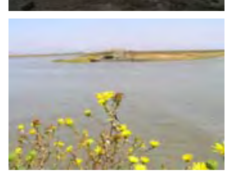
The Tubbs Setback Restoration Project: 2006 Final Report



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EXECUTIVE SUMMARY

- The San Pablo Bay National Wildlife Refuge leased the Tubbs Setback property in 1980 under a 66-year agreement with the California State Lands Commission. The 29-ha area, adjacent to San Pablo Bay between the Petaluma River and Sonoma Creek, was diked in the early 1900s and farmed until 1983. The Refuge initiated the Tubbs Setback Restoration Project in 1985 with funding support from the United Heckathorn Trustee Council. Ducks Unlimited engineered and constructed the restoration work, including a fortified setback levee to protect adjacent baylands. A 45.7-m (150 ft) breach opened the outer levee to tidal action on 8 March 2002.

- After restoring tidal flows in Mar 2002, the average tide range in the northwest corner increased 70% from 2.36 ft (all elevations NAVD88) (Mar-Apr 2002) to 4.02 ft (Feb-Aug 2005). In August 2005, the logger was relocated to deeper water.

- In 2005, we detected that our water level sensor had become buried underneath sediment. Minimum water levels were restricted to 2.7 ft at the northwest logger in Aug 2005, indicating gradual sediment buildup at the sensor. We relocated the northwest data logger to the main channel to reduce the likelihood of sensor burial. After the relocation, minimum water levels reached a low of 1.1 ft. Tidal range from Aug 2005 to Sep 2006 approached that of the bay at 5.17 ft.

- During 1 Jan 2006, the combination of high rains and annual high tides resulted in an extreme flood event in the region. We recorded a high water level of 8.90 ft and a tidal range of 7.53 ft. Benchmark elevations along the west, north, and east levee indicate that water did not overtop the levees.

- We classified land cover using georeferenced color infrared photographs (ERDAS, Imagine software). In Aug 2005, vegetative cover comprised 6% of the total project area and remained at 6% in Aug 2006.

- Overall sediment accumulation averaged 82 cm ± 17 cm (mean ± SE) using sediment pin data (n=24) and ranged from -43 cm (at sediment pin B) to 218 cm (at sediment pin 4) from Mar 2002 to Sep 2006. Accumulation of sediment benefits the restoration project by allowing vegetation to colonize subsided land.

- Sedimentation rates varied spatially, with greater sedimentation in the center of the project (173 cm) than at the margins (105 cm) between 2002 and 2006. The elevations of sediment pins along the interior mudflats converge at 3.24 ± 0.06 ft.

- Bathymetry surveys in Jan 2004 and Sep 2005 showed a main channel near the breach, which encircled the central mud flat and diminished with distance from the breach. We generated a bathymetry map from which we characterized channel morphology and identified the high sedimentation rates as a threat to channel persistence. The average change in sediment accumulation between the 2004 and 2005 bathymetry surveys was 57 cm throughout the project or 132,908 m^3 (4,693,589 ft^3) of sediment accumulation.

- Pickleweed was quick to colonize the levee bench. In quadrat surveys, pickleweed percent cover increased annually from 29.3% in 2002 to 47.3% in 2003 to 56.7% in 2004 to 61.3% in 2005 to 72.3% in 2006. The levee bench is dominated by native species cover.

- The central mudflat was first colonized by vegetation (*Spartina sp.)* in Aug 2006.

- Nineteen bird species were detected during 1999 pre-breach surveys (n = 4). We detected 75 bird species during 107 post-breach bird surveys (Mar 2002 to Sep 2006). As the mudflat has gained elevation, the number of shorebirds detected in each survey has increased and the number of diving ducks has decreased. The greatest number of birds was recorded at a single low tide survey in October 2006 with >4,000 birds, of which 90% were shorebirds.

- Five small mammal species have been detected since the restoration; deer mouse (*Peromyscus maniculatus*), California vole (*Microtus californicus*), house mouse (*Mus musculus*), salt marsh harvest mouse (*Reithrodontomys raviventris*), and Norway rat (*Rattus norvegicus*). A single salt marsh harvest mouse was captured spanning trapping efforts from 2002 to 2004, but 5 salt marsh harvest mice were detected in 2005 despite reduced capture effort. Only one salt marsh harvest mouse was captured in 2006, possibly due to the extreme high tide event in the winter before trapping.

INTRODUCTION

The San Francisco Bay Estuary (SFBE) is the largest estuary on the west coast of North America. Intense urban and agricultural developments since the 1800s have resulted in a loss of over approximately 80% of historic tidal wetlands in the estuary (Goals Project 2000). The 9 counties within the San Francisco Bay (Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma counties) support almost 6.8 million people (US Census Bureau 2001). This urban estuary has undergone drastic environmental changes; broad scale efforts to fill or drain wetlands have given way to an era of progressive restoration. Restoration efforts notwithstanding, numerous threats remain for tidal marsh inhabitants, such as: habitat loss (development, fragmentation, sea level rise), habitat degradation (invasive plants or animals, environmental contaminants, and human disturbance), and biological interactions (invasive species, predation, and disease) (Takekawa et al. 2006).

San Pablo Bay National Wildlife Refuge (SPBNWR) manages more than 5,340 ha of wetlands. San Pablo Bay comprises the largest remaining expanse of undeveloped baylands in the estuary. The Refuge is actively rehabilitating and 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) may benefit from the tidal salt marshes restoration projects, such as Mason's lilaeopsis (*Lilaeopsis masonii*), soft bird's beak (*Cordylanthus mollis ssp. mollis*), delta smelt *(Hypomesus transpacificus)*, California clapper rail (*Rallus longirostris obsoletus*), California black rail (*Laterallus jamaicensis coturniculus*), San Pablo song sparrow (*Melospiza melodia samuelis*), salt marsh 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*). By monitoring early marsh development to examine how physical attributes influence biota, management efforts can be directed towards increasing favorable habitat for target species and decreasing factors that promote the establishment and spread of unwanted invasive species.

Monitoring biophysical parameters is a critical component for wetland restoration and rehabilitation projects (Goals Project 2000). Documenting the response to wetland restoration actions is necessary to assess the effectiveness of restoration techniques and critical in developing adaptive management strategies. Despite its vital role, monitoring has traditionally received little attention in pre- or post-project planning, field efforts, and funding support. Despite numerous restorations in the bay, restoration outcomes are still largely unpredictable (Race 1985, Zedler 2001), partially because of the lack of sound methods to test scientific hypotheses addressing biological responses to physical changes through time and space. As a relatively new science, careful monitoring of changes occurring during tidal marsh restoration can provide a foundation in which to advance lessons learned for adaptive management. Here we document the comprehensive biophysical monitoring of Tubbs Setback. In addition, we highlight the incorporation of new methods to improve our understanding of early restoration progress.

Project Description

Tubbs Setback is a 29 ha parcel leased by the U. S. Fish and Wildlife Service (FWS) in 1981 has a long-term (66-year) agreement with the California State Lands Commission. It is located along the northern reaches of San Pablo Bay between the Petaluma River and Sonoma Creek, abutting the lower lagoon of Tolay Creek and Tubbs Island to the west, agriculture to the north, and a remnant marsh to the east (Fig. 1). Comprehensive monitoring of Tolay Creek was lead by the U. S. Geological Survey, Western Ecological Research Center (USGS), Ecosystem Restoration Sciences and partners from 1998 to 2006 (Bias et al. 2006, Takekawa and Woo unpubl data). Historically, the region had numerous tidal sloughs, as seen in Lower Tubbs Island, a 100 ha muted tidal marsh that was managed as a private duck club before acquired by The Nature Conservancy in 1978 (SPBNWR 1998). Tubbs Setback was diked for reclamation in the early 1900s and farmed until 1983. In 1985, the Refuge initiated restoration work with additional funding from United Heckathorn Trustee Council (consisting of the USFWS, National Oceanic and Atmospheric Administration, and the California Department of Fish and Game; SPBNWR 1998). Ducks Unlimited engineered and completed the construction of a fortified interior setback levee with riprap borrowed from the outer levee facing San Pablo Bay. The fortified levee included a levee bench and vegetation treatments to examine plant establishment alternatives on levees (Downard et al. 2003). USGS completed pre-project surveys and lead biophysical monitoring for the project as in the Tubbs Island Restoration Plan and Environmental Assessment (SPBNWR 1998) and Tubbs Island Setback Monitoring Plan (SPBNWR 2002). Tubbs Setback was restored to tidal flow when the outer levee was breached on 8 March 2002.

METHODS

Sampling Framework

Biological and physical monitoring was initially set up within a 125m x 125m grid system. A grid system is useful in characterizing spatially explicit data (such as bird concentrations) without knowledge of where future environmental features (such as mudflats or channels) will develop. After an initial assessment, we determined that the grid system was more appropriate for larger sized projects. Though we assigned grid numbers to all bird data, we pooled across grids for general analyses and do not present any grid specific data here.

Initial spatial data was collected in UTM NAD27 and NGVD29; however, in 2004 we converted our databases to UTM NAD83 Zone 10N. Aerial photographs were georeferenced to NAD83 using control points and previous data were converted to NAD83 in ArcGIS (ESRI). In 2005, benchmarks were resurveyed to NAVD88 feet, and previous datums were converted with the program Corpscon (USACE, v. 5.11.08). Subsequent data including tide loggers, sediment pins, and bathymetry surveys were completed and processed in NAD83 UTM zone 10N / NAVD88 ft, and all locations and elevations in this report will be in these data unless otherwise noted.

Our biophysical monitoring included photodocumentation (aerial photographs, land cover classifications, and repeated photopoints at the same location), hydrology (water levels and water quality), geomorphology (elevations, sedimentation dynamics using sediment pins and bathymetry, channel development, channel morphology, and mudflat development), vegetation (transect surveys, quadrat surveys, land cover classifications), invertebrates (benthic invertebrates), fish (beach seine and bag seine efforts), birds, and small mammals (Table 1, Fig. 2).

Hydrology

Our water level system (R-2100e, Telog Instruments, Inc., New York; Fig. 1) included a pressure transducer that was placed near the sediment surface and a datalogger that converted water pressure to water depth and recorded data every 15 minutes. Data were downloaded every 60 days using a palm pilot (Palm IIIxe, Palm Inc.) or laptop (Solo, Gateway Inc.). Spot checks were conducted periodically to test for sensor drift or errors by simultaneously recording datalogger spot readings to an adjacent staff gage that had been surveyed to a known benchmark. We used that difference to adjust water depth to surface elevations.

Two water level loggers were initially installed before the breach. These loggers produced identical hydrographs, so when the eastern logger failed, it was not replaced. In August 2005, the northwest logger was relocated because of sediment buildup at the sensor. The logger was moved to deeper water within the main channel near the breach (Fig. 2). To ensure the sensor was not buried by sediment, we monitored sedimentation by recording the distance from the sensor to the sediment during each logger download session.

Water Quality

Water quality can be used to assess detrimental or advantageous environmental conditions for invertebrates and fish in developing wetlands. We used a Hydrolab Minisonde water quality meter (Hydrolab-Hach Co., Loveland CO) to record changes in pH, conductivity (internally converted to salinity using the 1978 Practical Salinity Scale), dissolved oxygen, temperature, and turbidity. Data were collected quarterly in a continuous 48-hour deployment unless road conditions prevented access. The water quality meter was deployed adjacent to the water level logger eleven periods between 2002 and 2006 (Sep 2002; Mar, Jul, and Sep 2004; Jan, May, Jul, and Oct 2005, Feb, May, and Sep 2006). Prior to deployment, meters were cleaned, calibrated to standard solutions, and programmed to log at 15-minute intervals during a 48-hour period. Upon retrieval of the water quality meter, reading were taken in distilled water before and after cleaning to check for any possible fouling effects.

Geomorphology

We conducted three benchmark surveys between 2002 and 2006. In 2002, we utilized a benchmark set by Ducks Unlimited during levee construction. USGS installed four benchmarks (consisting of rebar driven into the levee) and in May 2003 contracted Shoreline Engineering & Restoration (P. Goebel) to survey the benchmarks to NGVD29 ft (Fig. 2). In spring 2005, USGS encased benchmarks in cement for added stability; however in Jul 2005, during an elevation survey at Tolay Creek, Environmental Data Solutions (J. Kulpa) surveyed a few benchmarks (FWS86, FWS88, and USGS2035) in NAVD88 ft and detected some inconsistencies. In Nov 2005, Shoreline Engineering & Restoration resurveyed all benchmarks to NAVD88 ft. These inconsistencies were resolved; thus we utilized the Nov 2005 survey data for our analyses.

Aerial Photograph and Land Cover Interpretation

A low-level, color infrared aerial photograph was taken in Oct 2002, Sep 2003, Sep 2004, Aug 2005 and Aug 2006 (Fig. 3). We georectified the Sep 2004, 2005, and 2006 aerial photographs to UTM NAD83 (ArcGIS; ESRI, Inc.) using control points. Control points (n = 7 for 2004 and 2005, n = 4 for 2006) consisted of large white "X's" spray-painted on 1.5 m^2 black plastic squares attached to the ground with landscape staples. We used a Trimble GeoXT Pocket Global Positioning System unit with a PDOP (position dilution of precision error) of <3 (the lower the PDOP, the greater the precision) to establish control point coordinates.

We analyzed aerial photos from Aug 2005 and Aug 2006 to identify land cover type classifications with ERDAS Imagine software (Leica Geosystems). We initially ran automatic partitions in which the color signatures of each pixel were analyzed and systematically grouped into 15 classifications (unsupervised classifications). Unsupervised classifications often resulted in redundant information because of slight differences in color by the same land cover type. For example, common pickleweed (*Sarcocornia pacifica*, formerly *Salicornia virginica*) dominated areas consisted of multiple infrared colors and was automatically classified into several groups. We were unable to distinguish plant species; however, we refined the ERDAS classifications and used personal knowledge of the site to distinguish five major land cover types: tidal marsh, water, mudflat, upland vegetation, and bare ground. Sediment deposition patterns and channel development are noticeable in the aerial photographs.

Photodocumentation

Ground photo points, along with aerial photographs, help document and describe qualitative differences in restoration progress. Digital color photographs were taken annually at four representative vantage photo points (Fig. 2). At each location several digital pictures were taken and later stitched into a panoramic photograph with Photoshop CS2 (Adobe). In addition, several photographs describe conditions of interest such as the project breach, restoration plantings, and mudflat formation.

Sedimentation: sediment pins

Twenty four sediment pins (5 cm diameter, schedule-40 PVC) were installed prior to the levee breach (Fig. 2). The length of the sediment pin was measured 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. Over time, a shorter sediment pin length indicated sediment accumulation, while a longer sediment pin length indicated sediment loss. The top of sediment pins and staff gages were re-surveyed in 2005 to check for any differences in height due to settling. Sediment elevations were calculated by subtracting the length of the sediment pin from the elevation of the sediment pin top. Identifying numbers were repainted on the sediment pin when they faded.

Sedimentation: bathymetry

Sediment pins provided rough measurements of sediment accretion; however, readings were limited to the very few pin locations and lacked the spatial resolution to adequately detect overall sedimentation patterns. Thus, we developed a bathymetry system to produce a map of the underwater sediment surface. Our bathymetry system consists of a variable frequency acoustic

profiler (Reson, Inc.; Slangerup, Denmark, Navisound 210), differential global positioning system unit (DGPS; Trimble, Ag132), and laptop computer mounted on a shallow-draft, flat-bottom boat (Bass Hunter, Cabelas, Sidney, NE). The sounder can record water depths as shallow as 10 cm of water and is thus ideal for shallow water systems. The boat was equipped with an electric trolling motor powered by a 12v marine battery. An observer recorded the tide level on a referenced staff gage every 10 minutes, which was later converted to surface elevations. The echosounder recorded water depth, which was converted to surface elevations using interpolated tide levels. We calibrated the system before each use with a bar check plate, and adjusted the sound velocity for salinity and temperature differences.
GPS and water depth readings were recorded as text files and later converted in a custom program written in SAS (SAS Institute 1999) to generate a bathymetric coverage. Inverse distance weighting maps (Geostatistical Analyst; ArcGIS, ESRI) were used to generate bathymetric grid (10 m) and contour profiles from elevation datasets.

Bathymetric surveys were conducted in 2004 and 2005. In Jan 2004, we surveyed north-south transects at 25m intervals. In Sep 2005, we resurveyed the project along both north-south and east-west transects at 25m intervals. Spatially explicit differences in sediment surfaces between the Jan 2004 and Sep 2005 bathymetric coverages were analyzed with Spatial Analyst's raster calculator (ArcGIS, ESRI, Inc).

We validated our bathymetry elevation recordings using several methods. During data collection a bar check was performed and a graduated pole was used to check and calibrate the system prior to data collection. We compared bathymetry survey points near the sediment pins to actual sediment pin readings.

Vegetation

Vegetation surveys were conducted annually in the late summer to capture peak biomass of the dominant salt marsh species. Surveys were conducted for baseline comparisons of restoration progress (project-wide line transects). The results of the experimental study of plant establishment on the levee bench are reported in Downard et al. (2003).

