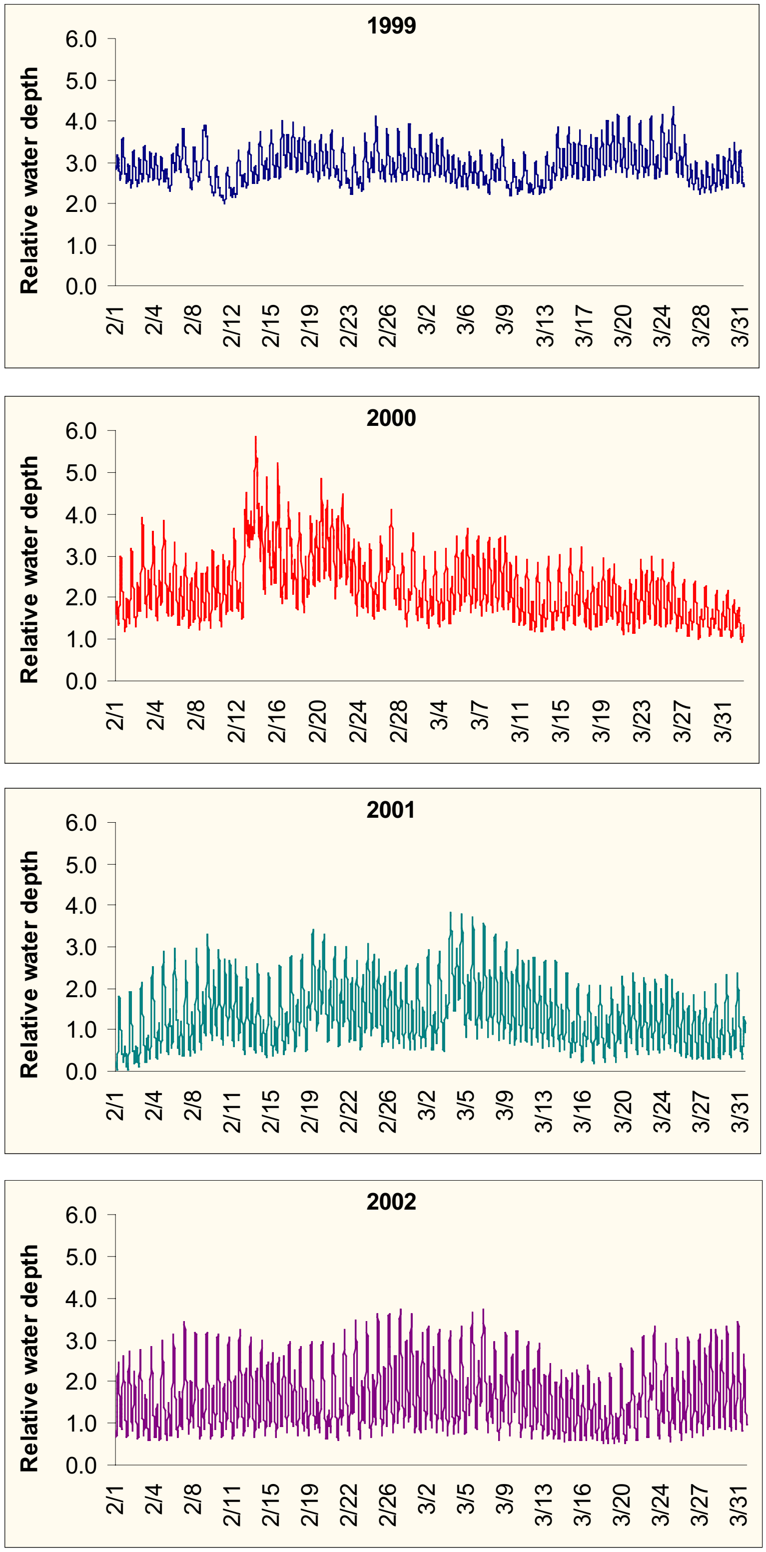


Figure 10. Relative water levels at the Upper Lagoon of the Tolay Creek Restoration Project from data loggers collecting measurements each 15 min during Feb-Mar, 1999-2002. Water levels are relative depths and are comparable among years, but were not adjusted to a benchmark

Figure 11. Panoramic views at photo points throughout the Tolay Creek project, August 2002 (See Figure 2 for locations).

Photopoint 4b

Photopoint 5a

Photopoint 5b (away from creek)

Photopoint 6

Photopoint 7

Photopoint 8

Figure 11. Continued.

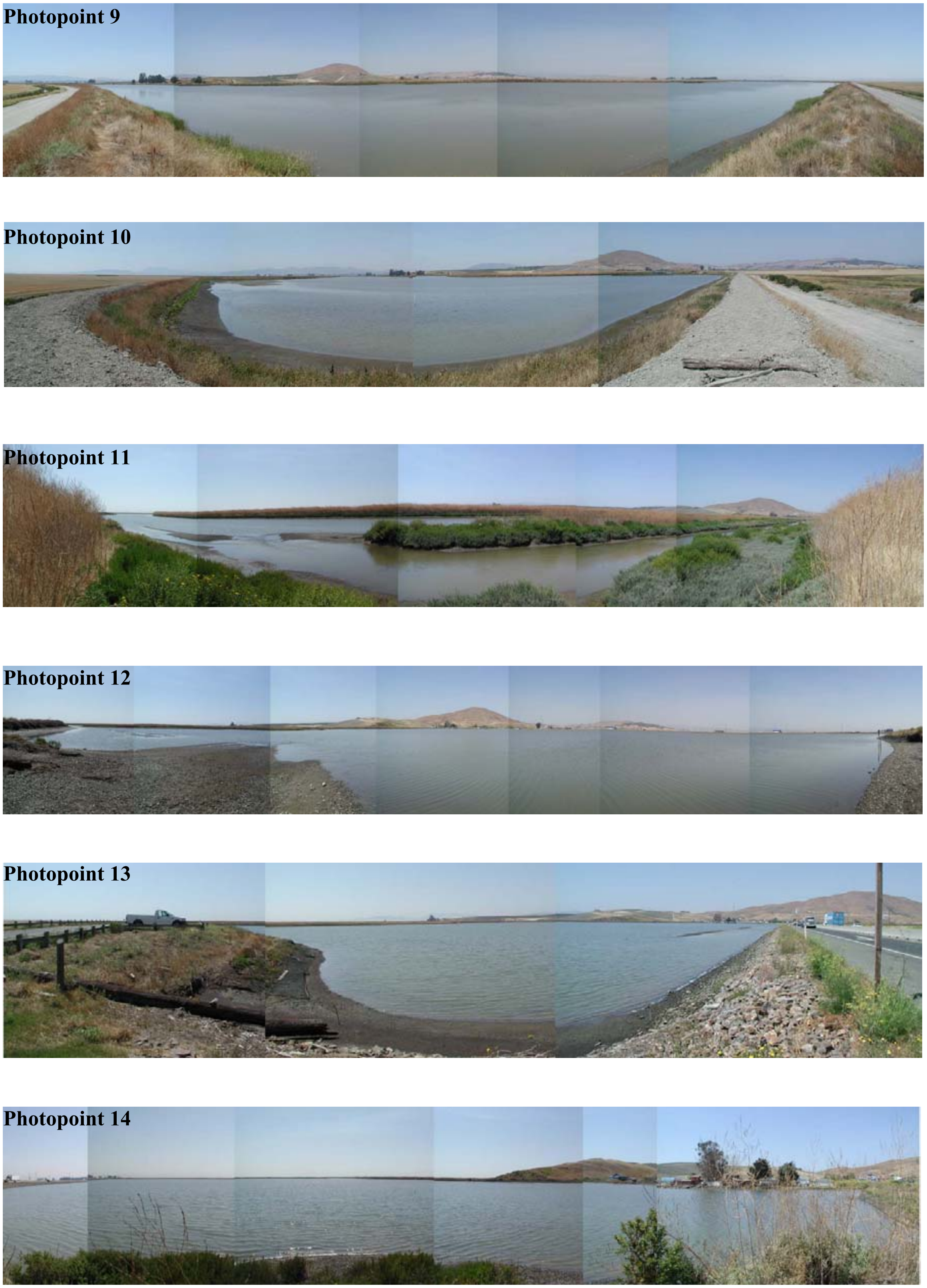


Figure 11. Continued.

August 2000

August 2002

Figure 12. Panoramic view of photo point #3 (See Figure 3 for location) in August 2000 and 2002, providing evidence of qualitative change. Here we document increased pickleweed cover from 2000 to 2002.

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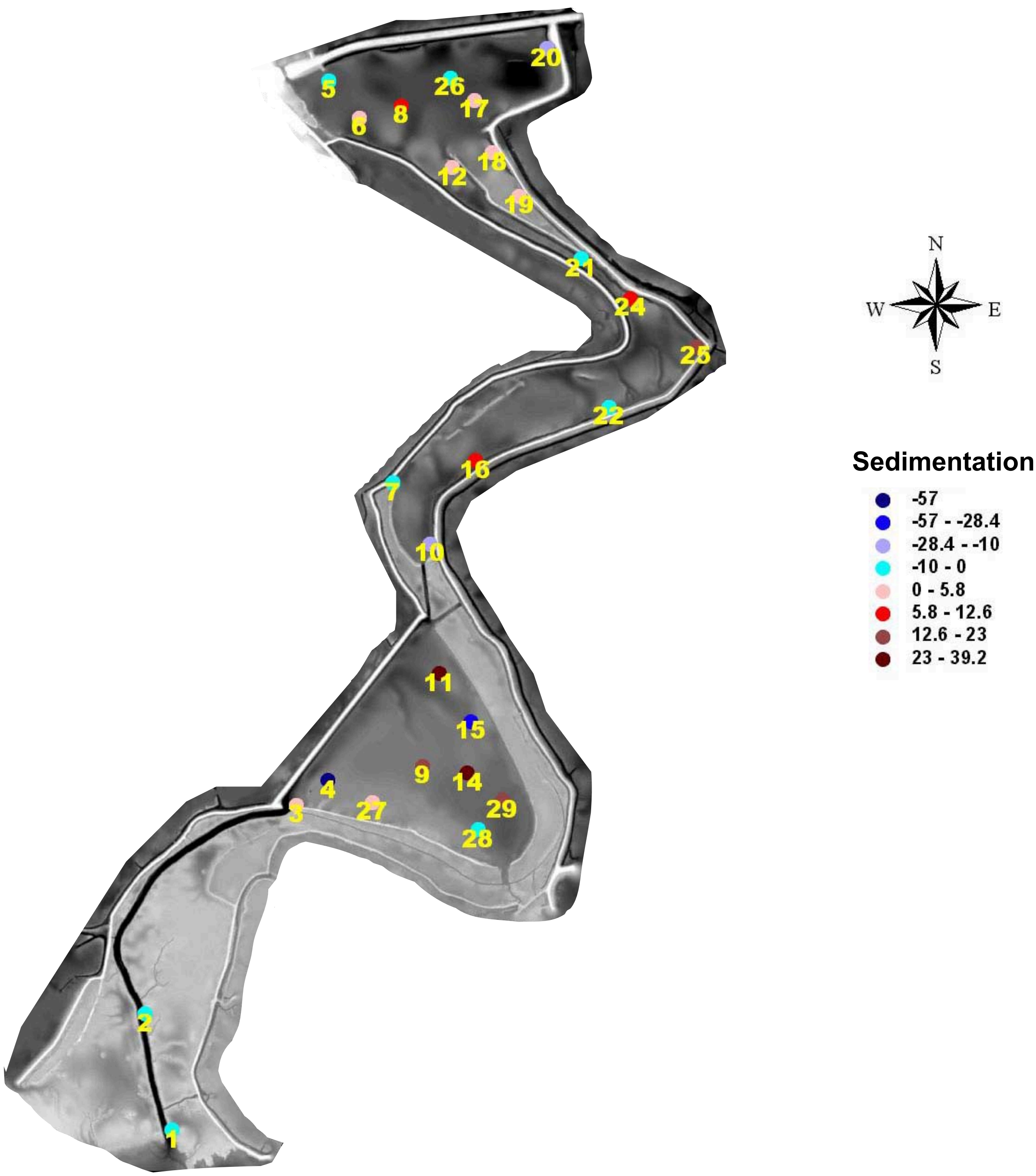

Figure 13. Sediment pins and sediment accumulation or loss represented by a color gradient throughout the Tolay Creek Restoration Project, 1999-2002.

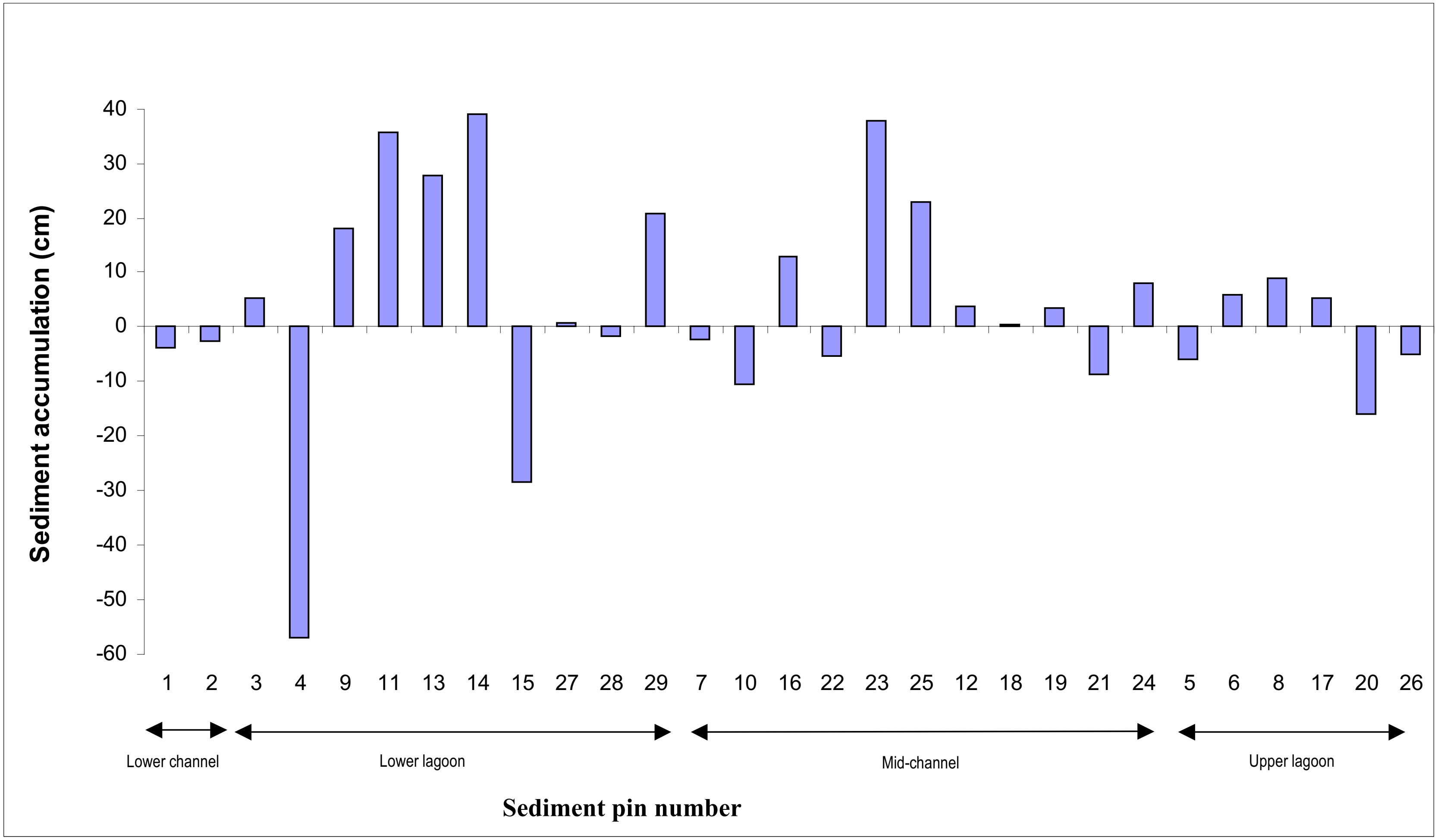

Figure 14. Sediment accumulation and loss in the Tolay Creek Restoration Project, May 1999- May 2002. Sediment pins (see Fig. 13) are organized by area from left-to-right from the Mouth at San Pablo Bay north to the Upper Lagoon at Highway 37. Sediment loss and accumulation is greatest in the Lower Lagoon.

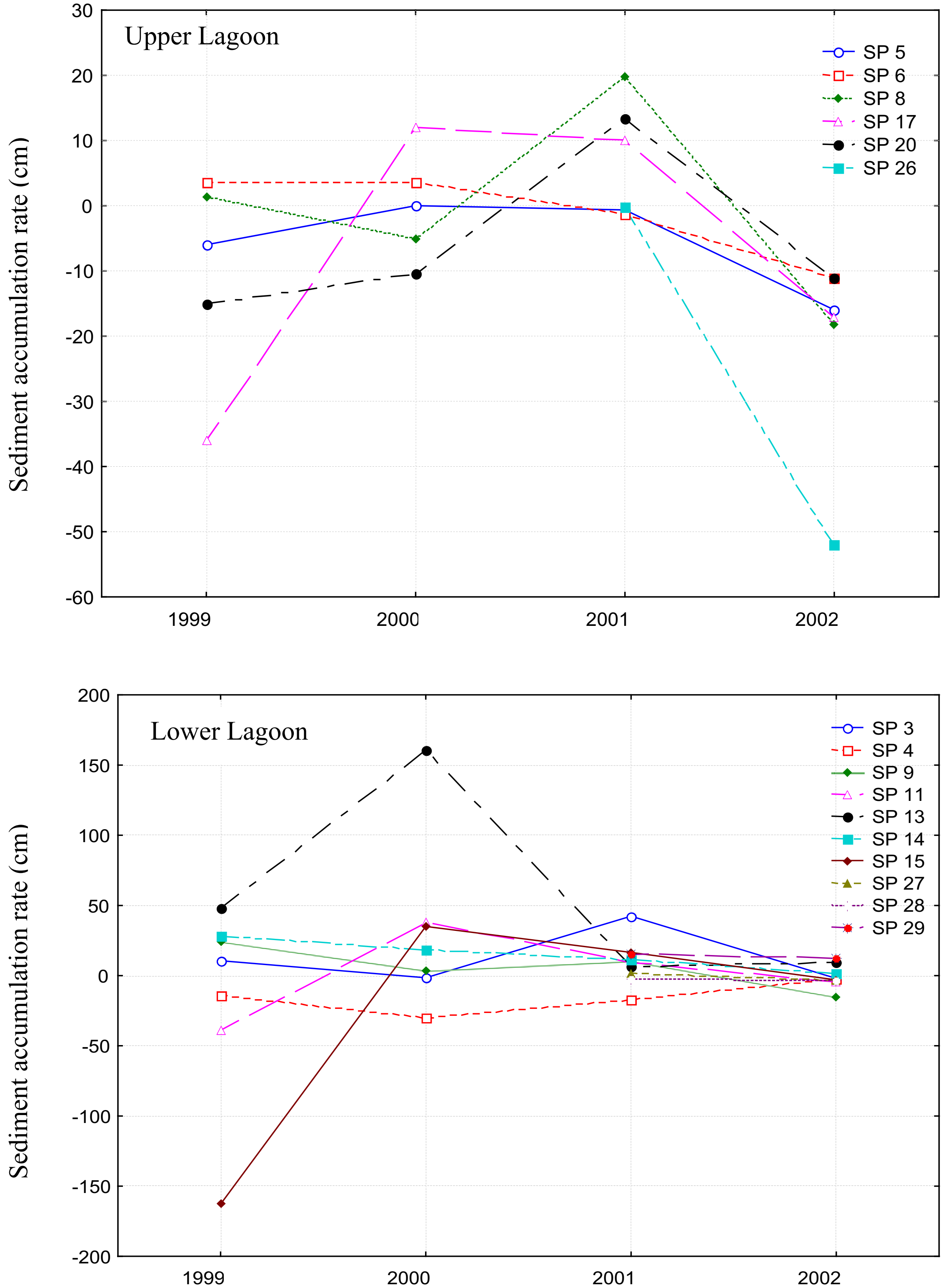

Figure 15. Rate of sediment accumulation and loss in the Upper (top) and Lower (bottom) Lagoons at the Tolay Creek Restoration Project, 1999-2002. Sediment is accumulating in the Lower Lagoon but is eroding in the Upper Lagoon.

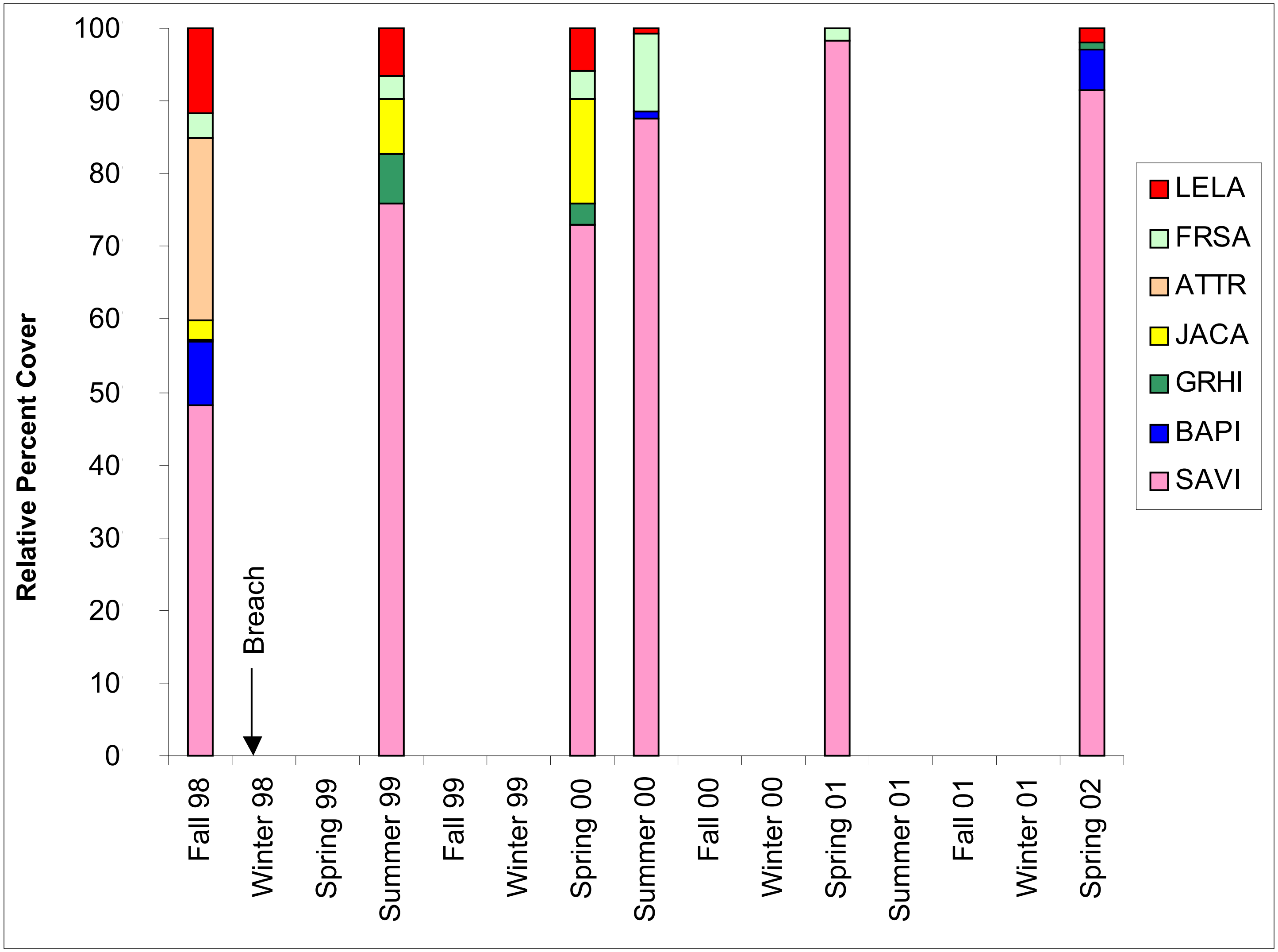

Figure 16. Relative percent cover for major plant species along 9 transects in the Tolay Creek Project, fall 1998 – spring 2002. Plant codes include: *Lepidium latifolium* (LELA), *Frankenia salina* (FRSA), *Atriplex triangularis* (ATTR), *Jaumea carnosa* (JACA), *Grindelia hirsutula* (GRHI), *Baccharus pilularis* (BAPI), and *Salicornia virginica* (SAVI).