A single pre-breach vegetation survey was conducted in July 1999 to characterize the vegetative community. Two north-south and two east-west continuous line transects divided the site into four quadrants (NE, NW, SE and SW), which were later used to describe the location of birds prior to the breach. Percent canopy cover was calculated by adding the length of a species' occurrence along the transect divided by the total transect length (Elzinga et al. 1998). In addition, 0.25 m^2 quadrats were placed directly alongside transects at 0 m, 7.5 m, and 14.5 m. Quadrant measurements consisted of species identification, ocular estimates of percent cover (total $\geq$ 100%), maximum height, and density (rooted individuals/m^2).

Post-breach vegetation surveys consisted of the same two north-to-south and two east-to-west transects that spanned the entire project (Fig. 2). Since the center of the project was primarily non- vegetated (soft mudflat), transect surveys started at the levee tops and continued into the project until vegetation was no longer visually detected. Species percent cover was estimated using point-intercept line transects at 1m intervals. Each plant species encountered was identified and measured for height. Percent canopy cover was determined by totaling the number of "hits" per species and dividing that number by the total point intercepts. In addition, a 0.25 m^2 quadrat was placed along transects every 3m until reaching open water. Quadrat measurements consisted of species identification, ocular estimates of percent cover (total $\geq$ 100%), maximum height, and density (rooted individuals/m^2). Tide levels were not recorded during vegetation surveys. Data were analyzed to determine the average percent cover of each species in quadrants and relative percent cover along transects.

Invertebrates

Benthic invertebrates were collected along four transects at Tubbs Setback on 13 and 16 Aug 2004. Each transect was located near erosion pins A, B, C, or D and was oriented along an elevation gradient so that it was perpendicular to the levee. Along each transect there were three sampling locations: mudflat, transitional, and barely vegetated areas. At each sampling location, we collected three sediment cores (10 cm diameter, 10 cm depth, for a volume of 785 cm^3) for a total of 36 cores. Entire cores were soaked for 2-5 minutes in an Epsom salt solution to help "relax" invertebrate parts before fixing them in ethanol. Samples were sieved with a 0.5 mm mesh screen on site and stored in a 70% ethanol and rose-bengal solution until further sorting and identification.

Fish

Fish were sampled with an 80-ft beach seine net from 2002 to 2005 with ECORP (T. Keegan). 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 three sides of a rectangle, with the shore forming the fourth side. Two sets of people hauled each end of the seine onshore so that fish 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. Fish and invertebrate species were identified, enumerated, measured, and released on site.

In May 2002 and Jun 2003 two hauls were conducted in the southwest corner. In Nov 2003, we conducted two hauls along the northern levee due to high sediment loads fouling sampling efforts. In Nov 2004, we conducted two hauls along the southern levee, an area that had less sediment accretion. The Jun 2005 and Dec 2005 surveys consisted of one haul per sampling session along the southern levee. Beach seining was no longer feasible along the south levee in Nov 2006 due to sedimentation; thus fish surveys were conducted above a 6 ft tide with two beach seine hauls and two bag seine hauls at two sites along the west levee. USGS personnel conducted fish sampling in 2006 under the direction of M. Saiki.

Birds

Point counts were used to assess pre-breach bird numbers because tall vegetation obscured birds from view and supported passerine species, which are easier to detect by song and call (DeSante 1981). The project area was partitioned into 4 quadrants NW, NE, SW, and SE and birds within

50 m of the center of each quadrant were recorded. Point counts were performed allowing a two minute settling time followed by an 8 minute listening and recording period at each point. A total of 4 pre-breach surveys were performed, two during low tide (tide –0.4 ft and 1.3 ft in Jun and Sep 1999, respectively) and two during high tide (tide 3.8 ft and 3.7 ft in Jul and Aug 1999, respectively). To date, point counts have not been conducted because the site has not developed to a stage where birds were concealed within tall, dense vegetation.

Area counts were used to survey post-breach Tubbs Setback because birds can easily be detected by sight. Area surveys were conducted during high (> 4.0 ft) and low tides (<2.0 ft) of each month. Bird species, behavior (foraging, roosting, calling, flyover, swimming, preening, alerting, unknown, courtship display, carrying nest material, carrying food, aggression), and the habitat (mudflat, marsh plain, open water, shallow water, levee inside project, levee on outer edge of project, aerial, channel edge, upland or levee, in channel water) were recorded. Age class (Adult or juvenile) was recorded when possible. Birds were grouped into guilds for analysis (diver, shorebird, gulls and terns, etc.).

Small Mammals

Small mammals were surveyed using Sherman live- traps (7.7 x 9.0 x 23.0-cm) for three consecutive nights in June 2003, June 2004, Sept 2005, and July 2006. Forty points were randomly located (as in Padget-Flores 2003) in ArcGIS (ESRI) and stratified along an elevation gradient of Tubbs Setback (Fig. 2). In 2003 and 2004, three traps were placed at each point for a total of 120 traps. In 2005 and 2006, a reduced trapping effort consisted of a single trap at each location for a total of 40 traps. Trap dates were selected to avoid extreme water levels and inundation by tide. Traps were set before dusk and checked within 3 hours of sunrise. Polyester batting was placed within each trap for warmth and a wooden shingle was placed above and below traps to protect captured animals from exposure. Traps were baited with a mixture of dry seeds, chopped walnuts, peanut butter, and dried crickets for insectivores.

Species identification, sex, age, mass (g), reproductive condition, and presence of wounds or parasites were recorded for all individuals captured. Reproductive condition was characterized by presence and development of the testes for males, presence and development of mammary glands for females, and whether or not the female was pregnant. Additional measurements were recorded for the genus *Reithrodontomys*, including body length, tail length, tail width at 2 mm from the base of the tail, left hind foot length, left ear length, venter coloration pattern, and bi-coloration of tail. Captured individuals were marked by fur clipping to identify recaptures.

RESULTS AND DISCUSSION

Hydrology

Shortly after the restoration of tidal flow, water remained pooled within the levee boundaries during low tides. We looked at daily minimum water levels to assess site drainage. Water levels did not fall below 3.8 ft (Fig. 4) and the average tidal range (daily max - daily minimum tide levels) was limited to 2.4 ft during the first month following the breach. Drainage steadily improved in 2003, as minimum water levels steadily declined (R^2=0.87, Woo et al. 2004), presumably because of the natural widening of the mouth and several natural breaches along the southern levee to San Pablo Bay. Over two years after the breach, we detected the lowest water levels in May 2004 at 1.65 ft and an average tidal range at 4.3 ft for May 2004, a 76% increase from March 2002.

In the fall of 2004 and in 2005, we first detected signs of sensor burial as daily minimum water levels steadily increased and did not fall below 2.71 ft (Woo et al. 2006) and the average tidal range from Feb to Aug 2005 was 4.0 ft. Since the water level sensor utilized a pressure transducer to calculate water depth, we felt that readings would be impaired if buried in sediment. We were able to correct for localized pressure induced by sediment burial by recording the height of the water at the staff gage and adjusting the logger output; however, sensor burial might cause future malfunction of the pressure transducer. Thus in Aug 2005, we removed the northwest data logger (DL 3393) and sent it in for manufacturer maintenance. We installed a backup logger (DL 3394) in the deep waters of the main channel near the mouth to reduce the risk of sediment buildup at the sensor. Water levels at the mouth showed a minimum water level of 1.1 ft. The water level logger at the mouth recorded a greater tidal range (5.16 ft from Aug 2005- Sep 2006) than at the previous location (4.02 ft from Feb- Aug 2005; Fig. 5).

We initiated sediment monitoring at the logger location near the mouth so that we can detect early signs of sediment buildup. One year after relocating the logger to the main channel, we detected that sediment once again was accreting at the sensor in Sept 2006. Due to the changing morphology of the entire site, especially in the main channel, tracking and assessing hydrologic patterns will continue to be a challenge because of sensor burial. USFWS can choose to 1) do nothing and leave the logger in the same location; 2) move the logger to deeper waters; or 3) utilize new logger technology to track water levels above water. 1) Logger 3394 is currently functioning properly, and although we were able to correct for the sediment burial by adjusting the height of the water to the staff gage readings, sediment burial might disrupt the pressure transducer sensor over time. By leaving the logger in the same location, the water level sensors are at greater risk of malfunction. 2) Relocating the water level logger to deeper water involves continual monitoring of sensor burial by sediment. Currently the main channel near the breach contains the deepest water; however, a logger positioned within the thalweg will be at greater risk of being hit by debris entering the channel. 3) New sensors have the ability to monitor water levels above water (Radar Level Sensor). These sensors are typically installed above a bridge and monitor water levels by using radar technology. This system has the benefit of not being unaffected by sediment burial, corrosion, fouling, or by moving debris in the water column; however, it must be secured on a stable structure above the water.

On 1 Jan 2006, heavy rains and high tides combined for extremely high water levels with localized flooding in Napa and Sonoma counties. The water level logger recorded the highest water levels yet documented at Tubbs Setback at 8.81 ft at 13:15 h (Fig. 6). The high tide did not overtop the levees, but came within a foot of the levee tops (9.65 ft).

Water Quality

While water quality monitoring was not part of the required monitoring before 2005, measurements were continuously logged during the following sessions: Sep 2002, Mar 2004, Jul 2004, Sep 2004, Jan 2005, May 2005, Jul 2005, Oct 2005, Feb 2006, May 2006, and Sep 2006 (Table 2). Due to equipment maintenance, water quality parameters were spot-checked on Feb 16th and not collected in Jul 2006.

Water quality parameters differed from Sep 2002 to Sep 2006 (Fig. 7), which reflect natural fluctuations. In Sep 2002 the conductivity reached 40.1 mS/cm, while in Sep 2006 the water was fresher at 34.9 mS/cm (Fig. 6), probably because an above-average rain season and abundant freshwater release from dams and tributaries that enter San Pablo Bay. Other measurements varied by tide, season, and year, but mean pH remained relatively constant. Spikes in the turbidity readings were presumably caused by sediment re-suspension with the incoming tide or high wind fetch.

We also detected seasonal differences in water quality (Table 2). Temperature and specific conductivity were higher in the summer, as expected, while turbidity was higher in the winter, despite high summer winds. Percent dissolved oxygen (DO) did not vary across seasons, but seemed to be more closely linked with daily tidal fluctuations. At times, the percent DO was oversaturated with readings greater than 100%, likely due to high rates of algae photosynthesis during daylight hours. Dissolved oxygen levels remained consistently above 5 mg/L, a threshold used by the California Regional Water Resources Control Board as an indicator of aquatic health because prolonged levels below 5mg/L can impair the development of fish larvae and other invertebrates (CWT 2004).

Geomorphology

Periodic benchmark surveys are necessary to maintain survey consistency between years. We established benchmarks with rebar encased in concrete to improve stability; however, this only acted to increase benchmark movement (P. Goebel, personal comm.). The levee soils cracked around the concrete blocks and loosened the benchmark. We discontinued the concrete blocks and re-established benchmarks with rebar (Woo et al. 2006).

Aerial Photograph and Land Cover Interpretation

Aerial photographs provide useful information in characterizing and quantifying restoration changes over time. The annual aerials clearly illustrated the development of the main channel and the formation of mudflats. The Sep 2003 aerial photograph revealed a sediment plume entering the project (Fig. 2). The Sep 2004 aerial showed mudflats exposed in the center of the project during low tide, and the Aug 2005 aerial showed a greater extent of mudflat than in previous photographs and increased channel development near the breach. The most recent Aug 2006 aerial shows sedimentation in the main channel near the breach and the filling in of the circular channel that previously encircled the central mudflat in 2005. Sediment dispersal patterns were confirmed and quantified by sediment pin and bathymetric data.

Once georeferenced, the Aug 2005 and Aug 2006 aerial photographs were analyzed using ERDAS Imagine software to estimate land cover (Fig. 8). In 2005, mudflat or bare areas comprised the largest habitat element (63% at 0.9 ft MLLW at Sonoma Creek), followed by open water (30%), tidal marsh vegetation (6%), and upland vegetation (1%). In the 2006 aerial, the mudflat and bare areas were 78% of the total project (at -0.6 ft MLLW), the open water was 15%, the tidal marsh vegetation was still 6% and the upland vegetation comprised 2% of the total area. This method is useful in establishing early baseline of vegetation colonization and spread in subsequent years using remote methods. At the adjacent Tolay Creek Marsh, we observed different spectral signatures of pickleweed adjacent to channels than those further away, which may be useful to detect the influence of channels on vegetation (Takekawa et al. 2004). As channels and vegetation at Tubbs Setback become further developed, we may be able to use this method to analyze how channels influence vegetation.

Photodocumentation

Photographs of the project area were taken annually from four established points along the project boundary (Fig. 2), although additional pictures were taken each year. In October 2000, the first set of images was taken to document pre-breach conditions (Fig. 9). During the low tide of 8 March 2002, the breach was excavated to allow reintroduction of water to Tubbs Setback (Fig. 10). Vegetation plantings along the levee bench were designed to hasten plant colonization; however, native colonization of the levee bench occurred rapidly (Fig. 11). These images clearly show the upland site dominated by weed species typical of fallow oat-hay fields. In the latest set of images (Sep 2006), post-breach conditions show the evolving tidal marsh along the levee bench (Fig. 12).

Sedimentation: sediment pins

Sediment deposition and changes through time are critical parameters that help determine the progress of tidal marsh restoration projects. Plastic (PVC) poles pounded into the substrate (sediment pins) are an inexpensive method to assess sedimentation at point locations (Siegel 1998, Takekawa et al. 2002). Sediment pins provide accurate readings from which sedimentation rates can be calculated; however, they lack the spatial resolution needed to detect sedimentation patterns.

We measured sediment accumulation using sediment pins during the spring, summer, and fall from 2002 to 2006 (n = 24) to the nearest 0.5 cm. Sediment accumulated rapidly the first year, (16.8 ± 4.2 cm, Takekawa et al. 2003) and most sediment pins continued to accumulate sediment in subsequent years, especially in 2004 (Table 3, Fig. 13-15). Sediment pins on land did not vary appreciably, and the following descriptive data includes only those sediment pins within the mudflats and channels (n=16). In March 2002 the elevations of sediment pins varied widely from -3.89 ft to 1.83 ft with an average elevation of -1.08 ± 0.55 ft. By Sept 2004, sediment pins varied from -2.60 ft to 2.56 ft NAVD88 with an average elevation of 1.13 ± 0.31 ft. In Sept 2006, sediment pins had converged and varied only slightly from 1.88 ft to 3.63 ft with an average elevation of 3.16 ± 0.10 ft (Fig 14).

By Nov 2004, a spatial pattern of sediment accumulation emerged. Mudflats were built up within the center of the site, compared to the outer margins and these mudflats were exposed during low tide (Fig. 14). To account for these spatial differences in sedimentation rates, we grouped sediment pins into categories based on location (Fig. 13, 15): land or marsh plain (n = 8), outer mudflat (n = 11), channel (n = 1), and central mudflat (n = 4). Sediment pins measured in Sep 2006 showed an overall average increase of 82 cm ± 17 cm over 4.5 years (Table 3). Sediment pins (SP) on the central mudflat showed the greatest sediment accumulation, with a maximum gain of 218.5 cm at SP 4. There was slightly less accumulation at pins on the outer mudflat with the exception of SP 17, which had a loss of 10.5 cm.

On average, sediment pins on land showed almost no change in elevation with the exception of SP B which showed a loss of 43 cm between 2002 and 2006, likely due to soil movement due to late construction activities. Sediment pin 12, the only sediment pin that is located in the main channel, showed a net loss in sediment (-16.5 cm) until 2004. Between Sep 2004 and Sep 2006, SP 12 has gained 27.5 cm of sediment, and is likely to be at mudflat elevations within the next year (Fig 15). Overall, sediment pins of central mudflat and outer mudflat show a steady gain in surface elevation, and have converged to 3.24 $\pm$ 0.06 ft (Fig. 14), despite a 91.4 cm difference in initial average elevations.

We re-surveyed sediment pins in 2005 to check for any vertical movement. We averaged the absolute value of the difference between the initial survey by Ducks Unlimited in 2002 to the USGS survey of 2005 (benchmark data from Shoreline Engineering and Restoration survey) and found that sediment pins on land (21.76 $\pm$ 3.75 cm) had moved more than those that were located underwater (2.82 $\pm$ 0.46 cm). The movement of sediment pins on land yielded surprising results since we calculated little movement of rebar stakes in the soil. The movement might be caused by the drying and rewetting of upland soils that may cause the surface to swell. Sediment pins in the mudflats and channel are not subjected to drying and other factors may contribute to the small differences we observed: small areas of sediment buildup and scour adjacent to sediment pins (Takekawa et al. 2002), slight penetration of the measuring rod into soft new sediments when measuring, movement of sediment pins, or survey error. Since the difference between the 2002 and 2005 surveys were not large for the interior sediment pins, we did not replace any sediment pins.