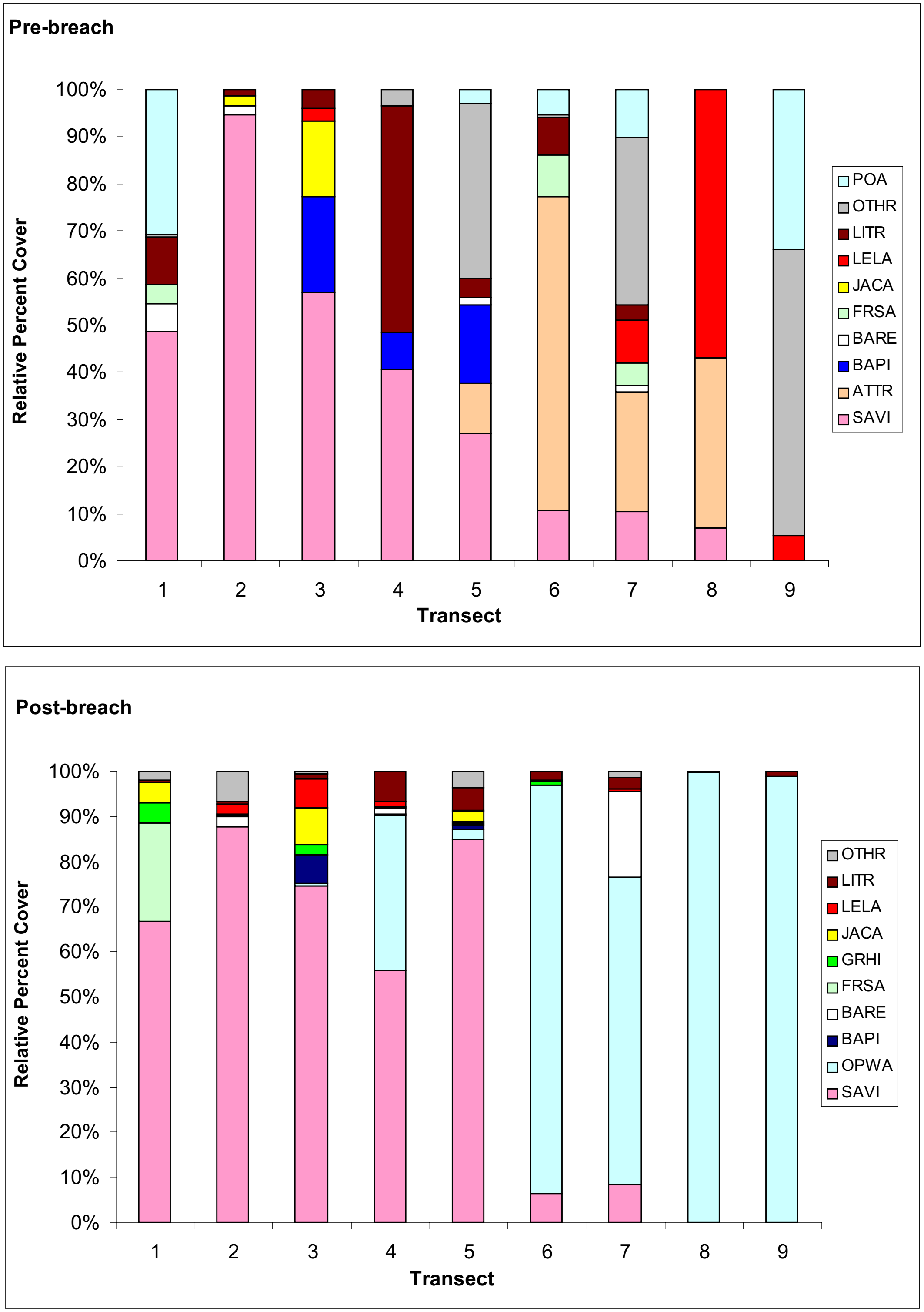

Figure 17. Relative percent cover of major plants, pre-breach (1999) and post-breach (1999-2002) along 9 transects in the Tolay Creek Restoration Project. Plant codes include: *Lepidium latifolium* (LELA), *Frankenia salina* (FRSA), *Atriplex triangularis* (ATTR), *Jaumea carnosa* (JACA), *Grindelia hirsutula* (GRHI), *Baccharus pilularis* (BAPI), and *Salicornia virginica* (SAVI).

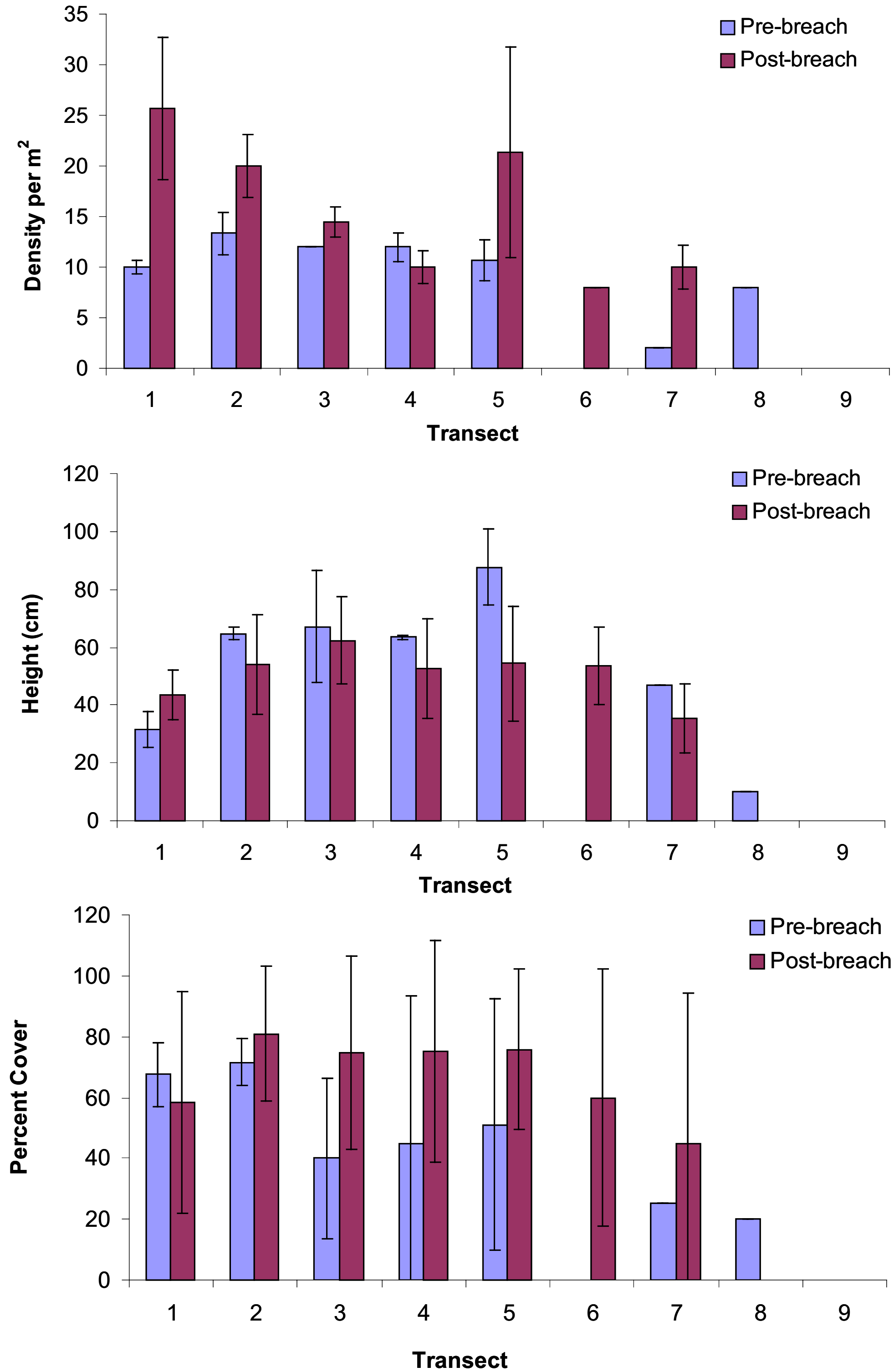

Figure 18. Density (stems/m^2,top), height (middle), and percent cover (bottom) of pickleweed (*Salicornia virginica*) pre-breach (1998) and post-breach (1999-2002) in the Tolay Creek Restoration Project. Error bars represent 1 S.D.

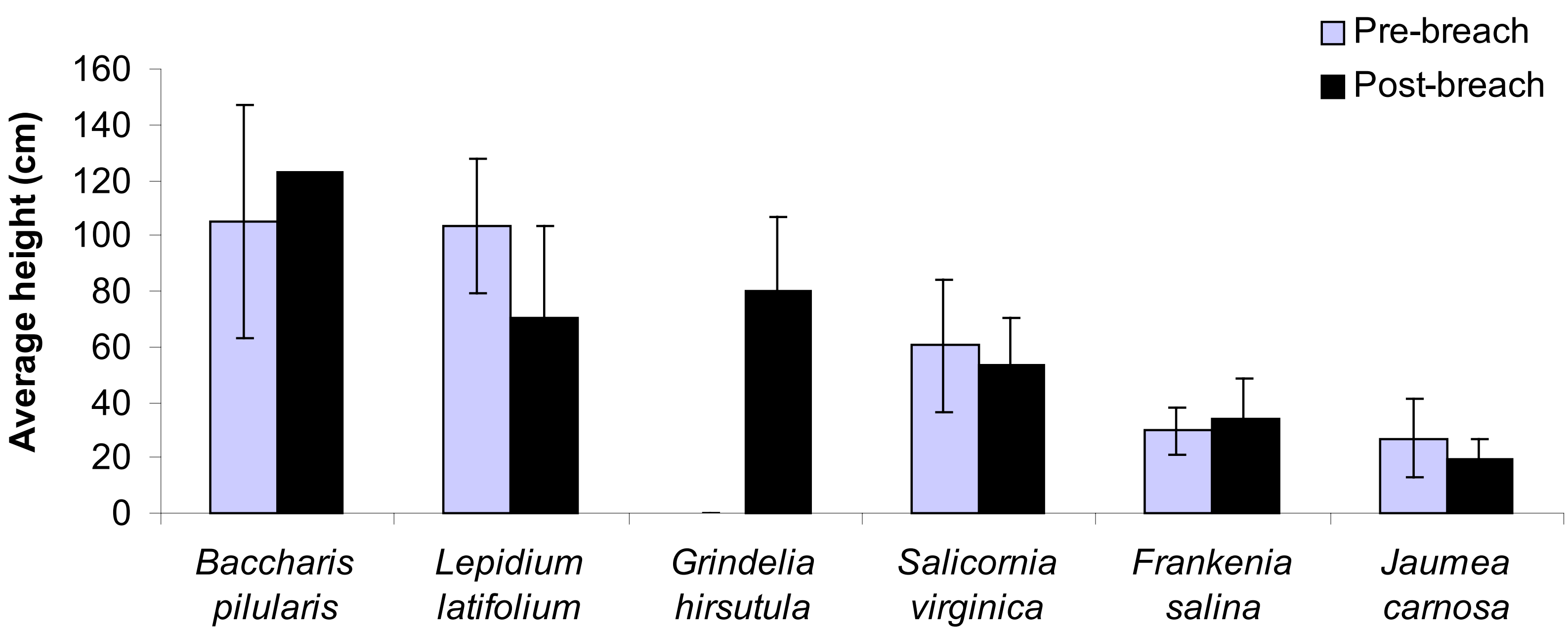

Figure 19. Average height of major plants, pre-breach (1999) and post-breach (1999-2002) at 9 transects in the Tolay Creek Restoration Project. Plant codes include: *Lepidium latifolium* (LELA), *Frankenia salina* (FRSA), *Atriplex triangularis* (ATTR), *Jaumea carnosa* (JACA), *Grindelia hirsutula* (GRHI), *Baccharus pilularis* (BAPI), and *Salicornia virginica* (SAVI).

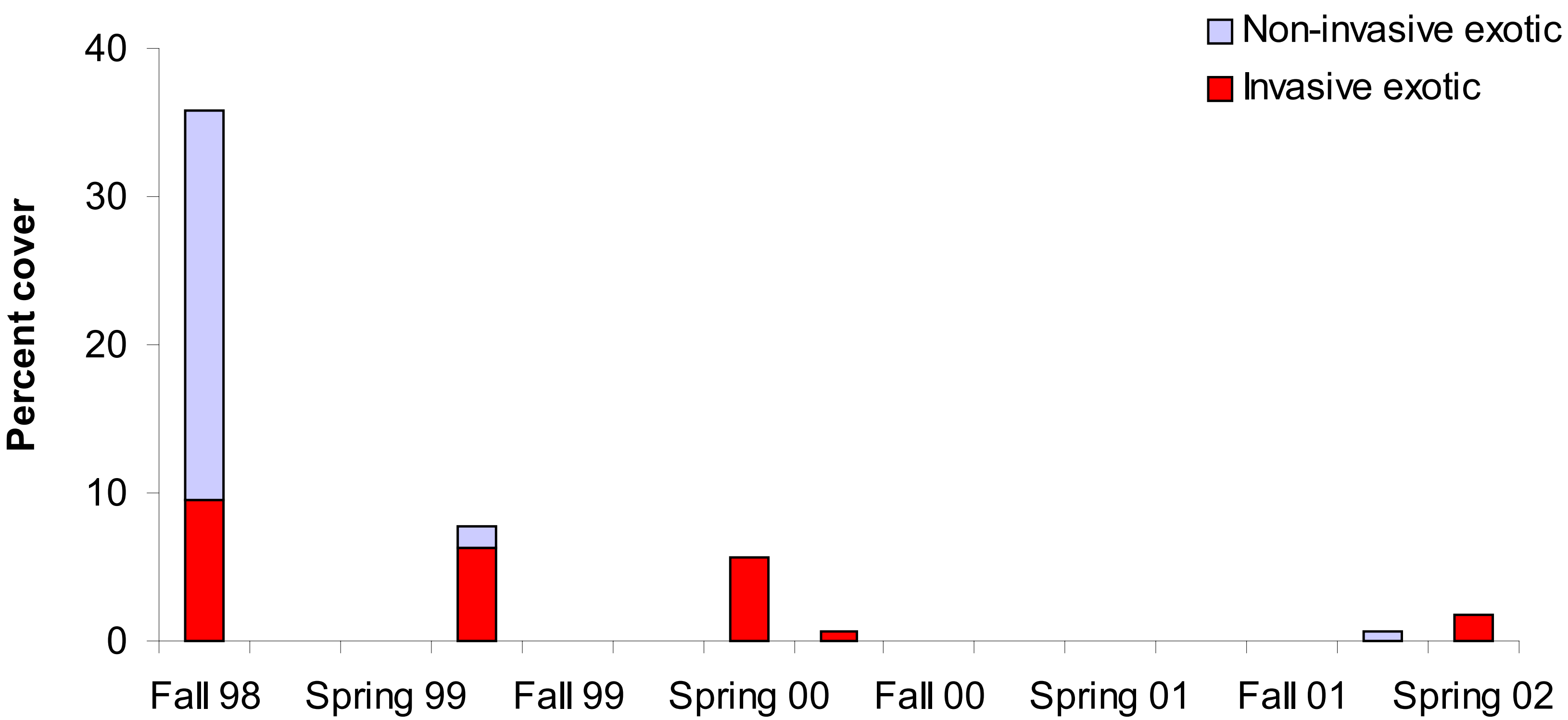

Figure 20. Percent cover of invasive and non-invasive plants in the Tolay Creek Restoration Project, Fall 1998 – Spring 2002. Exotic plant cover has steadily declined since the breach in 1998; however, invasive exotic species cover persisted in Spring 2002.

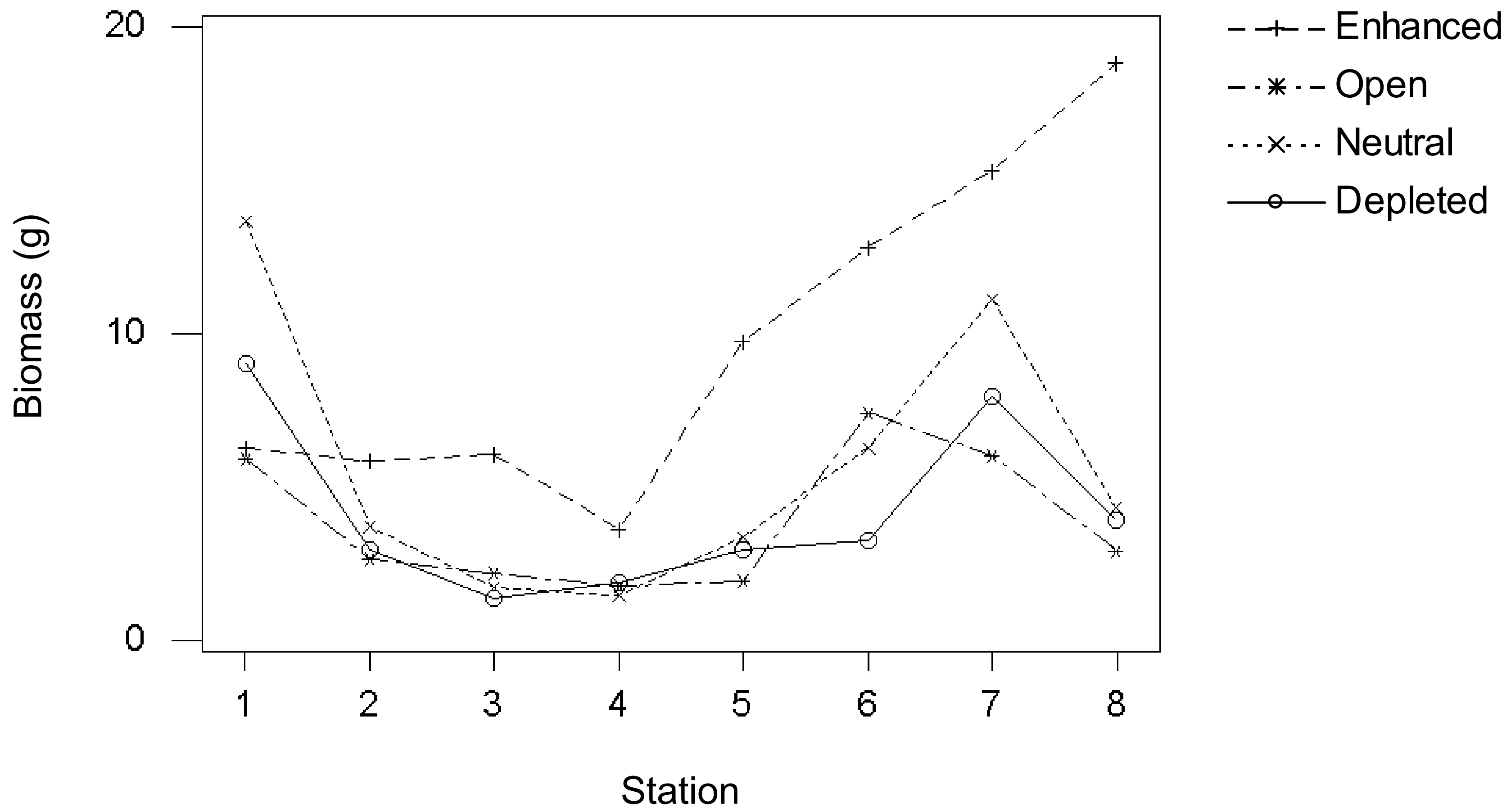

Figure21. Cumulative total biomass (g), Apr-Aug 2001, of beachhoppers (*Traskorchestia traskiana*) by station in the Tolay Creek Restoration Project. Enclosures include Depleted (amphipods removed from cage), Enhanced (amphipods added to cage), Neutral (cage only), and Open (no cage).

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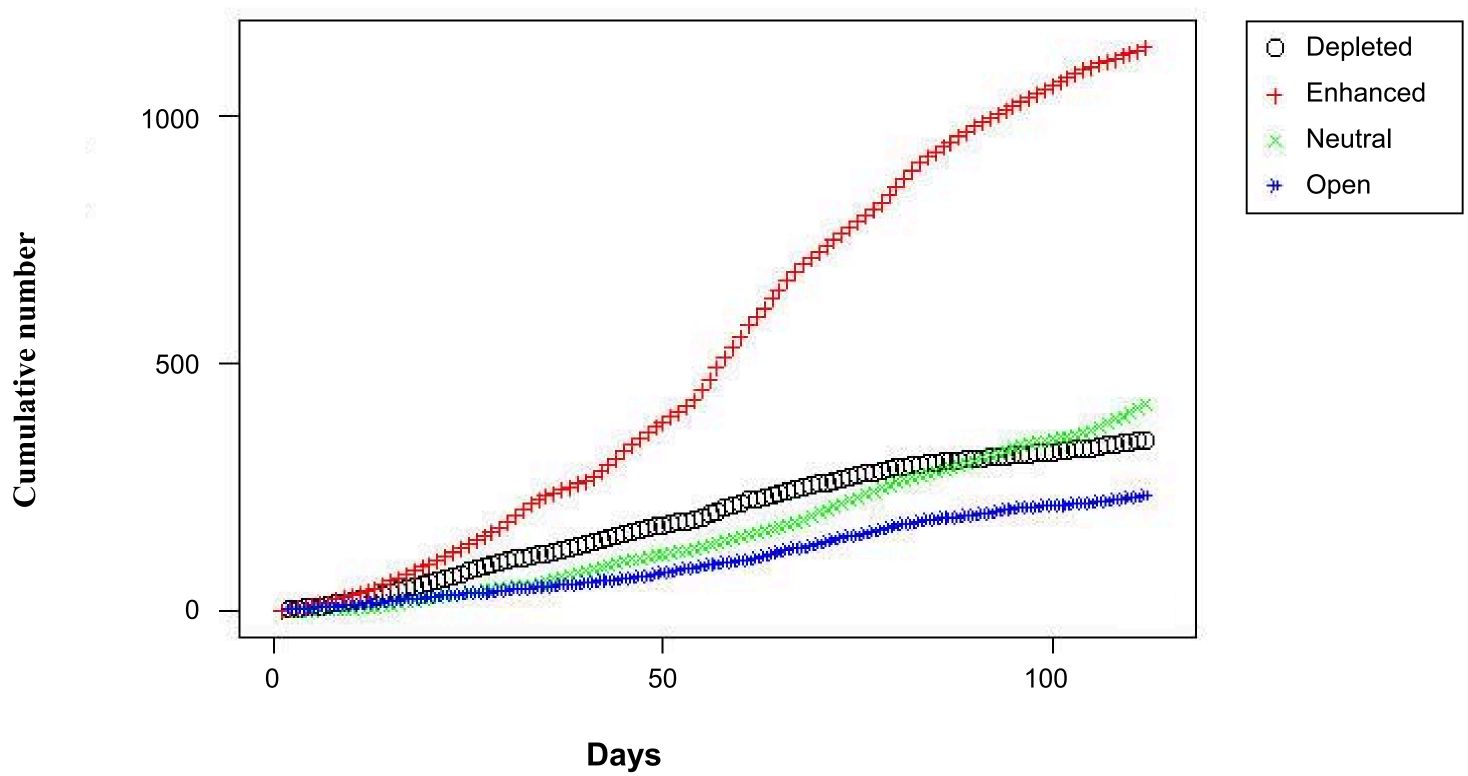