Sedimentation: bathymetry

Our bathymetry surveys quantified sediment dispersal patterns that were not detected using sediment pins. Sediment dispersal patterns were verified by aerial photographs. The bathymetry map from Jan 2004 showed sediment accretion in the center of the project (Fig. 16a) (elevation ranged from -1.22 to 2.74 ft; Woo et al. 2006). Between Jan 2004 and Sep 2005, sediment accreted in the entire project excluding the channel. A distinct deep water channel (-3.74 to 1.03 ft) had formed within 225 meters of the breach and had become shallower (1.03 to 1.62 ft) as the distance from breach increased (Fig. 16b). In such a sediment rich environment, shallow channels are at risk of filling in, and eventually reducing tidal drainage in the western and southern portions of Tubbs Setback. The central and outer margin areas of mudflat were at the highest elevation ranging from 3.3 to 4.25 ft. Sediment pin data corroborated the high sedimentation patterns detected by bathymetry throughout the project.

We used Spatial Analyst's raster calculator (ArcGIS, ESRI, Inc.) to determine changes in sediment surface elevations using the bathymetry data. From Jan 2004 to Sep 2005, the average sediment accumulation throughout the project was 57 cm and we calculated 132,908 m^3 (4,693,589 ft^3) of sediment accumulation. In comparison, sediment pins in the mudflats and channel (n=16) showed an average sediment accumulation of 38.1 $\pm$ 6.5 cm from Feb 2004 to Feb 2005. Since most of these sediment pins were located on the mudflats and only one sediment pin was located within a channel it is likely an underestimate of sediment accumulation.

We used several methods to validate our bathymetry data. Before each bathymetric survey, we calibrate the echosounder by conducting a bar check and set the frequency so that accurate depth readings were recorded. We also used a graduated pole to ensure depth readings were accurate for native substrate. As an indication of interpolation accuracy, elevation ranges from the bathymetry grids were compared to actual sediment elevations at sediment pin locations. The difference between surface elevations comparing the sediment pins and bathymetry interpolations was 10.7 $\pm$ 3.3 cm in 2004 (Woo et al. 2006), and 7.5 $\pm$ 2.4 cm in 2005. Sources of error may be attributed to difference in survey timing, accuracy of sediment pin measurements (2.8 $\pm$ 0.5 cm), local effects of sediment pins on accretion or erosion (Takekawa et al. 2002), penetration of the measuring rod into soft sediments, subsurface reflectance of the echosounder in soft, unconsolidated substrates, and interpolation of the echosounder measurements to 10-m grids.

Vegetation

Thirty-four plant species have been detected on the levee and levee bench zones (Table 4). Eleven species were reported in the pre-beach survey in 1999, and 28 species were observed during post-breach surveys (summer 2002, spring 2003, summer 2003, summer 2004, summer 2005, and summer 2006; Table 4). Common species found in the pre-breach survey included; *Raphanus sativus, Lactuca serriola, Cirsium vulgare, Scirpus californicus, Centaurea solstitialis,* and *Baccharis pilularis* of which only two were native: *Baccharis pilularis* and *Scirpus californicus.* Common species in the post-breach surveys included *Sarcocornia pacifica* formerly *Salicornia virginica, Centaurea solstitialis, Spergula arvensis, Raphanus sativus,* and *Lolium multiflorum.* The post-breach vegetation community was dominated by nonnative plant species with only 9 natives detected: *Sarcocornia pacifica, Jaumea carnosa, Spergularia macrotheca, Distichlis spicata, Atriplex triangularis, Frankenia salina, Grindelia stricta, Polygonum marinense,* and *Spartina foliosa.*

Increasing pickleweed and native *Spartina* (*S. foliosa*) cover is a desired outcome of restoration because it functions as a cover and a food resource for tidal marsh species. Pickleweed was not detected in the 1999 pre-breach survey since the site was former agricultural field and dominated by weeds; however it was known to occur along the southern ditch parallel to the levee (G.

Block, unpubl. data). Comparing between quadrat data from the summer season, average pickleweed percent cover increased annually from 29.3% in 2002 to 47.3% in 2003 to 56.7% in 2004 to 61.3% in 2005 to 72.3% in 2006. Bare ground cover declined from 71% to 30% (Fig. 17). The relative percent cover of pickleweed in relation to other species also increased through time (Fig 17). In 2002, pickleweed maximum height averaged 40.2 cm, probably because the pickleweed plants that were encountered were from transplanted soils and vegetation as part of the planting experiment on the levee bench. The average pickleweed maximum height increased from 34.1 cm in 2003 to 45.5 cm in 2006. Pickleweed density was very high in 2002 at 156.8 plants/m^2, remained relatively constant from 2003 to 2005 (66.4/m^2, 64/m^2, and 68.8/m^2 respectively), but declined to 20.9/m^2 in 2006; an indication of a more mature canopy with fewer adult plants as apposed to numerous seedlings.

Although *S. foliosa* was first detected in quadrat sampling five months after the restoration in August 2002 along the levee bench, it was not detected in the point-intercept line transects. The point-intercept transect method was not designed to detect rare or low cover species; however, when combined with quadrat sampling the likelihood of detecting low-occurrence species increases (Elzinga et a. 1998).

Salt marsh vegetation patterns often occur along elevation gradients due to species specific tolerances to salinity and tidal inundation (Mahall and Park 1976 a,b,c; Chapman 1974). The distribution of plants can also be limited by seedling germination requirements (Noe and Zedler 2000, 2001). Prior to Aug 2006, all vegetation had been detected and recorded on the levee bench, transitional upland, and levee area. Though mudflats had been at appropriate elevations for the species to occur since 2005 (1.2 to 3.0 ft, Wetland Regional Monitoring Program, unpubl data converted using VERTCON, NOAA benchmark on Mare Island Shipyard), we first detected *Spartina foliosa* in the central mudflat in August 2006 by visual observation. This species has extremely low germination success rates (Trnka 1998), which may explain the time lag for *Spartina* colonization here and at other restoration sites (PWA 2005). In addition, *S. foliosa* predominantly reproduces asexually through rhizomes (Trnka and Zedler 2000) and has a relatively slow rate of expansion (Takekawa et al. 2004, Bias et al. 2006), compared to the exotic *S. alterniflora,* which had a mean lateral growth rate of 79.3 cm $\pm$ 1.7 cm/yr in Willapa Bay (Feist and Simenstad 2000).

Non-native and invasive species are threats to habitat quality and can degrade a wetland's value to tidal marsh inhabitants. The majority of plant species overall were nonnative; however native plant species had greater percent cover along the levee bench—primarily due to the presence of pickleweed, which can form dense uniform stands (Fig. 18). The overall percent of native cover increased at a greater rate than nonnative cover (Woo et al. 2004). From Aug 2004 to Aug 2005, nonnative cover increased from 19.0%, to 20.9%. From Aug 2004 through Aug 2005, native cover increased from 29.8% to 47.3%. In 2006, there was a slight decrease in percent cover of both native (44.6%) and nonnative (14.2%) species. When we analyzed the relative percent cover by distance from levee top, we detected decreased nonnative cover with increasing distance from the levee, as we approached the levee bench (Fig. 19). The levee bench was comprised of native tidal marsh plants, except for brass buttons (*Cotula coronipifolia*), which is a rapid colonizer of bare ground and is eventually out competed by pickleweed. In contrast, the majority of species along the levee were weedy such as *Raphanus sativus.* We recorded a large portion of dead standing plant material that also comprised of *Raphanus sativus.* Upland and the upland transition zone can be particularly challenging to restore to native plant cover, especially if weeds or invasive species are present in the vicinity. USFWS will continue to encourage native vegetation through native plantings along the upland transition zone.

Invasive pepperweed (*Lepidium latifolium*) is a non-native plant of concern that is perennial and produces dense monospecific stands. Stems can reach up to 1.5 m in height, almost 1 m taller than pickleweed canopies (Renz 2000). Dense pepperweed can threaten native salt marsh habitat by altering soil ions (Blank and Young 1997) and displacing native plant species. Pepperweed had been detected in the pre-breach survey, but was not detected in any of the post-breach surveys except for a few scattered individuals (G. Block, unpubl. data), which are often hand pulled by observers or volunteers. USFWS has partnered with UC Davis in efforts to control pepperweed at the adjacent Tolay Creek restoration project.

To date we have not encountered invasive *Spartina* hybrids (SFEI *Spartina* Project 2004); however, continual monitoring for infestations is important for early detection and early eradication efforts. Populations of invasive *Spartina* hybrids are sparse in the North Bay (Invasive *Spartina* Project 2004). Confirmed sightings of *S. densiflora* have been reported as far north as Dutchman Slough and an unconfirmed sighting of *S. patens* was reported near Tubbs Island. With such a low occurrence of invasive *Spartina* hybrids in one of the largest stretches of undeveloped baylands, San Pablo Bay is of heightened importance for tidal marsh restoration in the estuary. Vertebrate species that may be affected through a cascading loss of habitat from invasive *Spartina* include shorebirds that depend on mudflats, California Clapper Rails that use deep slough channels, and passerine species dependent on the native *S. foliosa* stands.

Invertebrates

Benthic invertebrates were collected in Aug 2004 along elevation gradients representing three habitat types: mudflat, mudflat transition, and vegetated margin (n=12 transects). Invertebrates were identified to lowest possible taxa in 2005, enumerated, and core volume (785 cm^3) was extrapolated to m^2 plot with a depth of 10 cm (Table 5). Samples taken from mudflat consistently had the highest average number of taxa (11 taxa), as compared to the mudflat transition (7.5 taxa), and the vegetated margin (6 taxa). Amphipods (suborder gammeridea) and sedentary polychaetes were the only taxa present in all samples, reflecting their abundance and inundation tolerance in benthic invertebrate communities. Because of their abundance, these taxa are likely important prey items for migratory shorebirds. Gammaridean amphipods were the dominant group in 67% of cores sampled. They reached their highest average density in the vegetated margin (2,225 amphipods/m^2 at 10 cm depth), as compared to the mudflat transition (638 amphipods/ m^2 at 10 cm depth), and mudflat (514 amphipods/ m^2 at 10 cm depth). They are primarily detritivores, so their abundance on the periphery of the vegetated margin is consistent with their niche requirements. The gastropod, *Assiminea californica,* was detected in only two marsh samples, comprising 1.8%.

Bivalves reached their highest average density in the mudflats farthest from shore (452 bivalves/ m^2 at 10 cm depth), as compared to the mudflat transition (107 bivalves/ m^2 at 10 cm depth), and the vegetated margin (29 bivalves/ m^2 at 10 cm depth). *Macoma balthica* comprised 58% of bivalves in sediment cores. The invasive Asian clam, *Corbula amurensis*, was present in 3 samples but comprised only 2.7% of those samples. Observations of general shape and shell characteristics for the remaining small bivalves (< 1 cm) suggest that the majority were young *Macoma*. Invertebrates were archived in 70% ethanol and rose-bengal solution at the SFB Estuary Field Station.

Invertebrate abundance was higher at Tubbs Setback than at an adjacent site in the lower lagoon of Tolay Creek (Bias et al. 2006). Tubbs Setback had greater average number of crustaceans (1,251 / m^2 at 10 cm depth) and bivalves (953 / m^2 at 10 cm depth) than Tolay Creek (1,058 crustaceans/ m^2 at 10 cm depth and 72 bivalves / m^2 at 10 cm depth); however, we detected greater number of polychaetes at Tolay Creek than at Tubbs Setback (737 polychaetes / m^2, 455 polychaetes / m^2 at 10 cm depth, respectively). In contrast, the Napa-Sonoma salt ponds have entirely different invertebrate communities that are adapted to specific salinity regimes. Although different collection methods don't allow for direct comparisons, in general Pond 3 had a greater diversity of invertebrates (Miles et al. 2004). Before Pond 3 was breached, polychaetes were the most abundant taxa, while post breach surveys show a reduction in polychaetes and an increase in insects and crustaceans (primarily the brine fly, *Artemia*). Differences in invertebrate taxa and abundance may be due to differences in salinity and water quality, predation rates, landscape setting, and substrate quality. Tubbs Setback supports increasing numbers of shorebirds and is likely an important food resource for migratory birds.

Fish

Open water beach seining was conducted in May 2002, Nov 2002, Jun 2003, Nov 2003, Nov 2004, Jun 2005, and Dec 2005. Fish sampling in the summer of 2004 was not completed because large amounts of mud along inner levee borders precluded open water beach seining. Due to changing sediment conditions, sampling in Nov 2006 was conducted using both beach and bag seines. Though we did not detect many species in Nov 2006, a greater number of species (4) were caught using the beach seine than the bag seine (2).

We detected 15 species of fish and aquatic invertebrates during May 2002, 6 species in Nov 2002, 12 species in Jun 2003, 5 species in Nov 2003, 3 species in Nov 2004, 4 species in Jun 2005, 4 species in Dec 2005 (Table 6, Fig. 20) and 6 species in November 2006. Data from 2006 were not included in the table or figure because of the new collection method. No special status species were captured between 2002 and 2006. Between 2002 and 2005 we detected an increase in bay goby (40 to 141 individuals/haul), yellowfin goby (*Acanthogobius flavimanus;* (5 to 19 individuals/haul) Our sampling also detected the invasive chinese mitten crab (*Eriocheir sinensis*) in May and Nov 2002, and the invasive European green crab (*Carcinus maenas*) in Jun 2003, but neither species were detected in subsequent surveys.

Fish abundance and distributions may vary with season, salinity, and tide among other factors. Common fishes found have a high tolerance to sediment loads, in particular the bay goby. The bay goby is a benthic-dwelling fish with high tolerance to environmental changes. The bay goby is abundant in the San Francisco Bay estuary, and young-of-the-year densities are usually highest in South Bay or San Pablo Bay. More frequent fish sampling would be needed to determine seasonal trends in fish abundance, and to interpret how the fish are responding to physical variables.

Beach seining has become more challenging at the site because of high sediment deposition along the perimeter and center of the project. Beach seining in these soft sediments yields a large amount of mud, which can prolong sifting through mud to locate captured fish and invertebrates. Bag seining in 2006 proved to be a more efficient method of sampling, but our catch was still low, likely because of seasonal differences in fish abundance. We only detected two species with the bag seine method: inland silversides and three-spined stickleback. Future sampling might include larval sampling using plankton tows to accommodate the high sedimentation rates or bag seining limited to the deeper waters in the main channel.

Birds

During the four pre-breach surveys from Jun 1999 to Sep 1999, 19 species were detected in variable circular plots. We detected 75 species in 107 post-breach area surveys from Mar 2002 to Oct 2006 (Table 7). Overall, we detected the greatest numbers of birds during the fall and winter migratory season (Aug - Feb) and an overall increase in bird numbers each year (Fig. 21). Shorebirds and divers, which comprised the two dominant guilds, increased after the restoration. Other guilds such as passerines decreased from 77% to 1% of all birds observed.

Species composition varied by season and tide (Fig. 22). Greater shorebird numbers have traditionally been detected during low tide surveys; however, as mudflat areas increased and expanded, shorebird numbers during high tide surveys have increased as well (Fig 22). In Nov 2005, over 1,000 shorebirds were observed during a high tide. Divers were consistently abundant in high and low tide throughout the year, but with peak abundances during high tides in the summer months (Fig. 22). Scaup usually winter in the estuary and migrate to breeding grounds in the spring, but a summer population observed at the site was likely comprised of non-breeding individuals. The greatest number of birds was recorded at a single low tide survey in October 2006 with >4,000 birds in which 90% were shorebirds (Fig. 22). During this survey, the tide was just below 2 ft MLLW at Sonoma Creek, the mudflat was completely exposed at Tubbs Setback, and no mudflat was available in the adjacent bay. Though shorebirds were typically most abundant during low tide, they could be found during higher tides foraging along the edges of the mudflat and roosting on the levee bench (Fig 22). We also recorded behavior during our survey. Divers primarily utilized the site for foraging (16%) swimming (44%) and roosting (40%) on the open water during high tide while shorebirds were mostly observed foraging (67%), flying (17%), and roosting (15%).

Birds responded quickly to increased sedimentation and mudflat formation. The average number of shorebirds per month has increased annually from 1,087 in 2002, to 9,529 in 2006 (Fig 23)

In contrast, the average number of divers increased from 1,991 in 2002 to a maximum of 5,412 in 2004. In the late summer of 2004 mudflat within the center of the site first became exposed during low tide and the number of divers steadily declined to 2,985 in 2006 (Fig. 23). When we grouped the number of birds detected during the fall through spring migratory seasons (Aug - Feb), shorebirds and divers were detected in equal abundances from 2002 to 2004 (Fig. 23), and in 2006, the number of shorebird increased by 102% from 2005 averages and the number of divers declined. The average number of divers and shorebirds were highly correlated with the annual average sediment elevation ($R^2 = 0.97$ and $R^2 = 0.95$, respectively; Fig. 24). With increased mudflat areas in the evolving site, water depths may now be too shallow to support the number of diving birds found in previous years.

Rail surveys have been conducted along the western levee and adjacent interior marshlands over the last 5 years (FWS, PRBO Conservation Science). Rails have not yet been detected within the site; however, California Black Rails (*Laterallus jamaicensis*) have been detected at the adjacent tidal marshes of Tolay Creek (Takekawa et al. 2004) and Tubbs Island (FWS unpubl. data). Other rail species known to occur in adjacent marshlands include the California Clapper Rail (*Rallus longirostris obsoletus*) and the Virginia Rail (*Rallus limicola*). These adjacent marshlands may provide a source for colonization once habitat for rail species develops.

Small Mammals

The San Pablo Bay National Wildlife Refuge led surveys of small mammals on this site. New captures of mice in 2006 totaled 9 individuals: 2 deer mice (*Peromyscus maniculatus*), 4 California voles (*Microtus californicus*), 2 house mice (*Mus musculus*), and 1 salt marsh harvest mouse (*Reithrodontomys raviventris*). Deer mouse numbers decreased from 17.5 individuals/100*trapnight in 2003 to 2.5 individuals/100*trapnight in 2006. House mouse numbers increased from 1.1 individuals/100* trapnight in 2003 to 4.17 individuals/100* trapnight in 2005, but decreased to 1.7 individuals/100* trapnight in 2006 (Table 8).

Only one salt marsh harvest mouse (RERA) was captured in 2003 and no RERA were detected in 2004. Despite decreased trapping effort in 2005 (120 trapnights compared to 360 trapnights in previous years), 6 RERA were detected (5 new, 1 recapture). Adult and sub-adults were captured along with a reproductively active female. The apparent colonization by RERA in 2005 was likely related to the developing pickleweed marsh along the levee bench and dispersal from Lower Tubbs Island and Tolay Creek. The colonization pattern of RERA at Tubbs Setback was similar to that of Guadalcanal Village wetland mitigation site, where RERA was not detected until the third to fourth year. Similar trapping efforts were made during the 2006 trapping session but only one RERA was detected. A 98% decline in small mammal captures was also observed at Tolay Creek in the summer of 2006. These low captures may be due to the extreme high tide event that occurred in the winter prior to trapping. Levees surrounding these project sites provide little upland refugia during high tides for small mammals which make them highly susceptible to predation and drowning.

CONCLUSION AND MANAGEMENT RECOMMENDATIONS

Tubbs Setback has matured over the past four years. The site progressed from a fallow field (prior to restoration) to a site that remained ponded during low tides (the first year after restoration). Site drainage improved with natural breaches to San Pablo Bay, and sediment accretion rates were high. Sediment was initially deposited in the center of the site, forming mudflats that were exposed during low tide. The extent of the mudflats increased and sediment elevations of the central and outer mudflats converged to 3.24 $\pm$ 0.06 ft (sediment pins, n=15) by Sept 2006. We estimated sediment accumulation from 2004 to 2005 from bathymetry surveys (132,908 m^3 or 4,693,589 ft^3 of new sediment). In August 2006, we first detected *Spartina* colonization in the central mudflats. The levee bench was quickly colonized by native tidal marsh vegetation dominated by common pickleweed, though the upland transition and levee zones remained an area dominated by non-native plants. Birds were quick to utilize the changing conditions of Tubbs Setback. Average number of shorebirds detected per survey increased with higher sediment elevations (R^2=0.95), while diving duck numbers declined (R^2=0.97). Small mammals utilized the levee bench areas as vegetation developed. Lower Tubbs Island and Tolay Creek are adjacent properties from which support small mammal populations. Small mammals are likely to colonize Tubbs Setback from these source populations and use these sites interchangeably. In 2003, a single salt marsh harvest mouse was detected. Salt marsh harvest mice were also detected in 2005 and 2006.

The goal of the Tubbs Setback restoration was to restore and enhance tidal salt marsh habitat for the benefit of endangered and threatened species, migratory birds, and other estuarine dependent wildlife (SPBNWR 1998). More specifically, the restoration objectives were: (1) Restore 72 acres of diked historic wetlands, (2) Create a self-sustaining tidal salt marsh capable of providing wildlife resources adequate protection without artificially increasing the risk of predation; (3) Maintain floodplain protection for adjacent landowners; (4) Restore the site in a manner requiring minimal maintenance; (5) Monitor and evaluate the results of the proposed project for its effects on endangered species and estuarine resources; and (6) Integrate adjacent restoration projects to increase hydrologic circulation and ecological exchange when appropriate.

(1) Restore 72 acres of diked historic wetlands

On 8 Mar 2002, tidal flow was restored to Tubbs Setback with a single breach to San Pablo Bay. Native salt marsh vegetation quickly colonized the levee bench. Pickleweed percent cover increased annually from 29.3% in 2002 to 72.3% in 2006. High sedimentation rates have transformed the site from a deep water pond during high tide to an exposed mudflat during low tide. Vegetation colonization of the site interior has just begun with the visual observation of *Spartina* in the central mudflat.

(2) Create a self-sustaining tidal salt marsh capable of providing wildlife resources adequate protection without artificially increasing the risk of predation

Tubbs Setback, along with the adjacent baylands (Tolay Creek and Lower Tubbs Island), provides a variety of habitat types for wildlife. Tubbs Setback has demonstrated wildlife value. Exposed mudflats are utilized by thousands of shorebirds and water birds, especially during the fall and winter migratory season. In October 2006, we recorded over 4,000 individuals, and several thousand incidentally observed scaup directly adjacent to Tubbs Setback in San Pablo Bay. Pickleweed cover has increased and salt marsh harvest mice have been detected along the levee bench.

(3) Maintain floodplain protection for adjacent landowners

As part of the restoration design, armament materials on the outboard levee facing San Pablo Bay were recycled and used to fortify the levee to the north to protect adjacent landowners. During 1 Jan 2006, the combination of high rains and annual high tides resulted in an extreme flood event in the region. We recorded a tidal range of 7.53 ft and high water level of 8.90 ft. Benchmark elevations along the west, north, and east levee indicate that water did not overtop the levees.

(4) Restore the site in a manner requiring minimal maintenance

This restoration included elements of both "self-design" and "designer" approaches to restoration (Mitsch and Wilson 1996). Self-designs allows natural processes to sort out species presence and utilization of the restoration site, rather than "designer" marshes that have deliberate plantings and species introductions on site. In cases where natural colonization may be lengthy or areas of bare ground may encourage undesirable weeds, it may be beneficial to actively encourage native plant growth. The levee bench was planted using an experimental approach to promote native vegetation growth (Downard et al. 2003), while the inner area was allowed to develop naturally.

Perhaps one of the most persistent threats to habitat quality is non-native invasive species. At Tubbs Setback, Vegetation has rapidly colonized the levee bench (Downard et al. 2003) and now supports a majority of native plant cover, predominantly common pickleweed. Non-natives plants currently dominate the levee tops and upland transition areas. Currently the USFWS is planting natives at Tubbs Setback to help out-compete non-native plants.

(5) Monitor and evaluate the results of the proposed project for its effects on endangered species and estuarine resources

The apparent colonization of Tubbs Setback by the salt marsh harvest mouse suggests physical and biological parameters changed sufficiently to provide suitable habitat. The increase in pickleweed cover from 29.3% in 2002 to 72.3% in 2006 likely played a role in the observed changes in salt marsh harvest mouse numbers. Continued monitoring will document the nature of mouse colonization at Tubbs Setback. Adjacent tidal marshes (Tolay Creek, Lower Tubbs Island and surrounding baylands) may serve as important source populations for colonizing individuals as the habitat develops for the California black rail and the California clapper rail.

(6) Integrate adjacent restoration projects to increase hydrologic circulation and ecological exchange when appropriate

In 2005, bathymetric surveys showed a single main channel that encircled the central mudflat and was relatively deep within 225 meters from the breach, but was shallow for the remainder of its length. High sedimentation rates continued and, the shallow portions of the channel have begun to fill. Drainage may be improved by opening Tubbs Setback to Lower Tubbs Island or incising a deeper breach along a natural breach along the southern levee. However, prior to reconnecting tidal flow to Tubbs Setback and Lower Tubbs Island, managers must carefully consider the impacts. While Tubbs Setback might benefit from restoring tidal flow to Lower Tubbs Island with channel persistence, Lower Tubbs Island might not benefit from receiving high sediment loads from Tubbs Setback. Channels and shallow lagoons in Lower Tubbs Island might begin to fill.

Tubbs Setback is rapidly progressing towards a mature marsh. The partnership between USFWS and USGS has allowed USGS to develop and test new monitoring technologies and methods to better describe changing environments, such as utilizing a bathymetry system to quantify sedimentation patterns over time. Remote sensing techniques, such as utilizing ERDAS Imagine software to classify land cover types can be useful in quantifying vegetation colonization and expansion in soft substrates such as mudflats. The implementation of a broad-based, ecological monitoring program is essential to document lessons learned for the benefit of larger-scale tidal wetland restorations throughout the bay.

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Table 1. Biophysical monitoring completed at Tubbs Setback.

Survey	Number samples	Minimal Frequency	2002	2003	2004	2005	2006
Vegetation	4 transects	Annual	Spring and Fall	Spring and Fall	August	August	August
Birds	Area survey	Monthly	Monthly (High and Low Tide)	Monthly (High and Low Tide)	Monthly (High and Low Tide)	Monthly (High and Low Tide)	Monthly (High and Low Tide)
Fish	1-2	Annual	Spring, Fall	Summer, Fall	Nov	Jun, Dec	Nov
Mammals	360 trap nights 2003-4 120 trap nights 2005-6	Annual	---	June	June	Summer	Jun/Jul
Invertebrates	4 transects	---	---	---	Aug	---	---
Water Levels	1 logger	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
Sediment Pins	20 pins	Bi-annual	Quarterly	Quarterly	Quarterly	Feb, Jul, Oct	Feb, May, Sep
Erosion Pins	4 pins	Bi-annual	Quarterly	Quarterly	Quarterly	Feb, Jul, Oct	Feb, May, Sep
Water Quality	48 hour deployment	Quarterly	Fall	---	Spring	Jan, May, Jul, Oct	Jan, Mar, May, Jul, Sep
Aerial Photo	1 aerial,	Annual	Oct	Sep	Sep	Aug	Aug
Photopoints	4 photo-points	Annual	Bi-annual	Bi-annual	Summer	Aug/Sep	Sep
ERDAS	1 aerial	---	---	---	---	Aug	Aug
Elevation Survey	3 staff gages, 20 sediment pins, 4 erosion pins, 5 benchmarks	Every other year	---	May	---	Jul, Nov	---
Bathymetry	---	Every other year	---	---	Jan	Sep	---

Table 2. Water quality parameters (temperature, pH, specific conductivity, dissolved oxygen, turbidity and salinity) reported as mean ± standard error. Data was collected at staff gage 1 (see table 1 for locations) from September 2002 to July 2005 and at staff gage 2 (*) from October 2005 to September 2006.

	N	**Temperature** (ºC)	**pH** (units)	**Specific Conductivity** (mS/cm)	**DO** (% saturation)	**Turbidity /10** (ntu)	**Salinity** (ppt)
Fall							
2002 Sept	466	18.63 ± 0.04	7.79 ± 0.004	40.09 ± 0.01	63.95 ± 0.26	27.78 ± 0.21	
2004 Sept	206	21.95 ± 0.13	7.86 ± 0.01	39.56 ± 0.17	105.74 ± 1.15	1.83 ± 0.15	25.26 ± 0.11
2005 Oct *	187	16.72 ± 0.14	7.76 ± 0.005	38.23 ± 0.02	81.50 ± 0.40	5.36 ± 0.83	24.31 ± 0.02
2006 Sept *	154	16.26 ± 0.18	7.90 ± 0.01	34.88 ± 0.02	91.23 ± 0.70		21.94 ± 0.01
Winter							
2004 Mar	132	15.60 ± 0.18	8.32 ± 0.01	17.45 ± 0.167	88.63 ± 0.92	15.27 ± 1.41	
2005 Jan	157	7.66 ± 0.14	7.62 ± 0.004	11.41 ± 0.16	90.31 ± 0.53	14.88 ± 0.90	6.52 ± 0.09
2006 Feb *	1	11.08	8.14	12.38			7.1
Summer							
2004 July	93	24.00 ± 0.19	7.77 ± 0.01	40.17 ± 0.08	85.74 ± 0.61	6.20 ± 0.61	25.69 ± 0.05
2005 May	92	20.18 ± 0.14	7.75 ± 0.01	24.05 ± 0.06	100.84 ± 1.43	4.16 ± 0.51	14.54 ± 0.04
2005 July	90	22.93 ± 0.44	7.56 ± 0.01	32.66 ± 0.05	80.31 ± 0.52	7.70 ± 0.74	20.39 ± 0.04
2006 May *	143	21.68 ± 0.26	7.78 ± 0.01	18.43 ± 0.04	85.34 ± 0.47	21.21 ± 1.67	10.87 ± 0.03

****PLEASE DO NOT CITE PRELIMINARY DATA WITHOUT PERMISSION ****

Table 3. Changes in sediment elevation (NAVD88 ft) from March 2002 to September 2006. Sediment pins were grouped into four categories based on location: land, outer mudflat, central mudflat, and channel. See Fig. 13 for location of sediment pins.

Location	**SedPin**	3/1/2002	3/18/2002	5/16/2002	7/19/2002	10/22/2002	11/15/2002	12/12/2002	2/10/2003	6/8/2003	8/5/2003	11/4/2003	2/24/2004	6/25/2004	9/7/2004	2/26/2005	4/21/2005	7/29/2005	10/12/2005	2/13/2006	4/28/2006	5/29/2006	9/18/2006
Land	1	7.09	7.74	7.63	7.64	7.64	7.82	7.82	7.80	7.77	7.77	7.77	7.78	7.78	7.79	7.80	7.82	7.73	7.74		7.78		7.87
	5	7.35	7.32	7.21	7.28	7.30	7.35	7.31	7.30	7.37	7.39	7.39	7.38	7.38	7.47	7.38	7.46	7.44	7.38		7.36		7.37
	9	6.78	6.83	6.77	6.87	6.85	6.99	7.04	7.05	7.03	7.04	7.01	7.06	7.03	7.04	7.03	7.02	7.04	7.01		7.07		7.03
	13	6.85	6.84	6.83	6.89	6.94	7.08	7.09	6.94			6.97	6.94	6.98	6.99	6.99	7.03	6.99	7.01		6.99		6.99
	A	5.80	6.49	6.22	6.03	5.52	5.81	5.80	5.80	5.70	5.63	5.61	5.62	5.58	5.60	5.62	5.60	5.60	5.62		5.63		5.70
	B	7.66	7.69	7.61	7.19	7.12	7.14	7.15	7.09	6.95	6.85	6.79	6.78	6.80	6.74	6.68	6.72	6.51	6.43		6.36		6.26
	C	6.39	6.37	6.34	6.31	6.28	6.28	6.28	6.28	6.28	6.32	6.30	6.30	6.32	6.34	6.29	6.30	6.29	6.28		6.23		6.28
	D	6.22	6.18	6.11	5.96	5.92	5.90	5.90	5.92	5.95	5.99	5.97	5.99	6.03	6.04	5.98	6.01	5.97	5.97		5.97		5.96
Land Average		**6.77**	**6.93**	**6.84**	**6.77**	**6.70**	**6.80**	**6.80**	**6.77**	**6.72**	**6.71**	**6.73**	**6.73**	**6.74**	**6.75**	**6.72**	**6.75**	**6.70**	**6.68**		**6.67**		**6.68**
Land SE		**0.22**	**0.21**	**0.21**	**0.22**	**0.26**	**0.25**	**0.26**	**0.25**	**0.29**	**0.29**	**0.26**	**0.25**	**0.26**	**0.26**	**0.26**	**0.26**	**0.26**	**0.26**		**0.26**		**0.26**
Outer Mudflat	2	0.64	0.78	0.61	0.59	0.70	0.78	0.77	0.92	1.11	1.19	1.03	1.38	1.53	1.69	2.05	2.19	2.43	2.51	2.66		3.16	3.27
	6	0.10	0.12	0.05	0.19	0.42	0.46	0.49	0.63	0.68	0.77	0.80	1.12	1.56	1.85	2.17	2.20	2.42	2.55	2.69		3.15	3.27
	7	-2.82	-2.81	-2.79	-1.77	-1.23	-1.19	-1.18	-0.95	-0.69	-0.43	-0.09	0.41	0.65	1.15	1.70	1.83	1.88	1.97	2.21		2.77	2.84
	8	-2.01	-2.07	-2.13	-2.01	-1.84	-1.86	-1.82	-1.78	-1.53	-1.33	-1.24	-0.81	-0.42	0.28	0.86	1.12	1.56	1.60	1.77		2.60	2.87
	10	1.60	1.67	1.60	1.61	1.54	1.53	1.54	1.59	1.59	1.58	1.60	1.56	1.70	1.90	2.02	2.17	2.37	2.50	2.63		3.06	3.55
	14	-0.08	0.05	-0.09	0.14	0.36	0.37	0.38	0.59	0.95	1.00	1.18	1.43	2.11	2.41	2.57	2.74	2.89	2.94	3.07		3.46	3.57
	15	-0.39	0.84	-0.38	-0.33	-0.30	-0.26	-0.25	-0.05	-0.21	-0.27	-0.08	0.20	0.76	0.99	1.59	1.87	2.15	2.17	2.36		2.86	2.91
	16	0.24	0.35	0.27	0.45	0.61	0.74	0.68	0.82	1.08	1.08	1.09	1.30	1.64	1.84	2.05	2.29	2.43	2.43	2.49		3.05	2.96
	17	3.71	3.70	3.70	3.39	3.22	3.16	3.19	3.18	3.17	3.01	2.91	2.90	2.78	2.67	2.60	2.62	2.59	2.67	2.76		3.22	3.37
	19	-3.56	-3.55	-3.56	-3.48	-3.19	-3.25	-3.27	-3.08	-2.61	-2.48	-2.42	-1.84	-0.80	-0.03	0.31	0.71	1.44	1.64	2.00		2.98	3.22
	20	-2.50	-2.32	-2.54	-2.15	-1.55	-1.52	-1.49	-1.24	-0.86	-0.63	-0.37	0.22	1.11	1.49	1.93	2.12	2.33	2.43	2.45		3.03	3.04
Outer Mudflat Average		**-0.46**	**-0.30**	**-0.48**	**-0.31**	**-0.12**	**-0.10**	**-0.09**	**0.06**	**0.24**	**0.32**	**0.40**	**0.72**	**1.15**	**1.48**	**1.80**	**1.99**	**2.23**	**2.31**	**2.46**		**3.03**	**3.17**
Outer Mudflat SE		**0.64**	**0.65**	**0.65**	**0.59**	**0.53**	**0.54**	**0.54**	**0.52**	**0.49**	**0.46**	**0.44**	**0.39**	**0.32**	**0.25**	**0.21**	**0.18**	**0.13**	**0.13**	**0.11**		**0.07**	**0.08**
Central Mudflat	3	-2.91	-2.89	-2.92	-2.38	-1.57	-1.61	-1.56	-1.31	-0.84	-0.42	-0.29	0.25	0.82	1.46	1.90	2.20	2.33	2.29	2.62		3.32	3.44
	4	-3.86	-3.90	-3.93	-3.67	-3.29	-3.30	-3.27	-2.99	-2.75	-2.53	-2.26	-1.68	0.12	1.07	1.60	1.81	2.05	2.11	2.45		3.12	3.30
	11	-3.11	-3.09	-3.12	-2.61	-2.11	-2.05	-1.98	-1.80	-1.31	-0.73	-0.57	-0.05	0.43	1.18	1.49	1.82	2.03	2.02	2.22		2.88	2.96
	18	-2.69	-2.74	-2.80	-2.57	-2.08	-2.08	-1.96	-1.89	-1.63	-1.53	-1.31	-0.75	-0.54	0.18	0.80	1.46	2.15	2.21	2.48		3.28	3.45
Central Mudflat Average		**-3.14**	**-3.16**	**-3.19**	**-2.81**	**-2.26**	**-2.26**	**-2.19**	**-2.00**	**-1.63**	**-1.30**	**-1.11**	**-0.56**	**0.21**	**0.97**	**1.45**	**1.82**	**2.14**	**2.15**	**2.44**		**3.15**	**3.29**
Central Mudflat SE		**0.25**	**0.26**	**0.25**	**0.29**	**0.36**	**0.36**	**0.37**	**0.36**	**0.41**	**0.47**	**0.44**	**0.43**	**0.29**	**0.28**	**0.23**	**0.15**	**0.07**	**0.06**	**0.08**		**0.10**	**0.11**
Channel	12	**-2.15**	**-2.15**	**-2.28**	**-2.38**	**-2.37**	**-2.41**	**-2.49**	**-2.43**	**-2.41**	**-2.49**	**-2.55**	**-2.43**	**-2.66**	**-2.69**	**-2.46**	**-2.52**	**-2.34**	**-1.93**	**-0.91**		**0.53**	**1.79**