Figure 22. Cumulative number of beachhoppers (*Traskorchestia traskiana*) counted at 8 stations through time at the Tolay Creek Restoration Project, Apr-Aug 2001. Enclosures include Depleted (amphipods removed from cage), Enhanced (amphipods added to cage), Neutral (cage only), and Open (no cage).

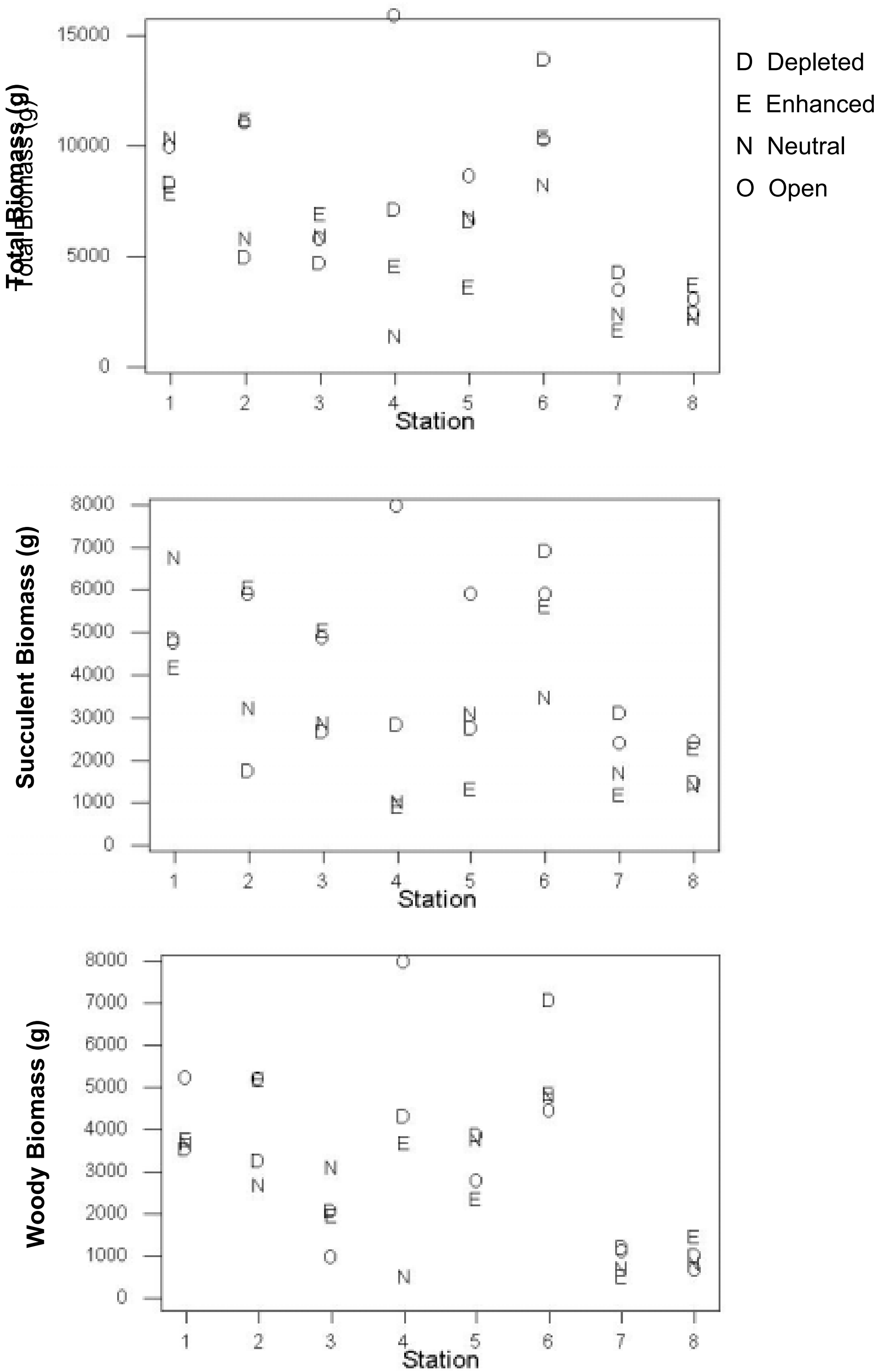


Figure 23. Total (top) (g), succulent (middle), and Woody (bottom) biomass of pickleweed *Salicornia virginica* in enclosures with different beachhopper (*Traskorchestia traskiana*) treatments by station in the Tolay Creek Restoration Project, Apr-Aug 2001. Enclosures include Depleted (amphipods removed from cage), Enhanced (amphipods added to cage), Neutral (cage only), and Open (no cage).

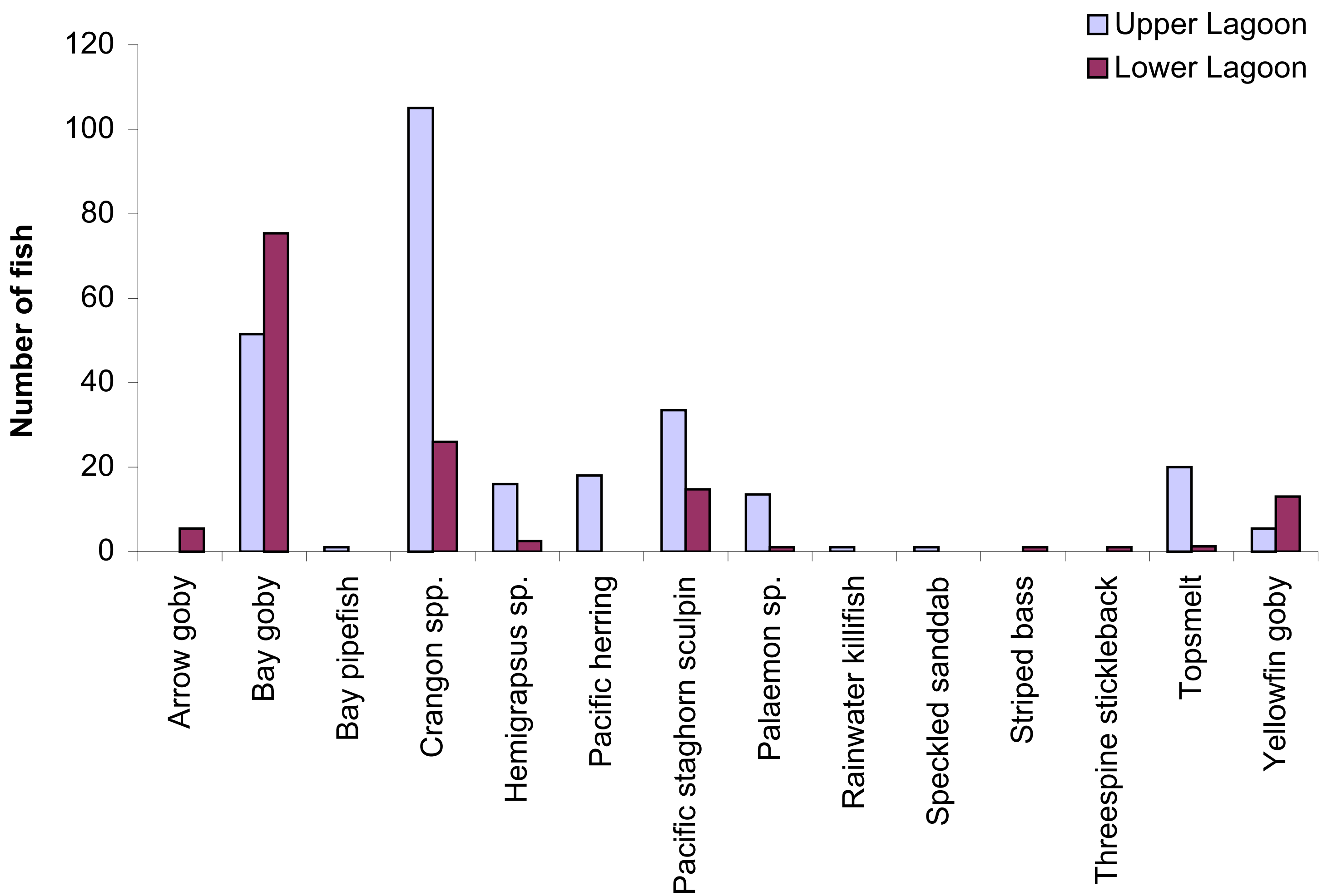


Figure 24. Fishes captured in beach-seines one year after breach (1999) and post-breach (2002) at Tolay Creek.