Table 4. List of native and non-native plant species detected during pre- and post-breach surveys.

Common Name	**Scientific Name**	**Code**	Native[1]	Pre-breach	Post-breach
Alkali heath	*Frankenia salina*	FRSA	Y		X
Australian saltbush	*Atriplex semibaccata*	ATSE	N		X
Birdfoot trefoil	*Lotus corniculatus*	LOCO	N		X
Brass buttons	*Cotula coronopifolia*	COCO	N		X
Bristly oxtongue	*Picris echioides*	PIEC	N	X	X
Bull thistle	*Cirsium vulgare*	CIVU	N	X	
California bullrush	*Scirpus californicus*	SCCA	Y	X	
Common vetch	*Vicia sativa*	VISA	N		X
Common wild radish	*Raphanus sativus*	RASA	N	X	X
Cordgrass	*Spartina foliosa*	SPFO	Y		X
Corn spurry	*Spergula arvensis*	SPAR	N		X
Coyote bush	*Baccharis pilularis*	BAPI	Y	X	
Curly dock	*Rumex crispus*	RUCR	N	X	X
Fat hen	*Atriplex triangularis*	ATTR	Y		X
Fox tail	*Festuca myuros*	FEMY	N		X
Gum plant	*Grindelia stricta*	GRST	Y		X
Italian rye grass	*Lolium multiflorum*	LOMU	N	X	X
Marin knotweed	*Polygonum marinense*	POMA	Y		X
New Zealand spinach	*Tetragonia tetragonioides*	TETE	N		X
Perennial pepperweed	*Lepidium latifolium*	LELA	N	X	
Perennial rye grass	*Lolium perenne*	LOPE	N		X
Pickleweed	*Sarcocornia pacifica*	SAPA	Y		X
Prickly sow thistle	*Sonchus asper*	SOAS	N	X	
Prostrate knotweed	*Polygonum arenastrum*	POAR	N		X
Rabbitfoot beardgrass	*Polypogon monspeliensis*	POMO	N		X
Salmarsh daisy	*Jaumea carnosa*	JACA	Y		X
Salt grass	*Distichlis spicata*	DISP	Y		X
Sand spurrey	*Spergularia macrotheca*	SPMA	Y		X
Sand spurrey	*Spergularia rubra*	SPRU	N		X
Scarlet pimpernel	*Anagallis arvensis*	ANAR	N		X
Soft chess	*Bromus hordeaceous*	BRHO	N		X
Wild lettuce	*Lactuca serriola*	LASE	N	X	
Wild turnip (mustard family)	*Brassica rapa*	BRRA	N		X
Yellow star thistle	*Centaurea solstitialis*	CESO	N	X	X
Bare ground		BARE			
Brown algae		ALGB			

Dead & standing	DOM
Green algae	ALGG
Litter (dead & not standing)	LI
Mudflat	MF
Open water	OPWA
Unknown	UNKN
Wrack	WR

Table 5. Invertebrate volume per m^2 (10 cm depth) at Tubbs Setback along four transects (2 transects along both north and west shore). Transects A, B, C, D were located adjacent to erosion pins A, B, C, D. Habitat types were classified as vegetated margin (1), mudflat transition (2), and mudflat (3).

Class	Taxon	Transect												Total
		North						West						
		A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	
Bivalvia	*Corbula amurensis*	-	51	102	-	127	25	-	-	38	-	-	-	4,355
	Macoma spp.	-	51	191	-	191	991	-	191	356	-	102	368	30,968
	Unknown bivalve	-	-	229	25	152	1,029	13	38	203	51	25	254	25,645
	family Ephydridae	-	-	-	13	-	-	-	-	-	-	-	-	161
Insecta	Order Diptera	-	-	-	-	-	25	-	-	-	-	-	-	323
	Order Hymenoptera	-	-	13	-	-	-	-	-	-	-	13	13	484
	Family Mysidae	64	-	38	-	-	343	13	13	51	-	-	483	12,742
Crustacea	Infraorder Caridea	-	-	-	-	-	13	-	-	-	-	-	-	161
	suborder gammaridea	3,988	826	864	394	1,016	533	3,429	597	406	419	114	254	163,064
	Order Isopoda	25	38	64	13	-	-	-	25	-	-	-	13	2,258
	Order Cumacea	13	-	216	-	-	851	-	64	394	13	51	483	26,452
	Unknown crustacean	-	-	-	-	-	-	-	-	-	13	-	-	161
Gastropoda	*Assiminea californica*	-	-	-	-	-	-	-	-	25	-	-	-	323
	Nassarius obsoletus	-	13	-	-	-	-	-	-	-	-	-	-	161
	Odostomia spp.	-	-	-	-	-	-	-	-	13	-	-	-	161
	Unknown gastropod	-	13	-	-	-	-	-	25	38	-	-	-	968
Polychaeta	*Heteromastus sp.*	-	-	51	-	-	-	-	-	-	-	-	-	645
	Family Spionidae	-	-	13	-	-	-	-	-	-	-	-	-	161
	sedentary polychaete	51	64	330	64	140	470	51	533	457	13	254	216	33,548
	errant polychaete	-	51	25	25	25	89	13	-	127	38	13	38	5,645
Oligochaeta	Unknown oligochaete	114	-	457	38	-	203	-	25	-	-	-	-	10,645
Grand Total		54,032	14,032	32,903	7,258	20,968	58,064	44,677	19,194	26,774	6,935	7,258	26,935	4,051,702

Table 6. List and average number of fish species detected between spring 2002 and winter 2005. Invasive species are denoted with an asterisk* (SFEI 2006)

Common Name	Scientific Name	Native[1]	May 2002	November 2002	June 2003	November 2003	November 2004	June 2005	December 2005	Total
American shad	*Alosa sapidissima*	N	1							1
Northern anchovy	*Engraulis mordax*	Y	10		4					14
Arrow goby	*Clevelandia ios*	Y	2		14		1	9		26
Bay goby	*Lepidogobius lepidus*	Y	40					141		181
Bay pipefish	*Syngnathus leptorhyncos*	Y	5		2					7
Pacific herring	*Clupea pallasi*	Y	18						7	25
Pacific staghorn sculpin	*Leptottus armatus*	Y	40	2		7			2	51
Rainwater killifish	*Lucania parvu*	N			4	1				5
Shiner surfperch	*Cymatogaster aggregata*	Y	15							15
Starry flounder	*Platichtys stellatus*	Y			5	4			1	10
Striped bass	*Morone saxatilis*	N	3	3	28					34
Threespine stickleback	*Gasterosteus aculeatus*	Y	52		1					53
Topsmelt	*Artherinops affinis*	Y	14	10	114	320	28		7	493
Yellowfin goby	*Acanthogobius flavimanus*	N	5		225			19		249
Chinese Mitten crab*	*Eriocheir sinensis*	N	3	1						4
Green crab*	*Carcinus maenas*	N			1					1
Hemigrapsus crab	*Hemigrapsus spp.*	Y			9			7		16
Crangon shrimp	*Crangon spp.*	Y	56	1		130	43			230
Palaemon shrimp	*Palaemon sp.*	N	4		7					11
Jellyfish	*Cnidarian*	Y	1	1						2
Grand Total			**269**	**18**	**414**	**462**	**72**	**176**	**17**	**1428**

[1] Y=yes, N=no

Table 7. Bird species, bird type, and average number of birds observed per survey pre-breach (4 surveys) and post-breach (107 surveys).

Bird Type	Common name	Pre-breach	Post-breach
Dabbler	American Widgeon	0	0.62
	Gadwall	0	1.58
	Green-winged Teal	0	0.30
	Mallard	0	2.80
	Northern Pintail	0	0.55
	Northern Shoveler	0	1.21
Dabbler Total		0	7.06
Diver	American Coot	0	0.07
	Bufflehead	0	1.35
	Canvasback	0	25.78
	Clark's Grebe	0	0.23
	Common Goldeneye	0	0.21
	Common Murre	0	0.01
	Eared Grebe	0	0.07
	Greater Scaup	0	0.77
	Pied-billed Grebe	0	0.02
	Ruddy Duck	0	17.55
	Scaup	0	130.89
	Surf Scoter	0	0.02
	Western Grebe	0	1.12
Diver Total		0	178.16
Gull/ Tern	Bonaparte's Gull	0	0.58
	California Gull	0	0.13
	Caspian Tern	0.25	0.01
	Forster's Tern	1	0.68
	Franklin's Gull	0	0.02
	Herring Gull	0	0.01
	Ring-billed Gull	0	2.75
	Western Gull	0	0.70
Gull/ Tern Total		2.25	8.86
Other	American White Pelican	0	0.22
	Black-crowned Night-Heron	0	0.03
	Canada Goose	0	0.52
	Double-crested Cormorant	0.75	1.35
	Great Blue Heron	0	0.22
	Great Egret	0	0.37
	Ring-necked Pheasant	3.25	0.32
	Snowy Egret	1.5	1.16
	Turkey Vulture	0.75	0.20
Other Total		6.25	5.63
Passerine	American Crow	0.25	0.01
	American Goldfinch	6	0.04

Bird Type	**Common name**	**Pre-breach**	**Post-breach**
	American Pipit	0	0.02
	Barn Swallow	0	0.12
	Bushtit	1.5	0.00
	Cliff Swallow	0	0.12
	Common Raven	0.5	0.02
	Common Yellowthroat	0	0.07
	Golden-crowned Sparrow	0	0.10
	House Finch	0.5	0.30
	Marsh Wren	0	0.02
	Red-winged Blackbird	22.75	0.27
	Rock Dove	0	0.01
	Savannah Sparrow	1.25	0.00
	Song Sparrow	5.75	1.01
	Violet-green Swallow	0.75	0.00
	Western Meadowlark	0	1.49
	White-crowned Sparrow	0	0.22
Passerine Total		39.25	4.47
Raptor	American Kestrel	0	0.01
	Northern Harrier	2	0.22
	Osprey	0	0.02
	Peregrine Falcon	0	0.03
	Red-shouldered Hawk	0	0.01
	Red-tailed Hawk	0.25	0.07
	White-tailed Kite	1	0.03
Raptor Total		3.25	0.40
Shorebird	American Avocet	0	27.79
	Black-bellied Plover	0	2.64
	Black-necked Stilt	0	0.44
	Dowitcher	0	0.74
	Dunlin	0	17.18
	Greater Yellowlegs	0	0.16
	Killdeer	0	0.48
	Least Sandpiper	0	18.31
	Lesser Yellowlegs	0	0.07
	Long-billed Curlew	0	3.08
	Long-billed Dowitcher	0	0.02
	Marbled Godwit	0	10.66
	Western Sandpiper	0	34.60
	Whimbrel	0	0.13
	Willet	0	22.15
	Yellowlegs	0	0.01
Shorebird Total		0	205.12
Grand Total		51	409.69

Table 8. List of small mammal species and abundance index (new captures per 100 trap nights) for each trapping year at Tubbs Setback.

Common name	**Scientific name**	**2003**	**2004**	**2005**	**2006**
California vole	*Microtus californicus*	1.39	0.56	0.83	3.33
House mouse	*Mus musculus*	1.11	0.28	4.17	1.67
Deer mouse	*Peromyscus maniculatus*	17.50	4.72	2.50	2.50
Salt marsh harvest mouse	*Reithrodontomys raviventris*	0.28		4.17	0.83
Norway rat	*Rattus norvegicus*			0.83	0.83

Figure 1. Regional map showing Tubbs Island Setback, Tubbs Island and Tolay Creek Restoration Marshes in the northern San Pablo Bay. Photo was taken in 1998 before restoration was implemented at Tubbs Setback.

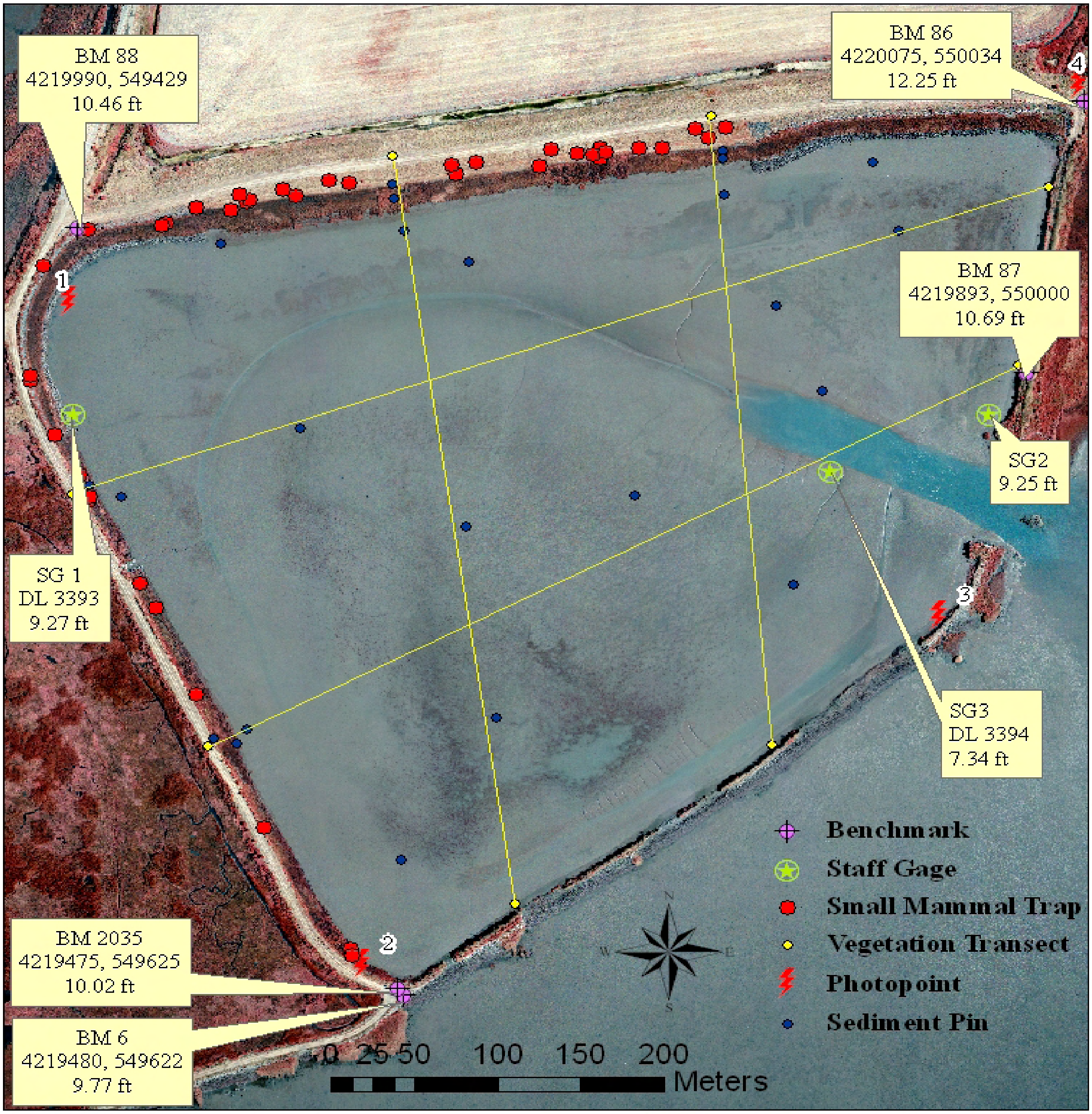
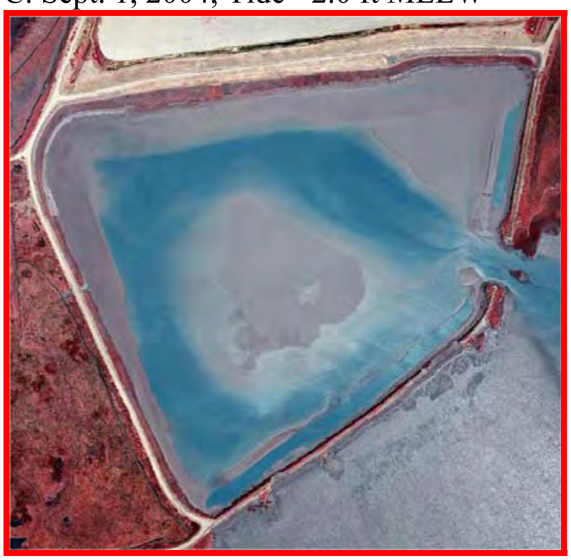


Figure 2. Location of sampling points for benchmarks, staff gages, small mammal traps, vegetation transects, photopoints, and sediment pins. Benchmark labels report name, location (NAD83 UTM Zone 10), and elevation (NAVD 88 surveyed in 2005 by Paul Goebel). Staff gage labels report staff gage name, datalogger name, and elevation at top of staff gage plate (NAVD 88 surveyed in 2005 by USGS using reported benchmark elevations).

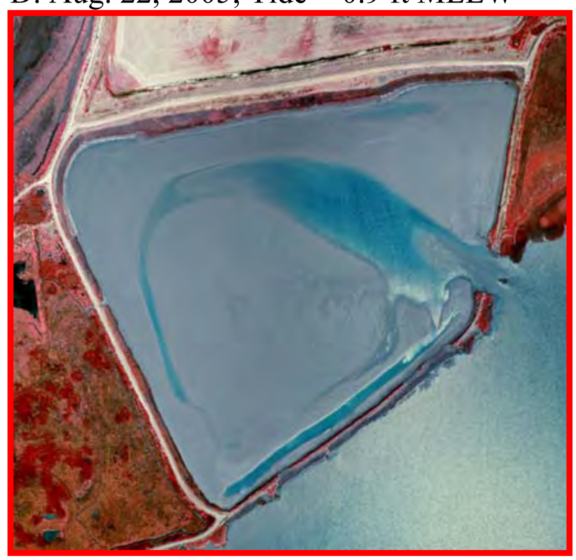
A. Oct. 9, 2002; Tide = -0.1 ft MLLW

B. Sept. 23, 2003; Tide < 2.0 ft MLLW

C. Sept. 1, 2004; Tide <2.0 ft MLLW



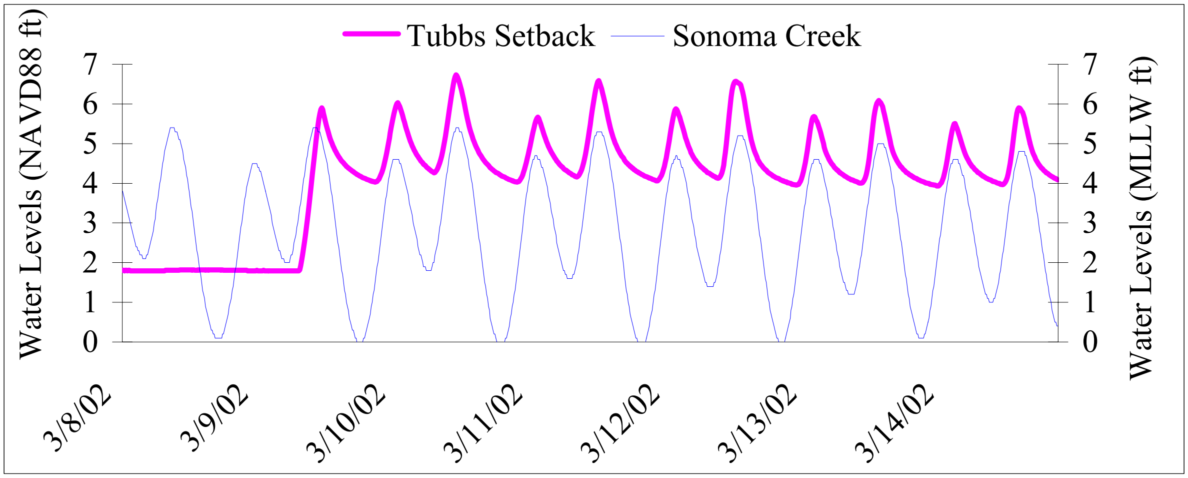
D. Aug. 22, 2005; Tide = 0.9 ft MLLW



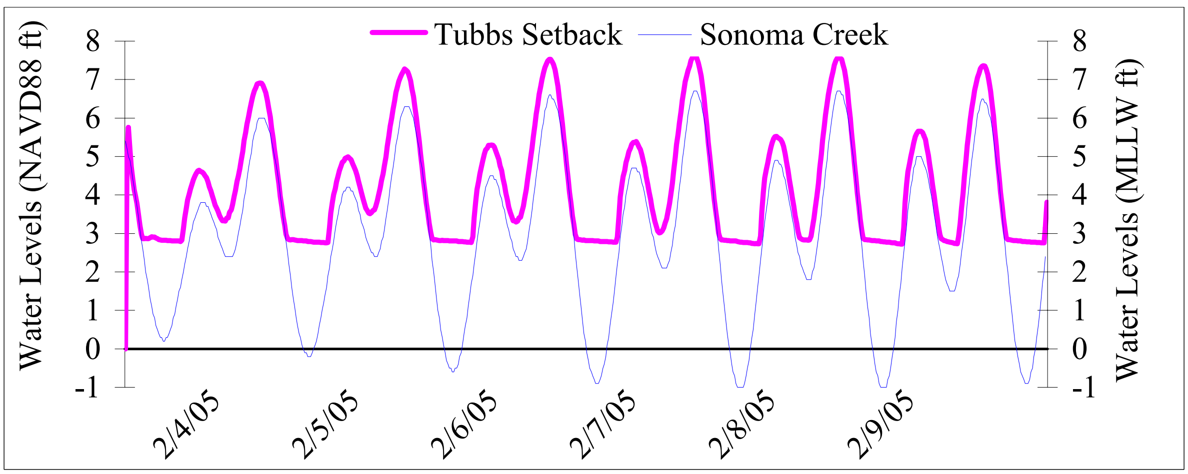
E. Aug. 9, 2006; Tide = -0.6 ft MLLW

Figure 3. The 29-ha Tubbs Setback restoration project color infrared aerial photographs taken in Oct. 2002 (A) Sept. 2003 (B), Sept. 2004 (C), Sept. 2005 (D) and Aug. 2006 (E).

A. Tidal elevations a few days after the breach at staff gauge 1.



B. Tidal elevations almost three years after the breach at staff gauge 1.



C. Tidal elevations over four years after the breach at staff gauge 3.

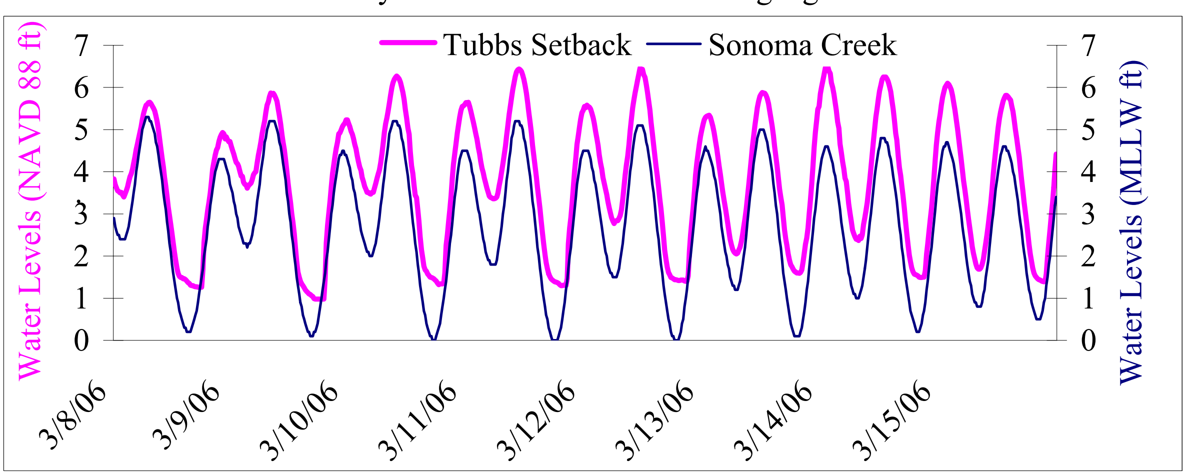
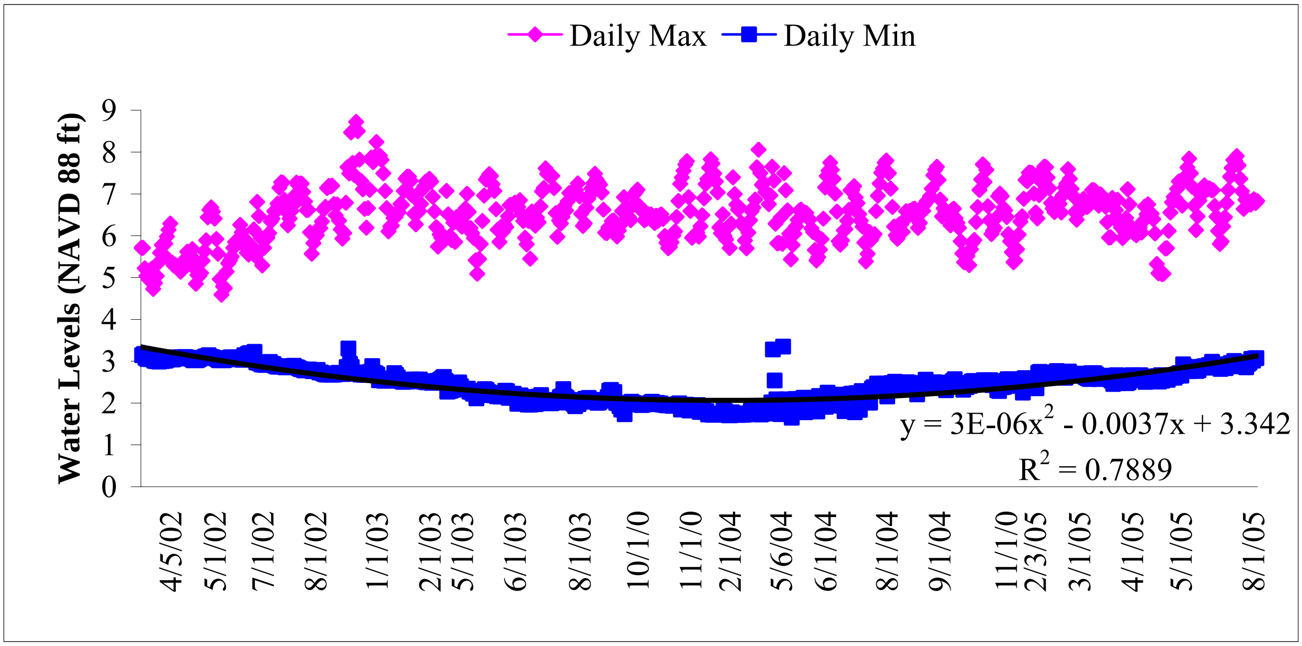


Figure 4. Water levels at Tubbs Setback (NAVD88 ft) and Sonoma Creek (MLLW ft) shortly after the restoration in March 2002 (A), February 2005 (B), and March 2006 (C). The data logger at staff gage 1 became buried in sediment to a level of 2.7 feet (NAVD88), and staff gage 3 was installed in August 2005 in deeper water.

A. Daily minimum and maximum water levels from February 2002 to August 2005 at staff gage 1.



B. Daily minimum and maximum water levels from August 2005 to September 2006 at staff gage 3.

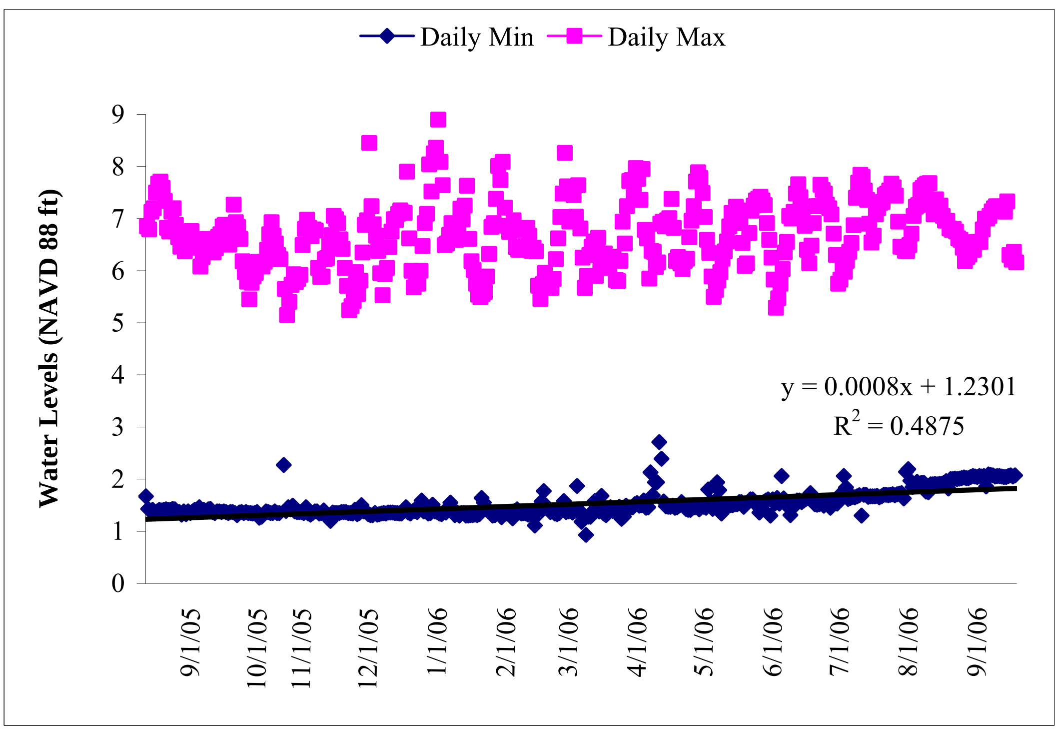


Figure 5. Daily minimum and maximum water levels (NAVD88, feet) at Tubbs Setback from February 2002 to September 2006 at loggers as recorded by the northwest datalogger (A) and the southeast datalogger (B). Minimum water levels appeared to decrease slightly in 2003 and increase slightly in 2005.