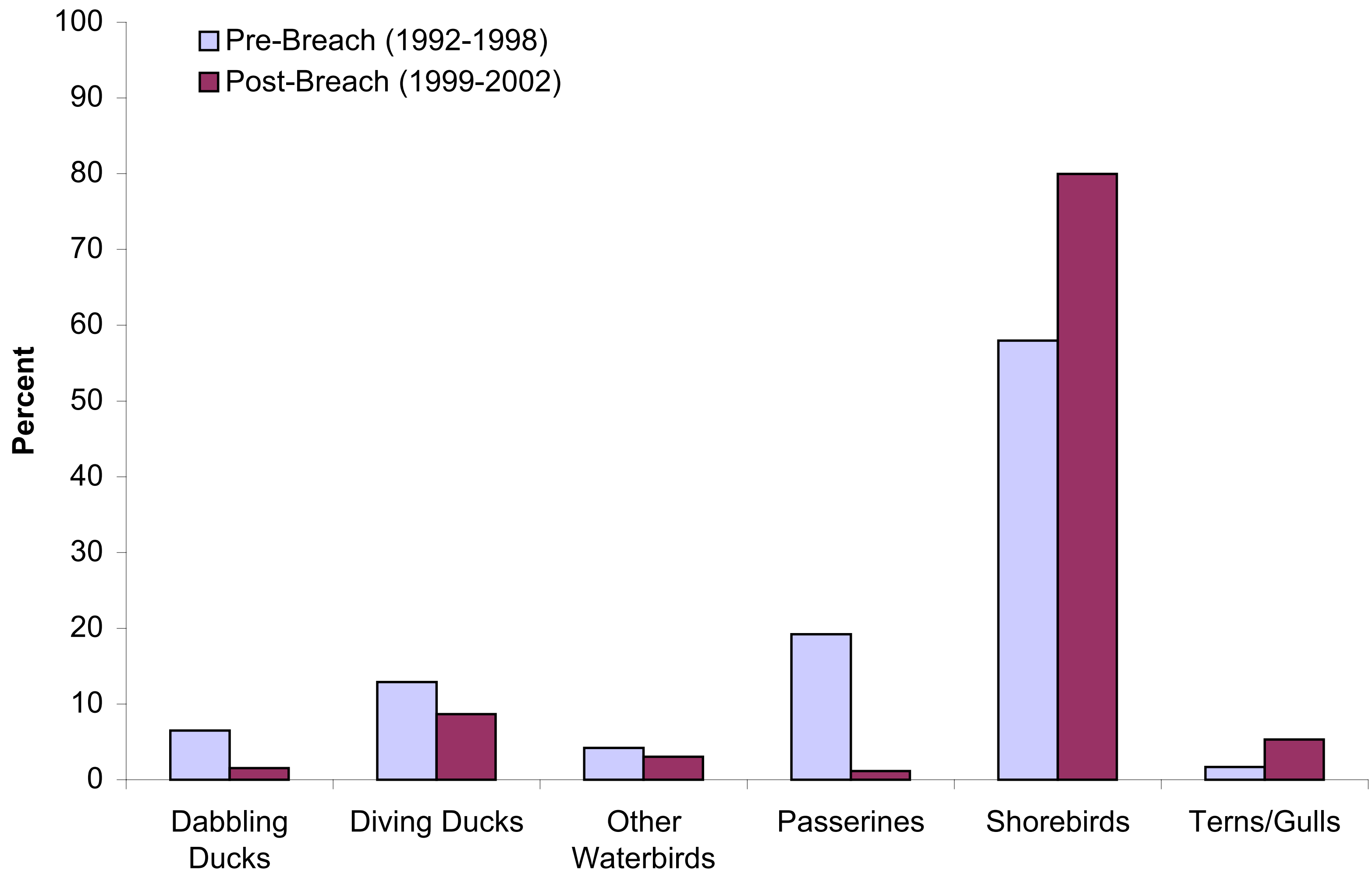


Figure 25. Percent occurrence of avian guilds at Tolay Creek, pre-breach (1992-1998) and post-breach (1999-2002).

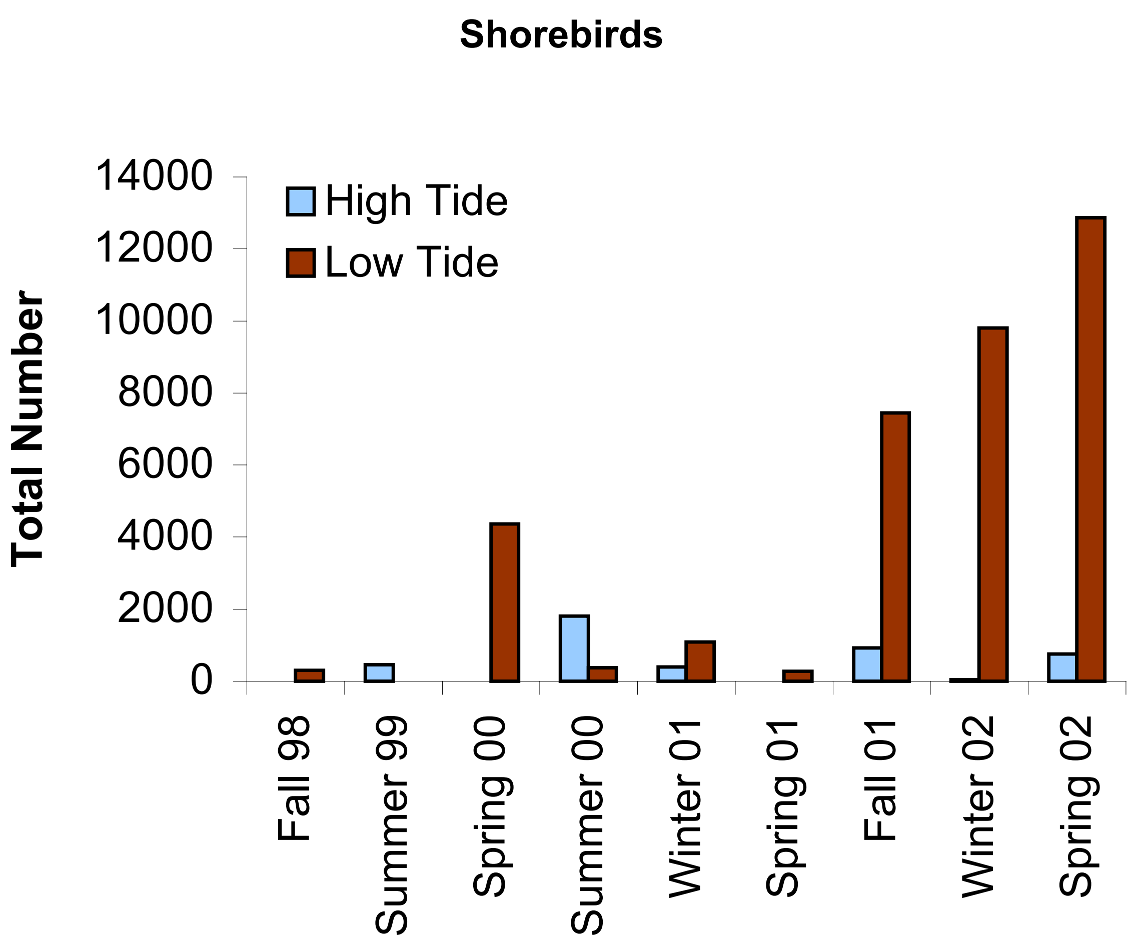


Figure 26. Total number of shorebirds observed on low and high tides at the Tolay Creek Restoration Project, 1998-2002.

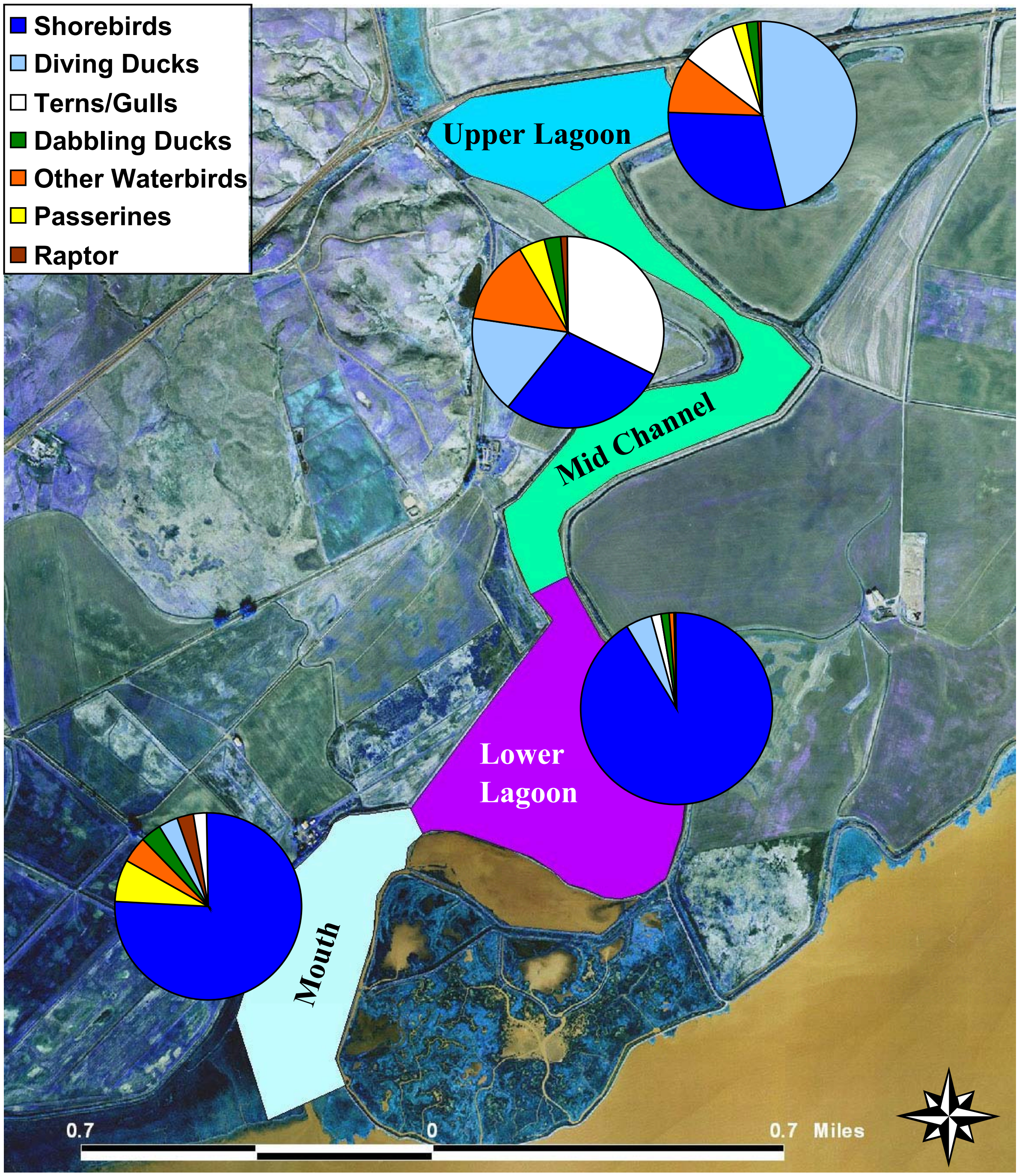


Figure 27. Percent occurrence of avian guilds in the Mouth, Lower Lagoon, Mid Channel, and Upper Lagoon of the Tolay Creek Restoration Project (1999-2002).