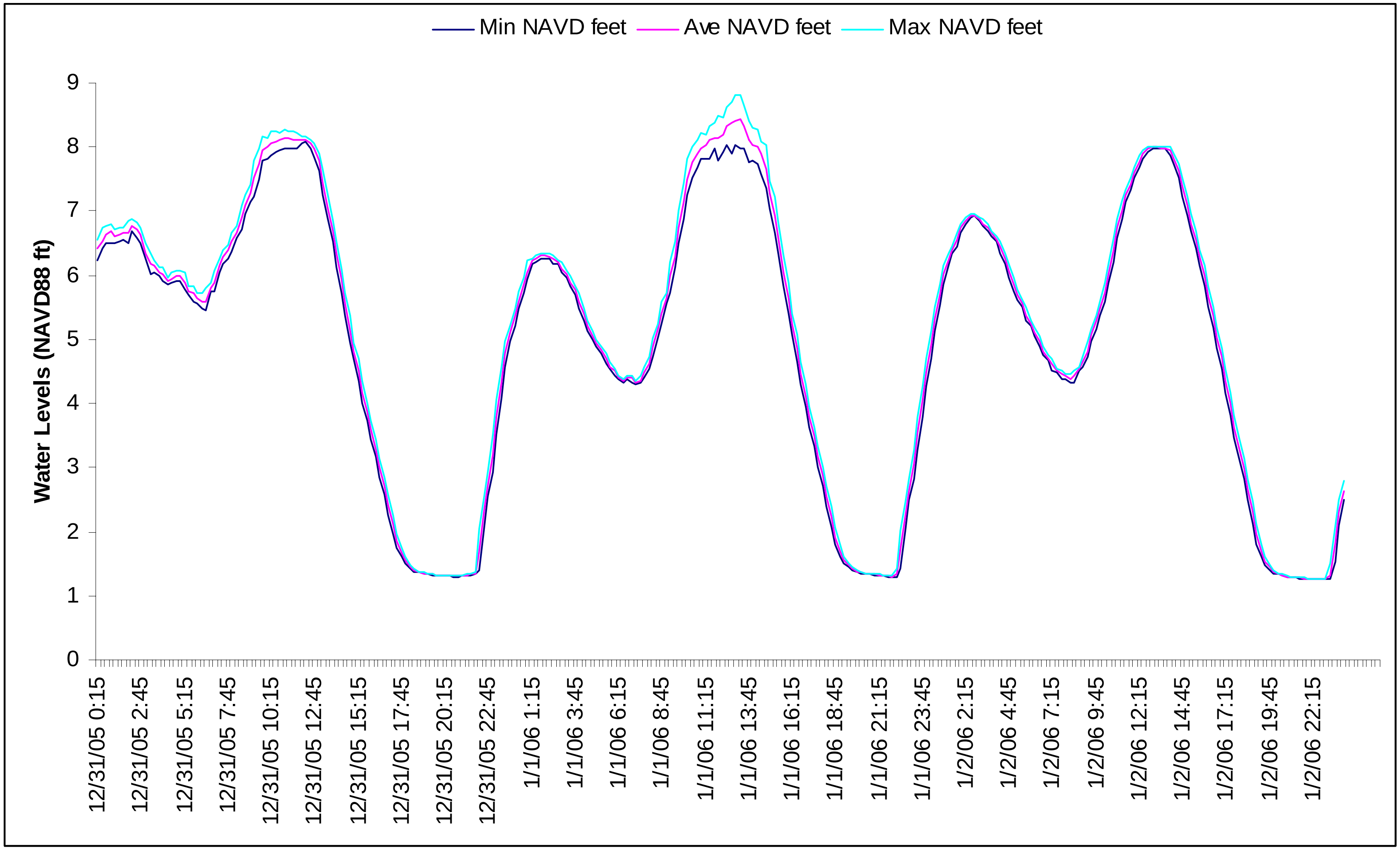


Figure 6. Water levels from 31 December 2005 to 2 January 2006 documented extremely high water levels from an extreme high tide event combined with heavy rains, which produced local flooding in Sonoma, Napa, and Solano counties on 1 January 2006. Despite high water levels, the north levee remained above water since project benchmarks located on levee tops range from 9.77 ft to 12.25 ft NAVD 88.

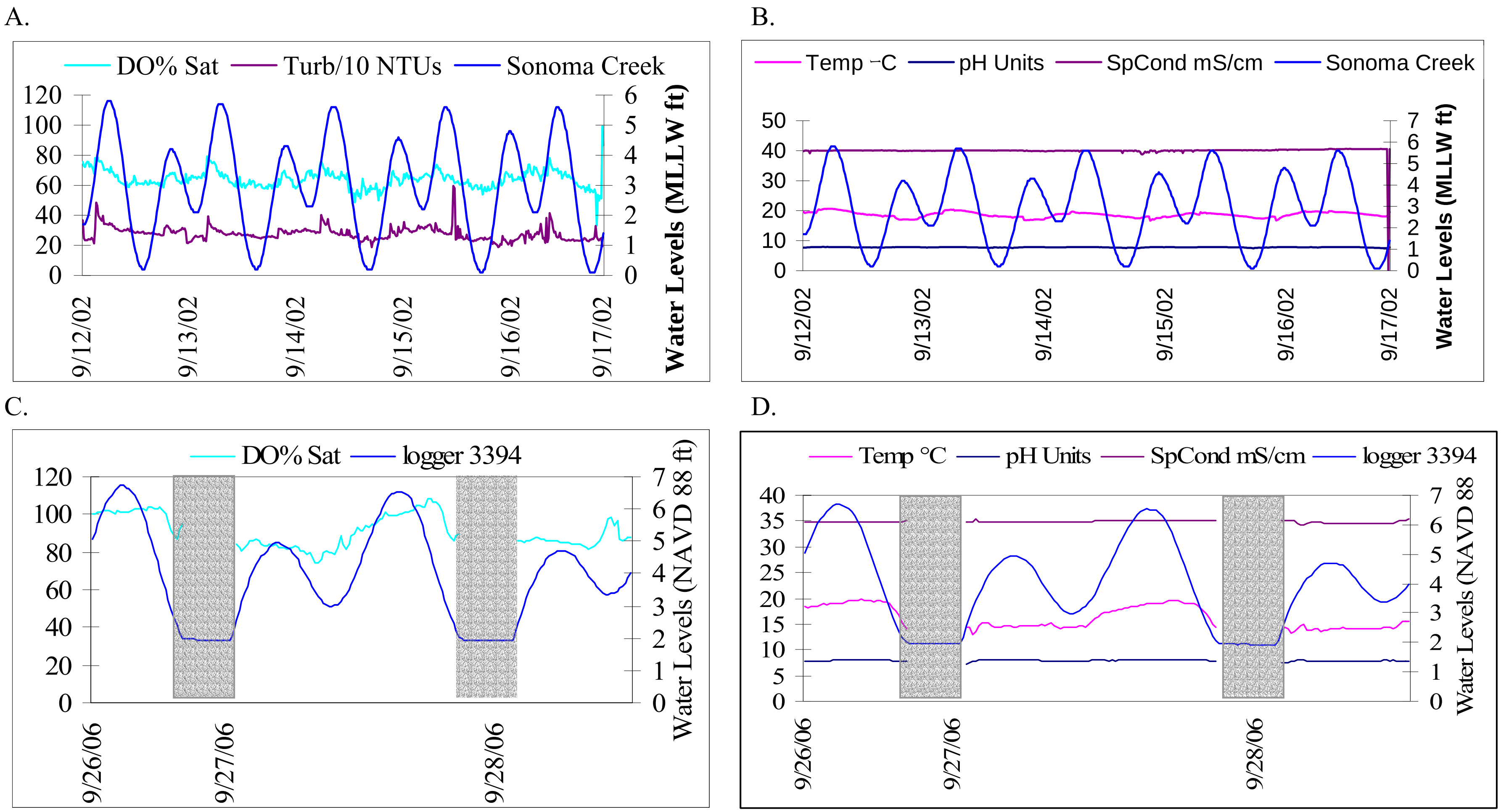


Figure 7. Water quality data from Tubbs Setback from 12 to 17 September 2002 (A, B), and 26 to 28 Aug 2006 (C, D). Percent dissolved oxygen, turbidity (divided by 10 for scale) are shown with the Sonoma Creek tide profile (A) and the water level logger data (C). Temperature (degrees Celsius), pH, and specific conductivity (mS/cm) are shown with Sonoma Creek tide profile (B) and with the water level logger data (D). By July 2005, water quality parameters are inaccurate during low tides due to sedimentation during times indicated by grey bars.

(A) August 22, 2005, 11:57; Tide= 0.9 ft MLLW

(B) August 9, 2006, 9:19; Tide= -0.6 ft MLLW

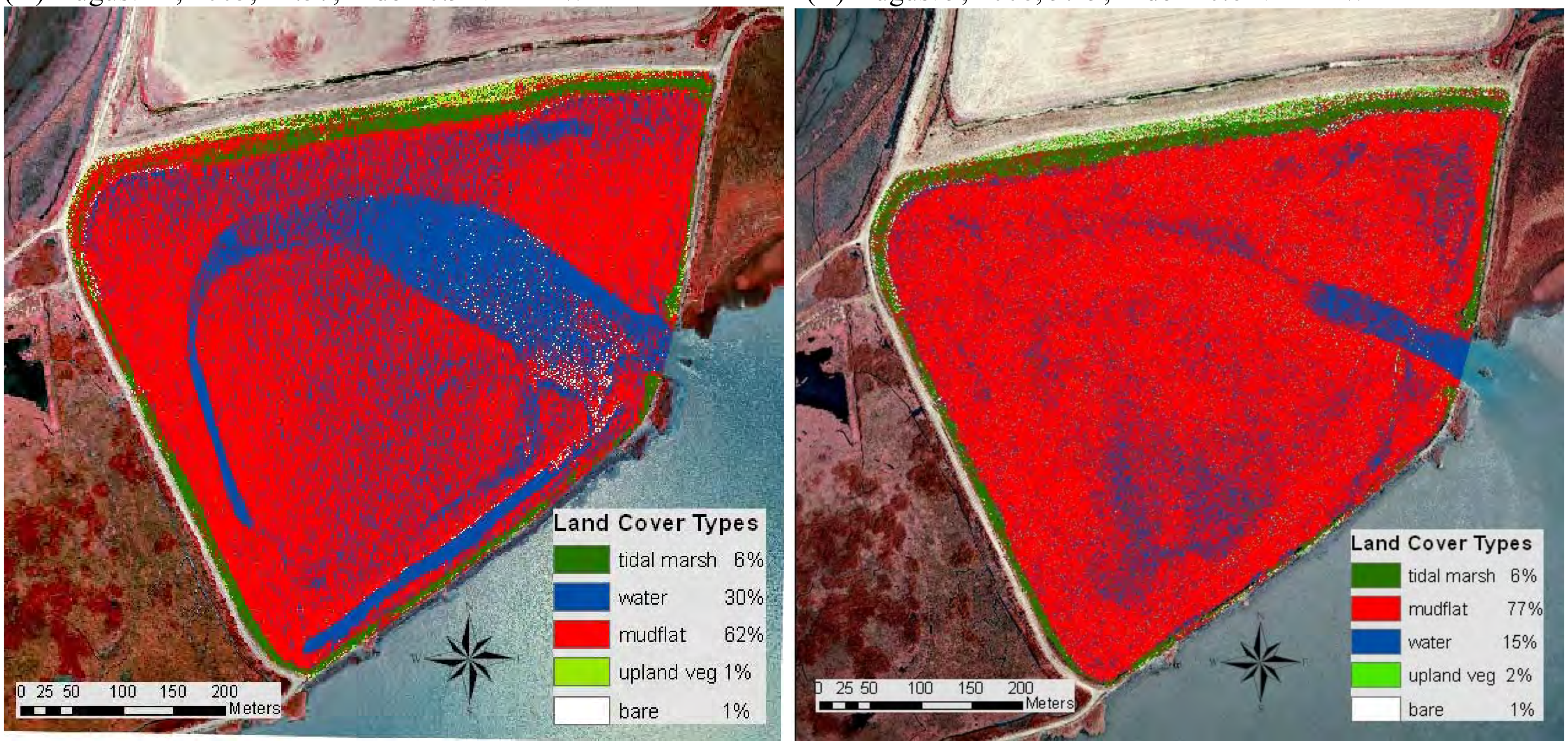


Figure 8. Land cover classifications using the August 2005 and 2006 color infrared aerial photographs. We used ERDAS Imagine Software, which automatically generated 15 classifications. Classifications were then grouped into five major land cover types: tidal marsh, water, mudflat, upland vegetation, and bare. There were slight differences among the color signatures which resulted in multiple classifications per land cover type. For example, some bare areas on the levee returned a mudflat signature in the 2005 image.

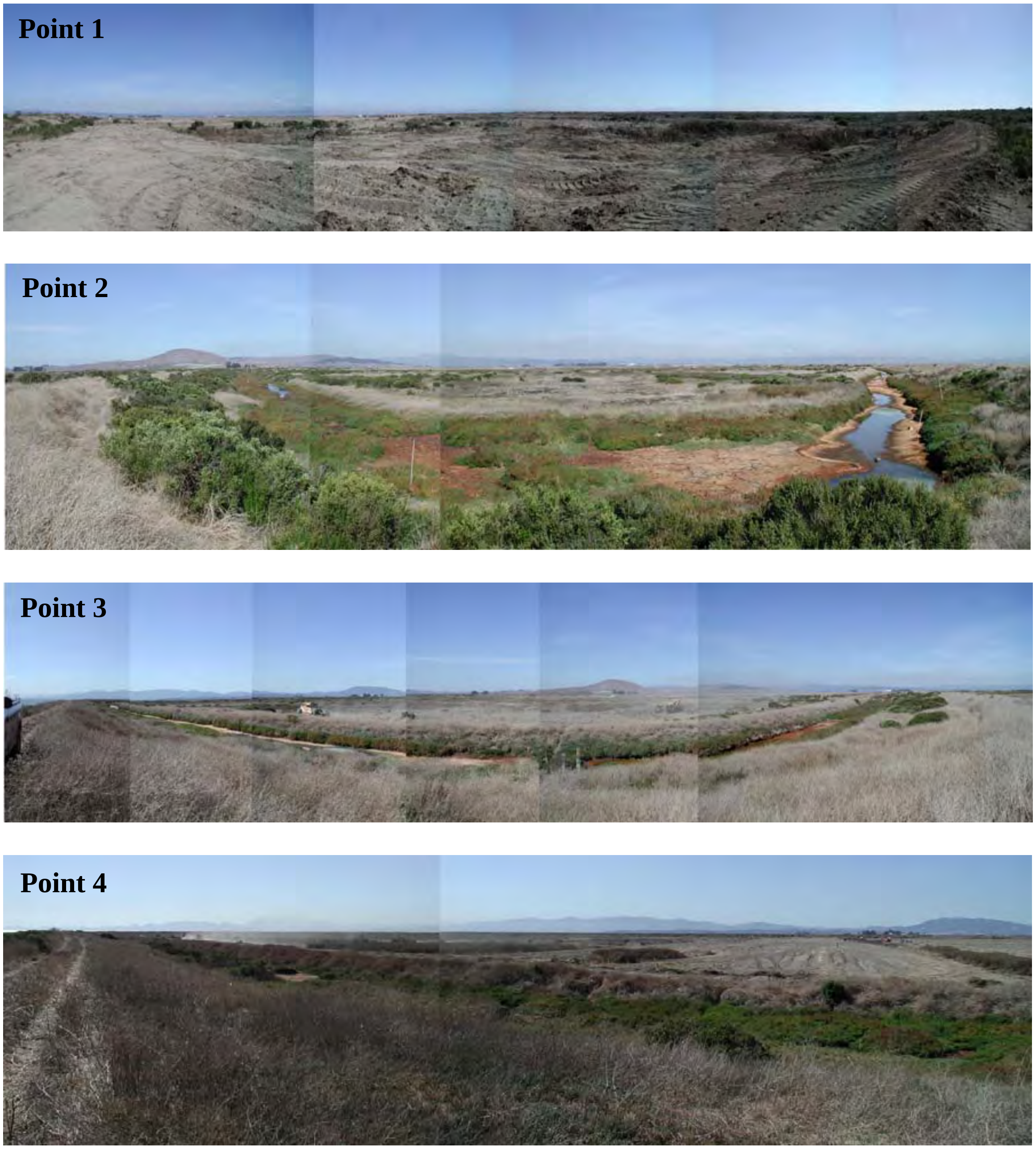


Figure 9. Panoramic views of photopoints of pre-breach conditions at Tubbs Setback showing typical fallow field vegetation, October 2000 (See Figure 2 for locations).

Figure 10. Images of breach construction at Tubbs Setback on March 8th, 2002.

A. Plantings during initial restoration phase, Mar 2002.

B. Current conditions of vegetative cover, Aug 2006.

C. *Spartina* colonizing mudflats, Sep 2006.

Figure 11. Images of Tubbs Setback when vegetation was first planted in 2002 (A) and condition of vegetation in August 2006 (B). No bare ground remains between levee upland and high water line. *Spartina* is beginning to colonize the intertidal zone (C).

Point 1

Point 2

Point 3

Point 4

Figure 12. Panoramic views of photopoints of post-breach conditions at Tubbs Setback showing sedimentation and pickleweed establishment on levee bench, September 2006 (See figure 2 for locations).