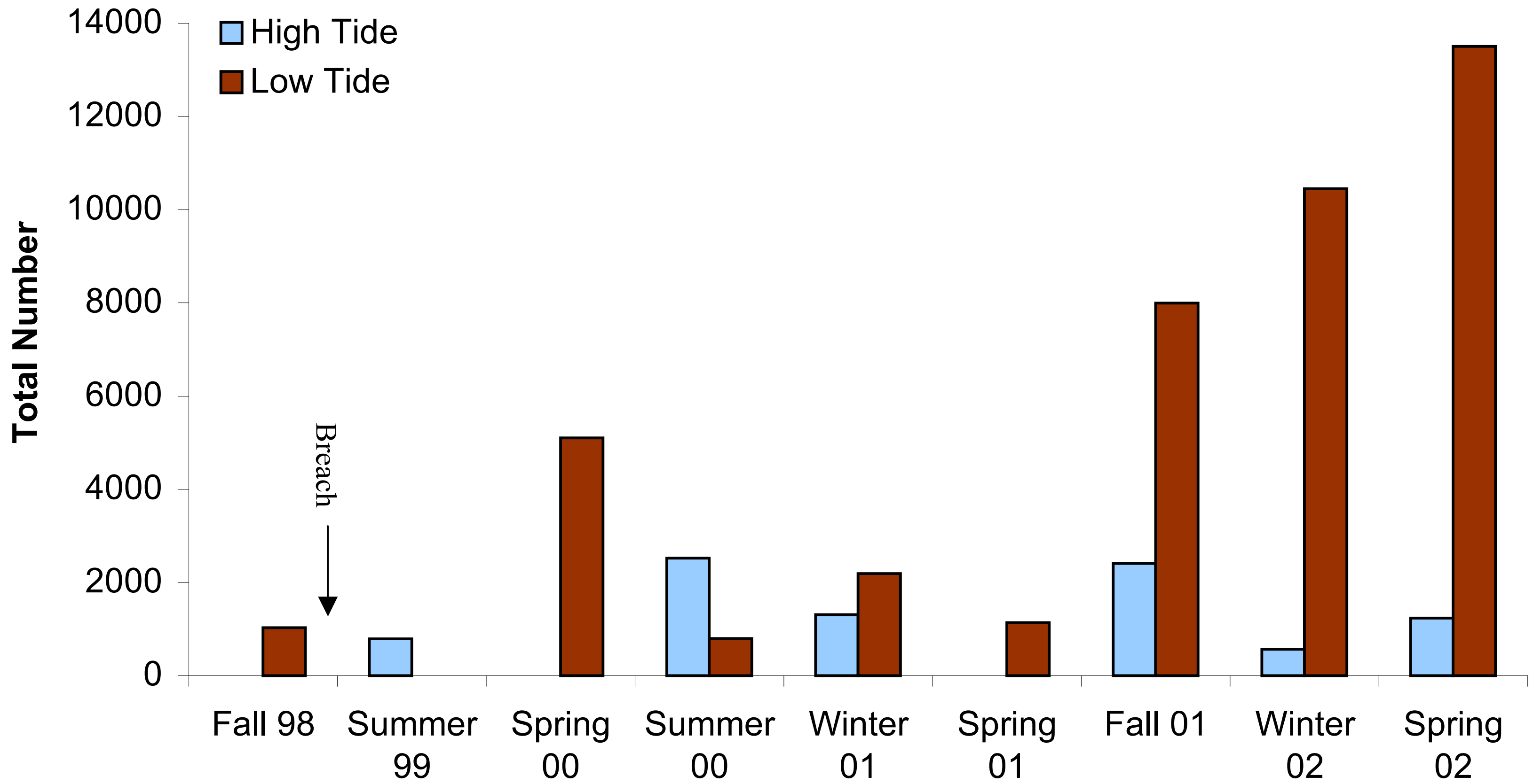


Figure 28. Total number of birds recorded at high and low tide in the Tolay Creek Restoration Project, fall 1998 – spring 2002.

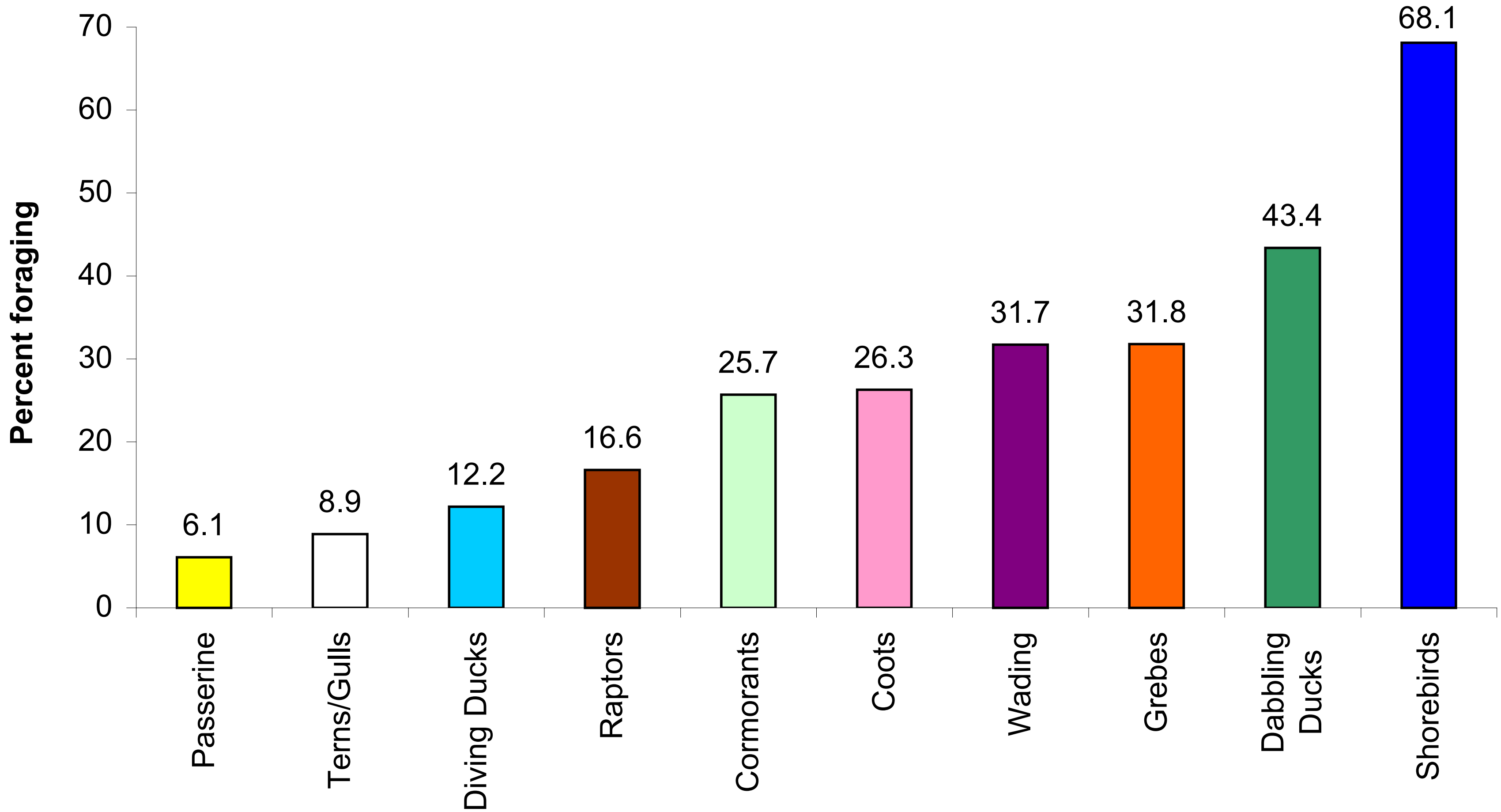


Figure 29. Percent of birds foraging by guild in the Tolay Creek Restoration Project, 1999-2002.

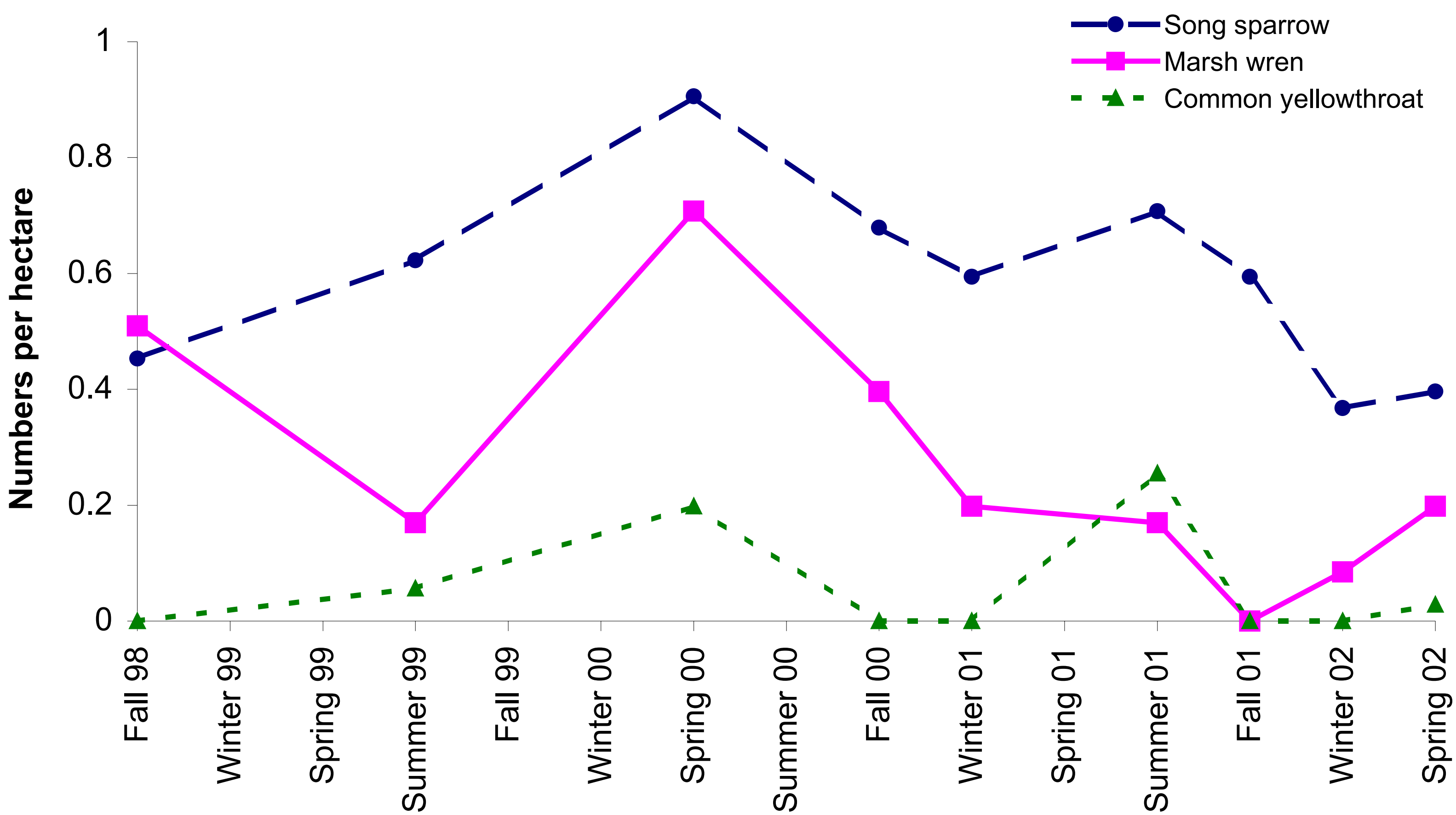


Figure 1. Density (numbers/ha) of 3 tidal marsh passerines (San Pablo song sparrow *Melodia melospiza samuelis*; marsh wrens *Cistothorus palutris*, and common yellowthroat *Geothlypis trichas*) in the Tolay Creek Restoration Project, fall 1998 to spring 2002.

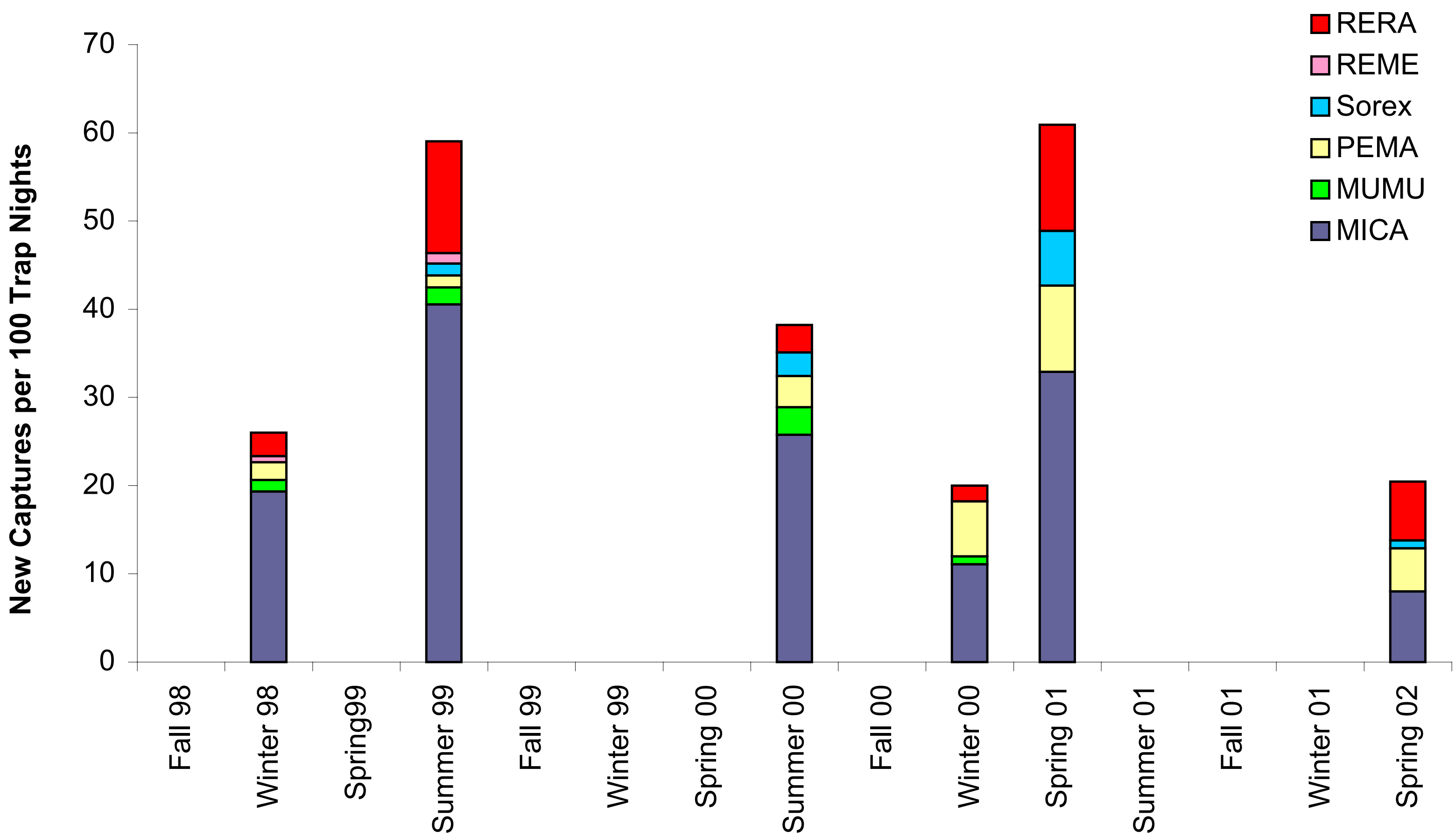


Figure 31. Abundance index (new captures/ 100 trap nights) of small mammals in the Tolay Creek Restoration Project across trapping grids, fall 1998 – spring 2002. Codes include: *Reithrodontomys raviventris halicoetes* (RERA), *Reithrodontomys megalotis* (REME), *Sorex spp.* (Sorex), *Peromyscus maniculatus* (PEMA), *Mus musculus* (MUMU), and *Microtus californicus* (MICA).

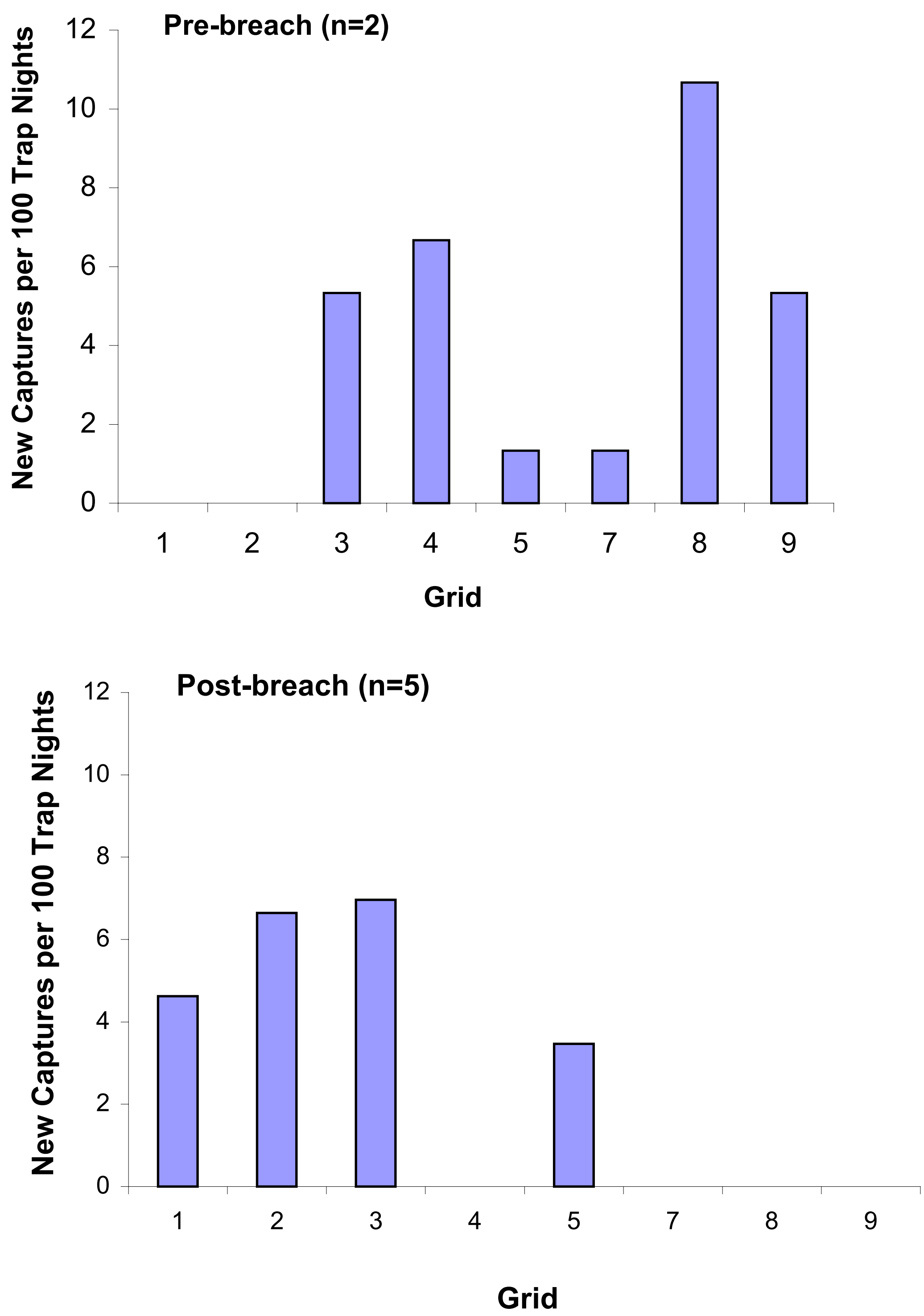
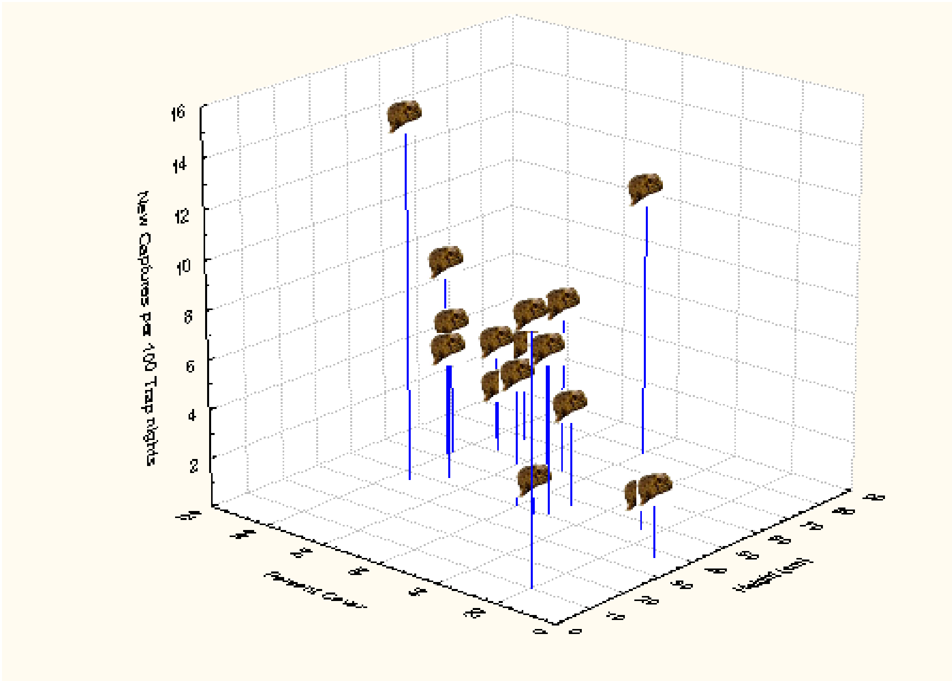


Figure 32. Abundance index (New Captures/ 100 Trap Nights) of the salt marsh harvest mouse (*Reithrodontomys raviventris*) in the Tolay Creek Restoration Project across 9 trapping grids, pre-breach (1998-1999) and post-breach (1999-2002).



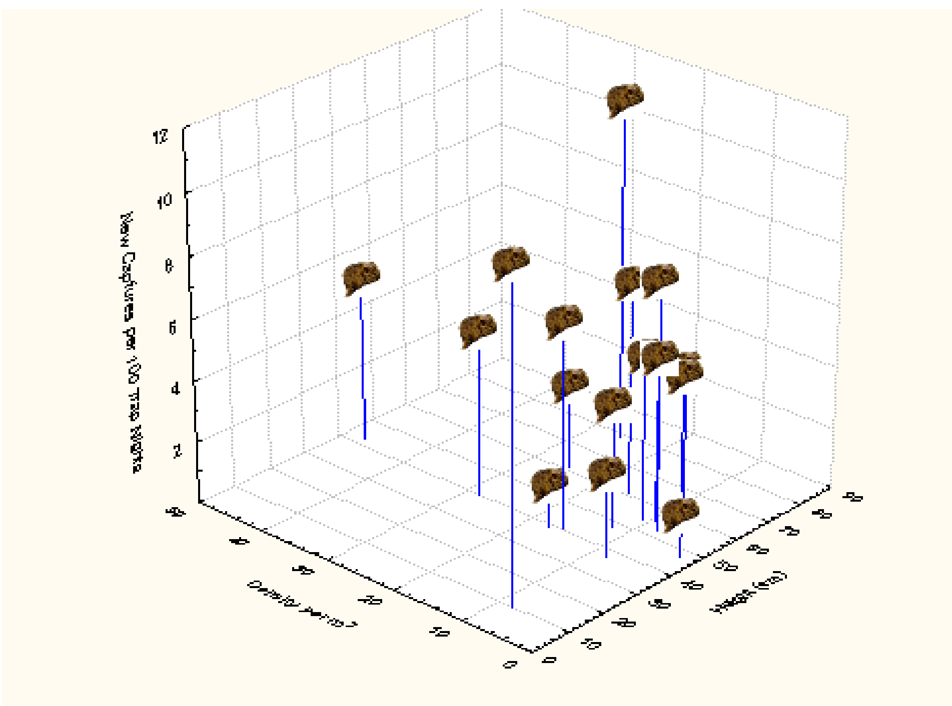


Figure 33. Three dimensional relation graphs between the salt marsh harvest mouse (*Reithrodontomys raviventris*) abundance index (new captures/ 100 trap nights) with pickleweed (*Salicornia virginica*) height (cm) and percent cover (top); and density (plants/m^2: bottom) and height (cm) at the Tolay Creek Restoration Project, 1999-2002.