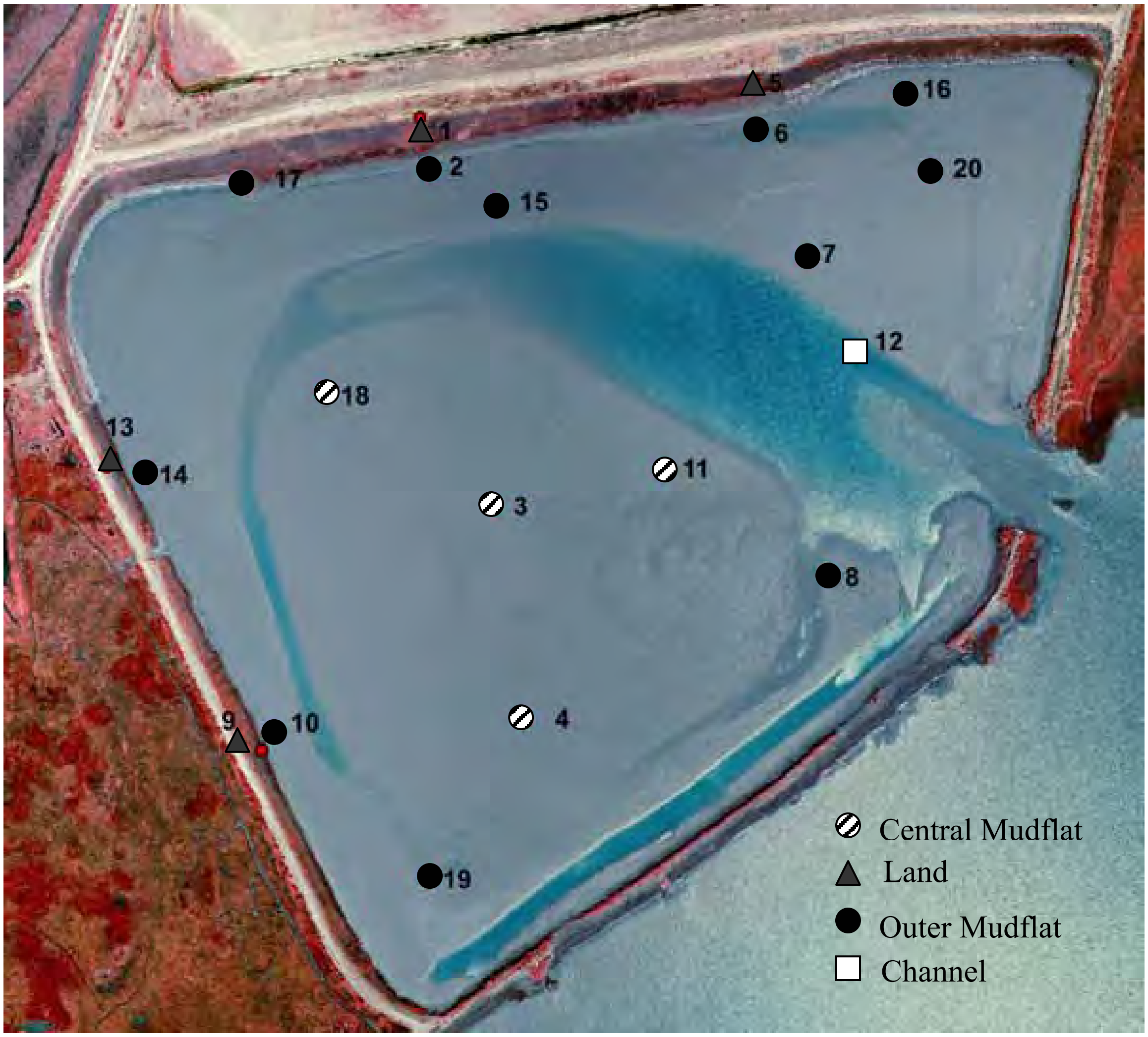


Figure 13. Sediment pins grouped into four categories in Tubbs Setback: Central Mudflat, Land, Outer Mudflat, and Channel.

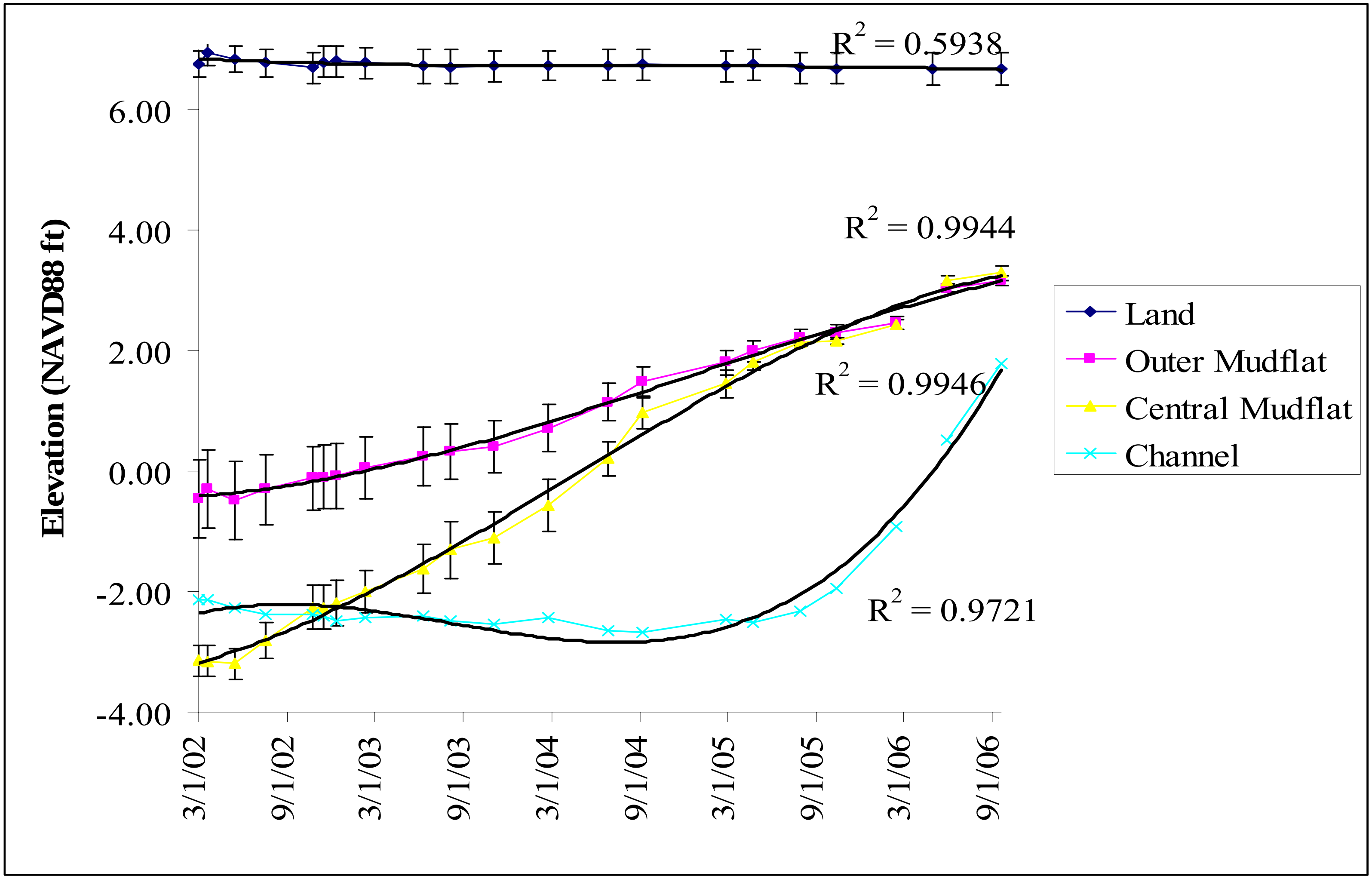


Figure 14. Sediment elevation (NAVD88 ft) at 24 sediment pin locations from March 2002 to September 2006. After 3.5 years, the central and outer mudflat areas reached an intersection point despite an almost 3 ft difference in average initial elevations. The channel has shown an almost 3ft increase in elevation since 2005.

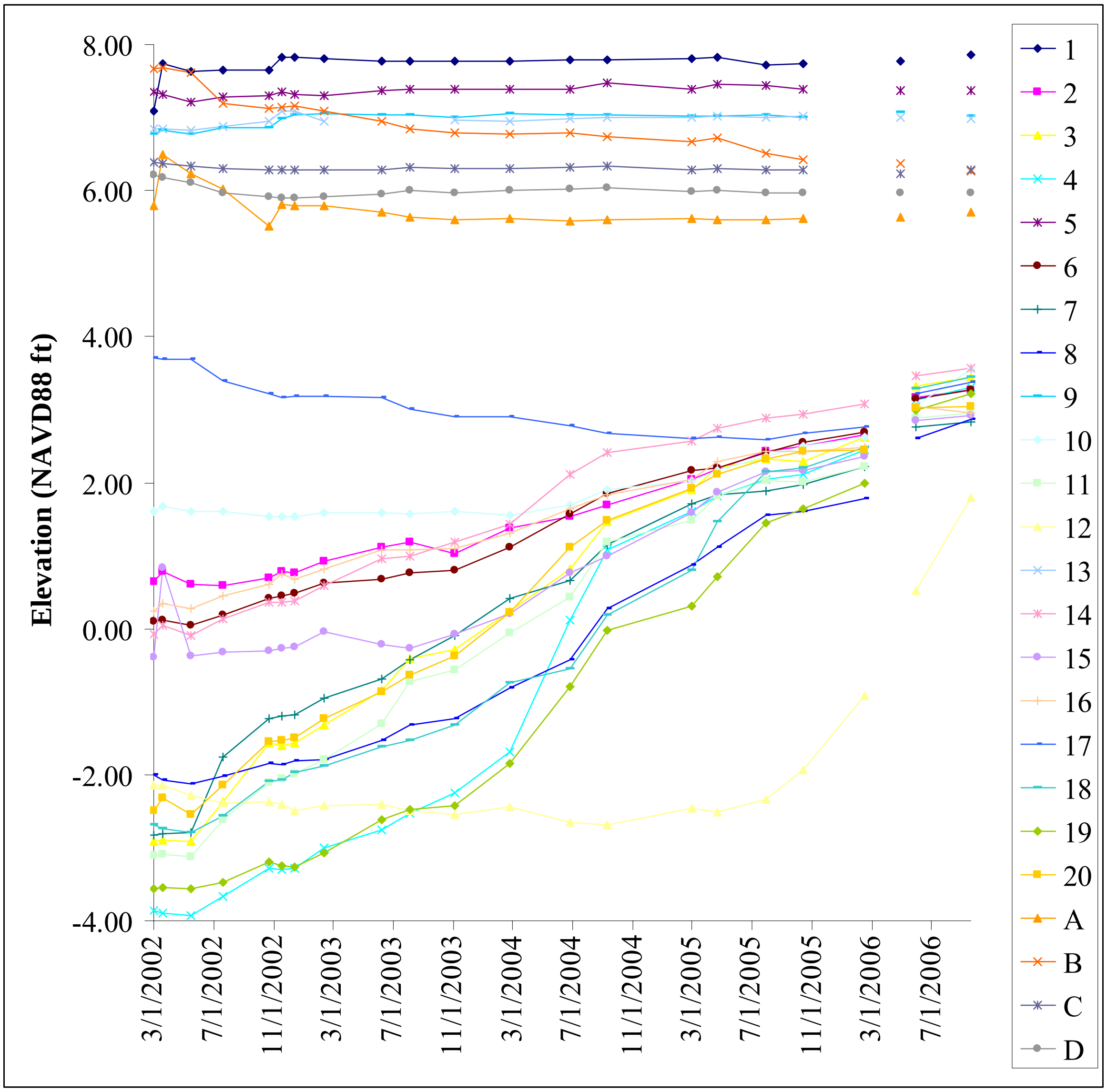
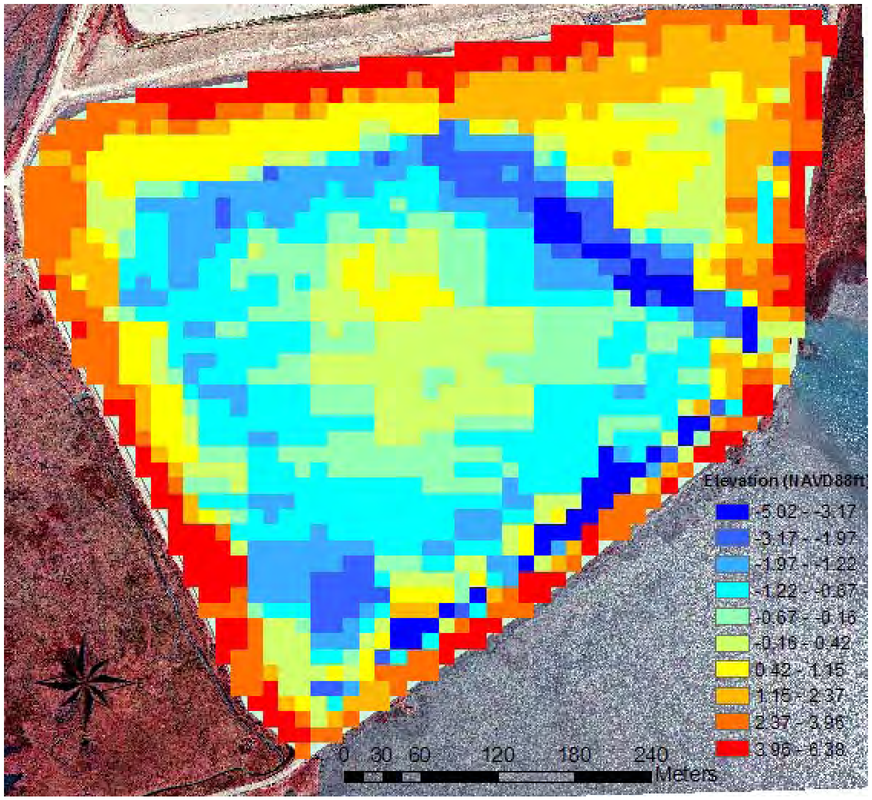


Figure 15. Sediment surface elevations (NAVD88 ft) measured from March 2002 to September 2006. Sediment Pins 1,5,9,13 and A,B,C,D are on land.

(A)



(B)

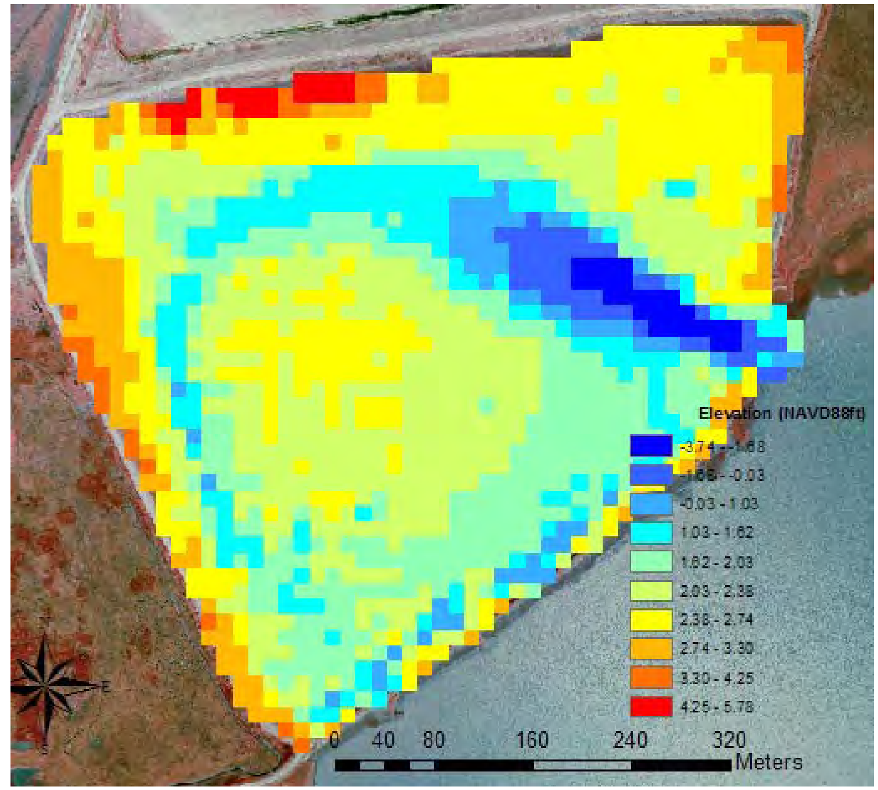


Figure 16. Bathymetric surveys at Tubbs Setback on (A) 21 January 2004 and on (B) 27, 28, and 29, September 2005 show sediment surface elevations (NAVD88 ft). The bathymetric map in 2004 was created using North to South transects, while the 2005 survey was conducted using North to South as well as East to West transects. In 2005, the bathymetric map identified the development of a main channel (dark blue) that is deep in the first 225 meters from the breach and becomes shallow as the channel encircles the central mudflat.

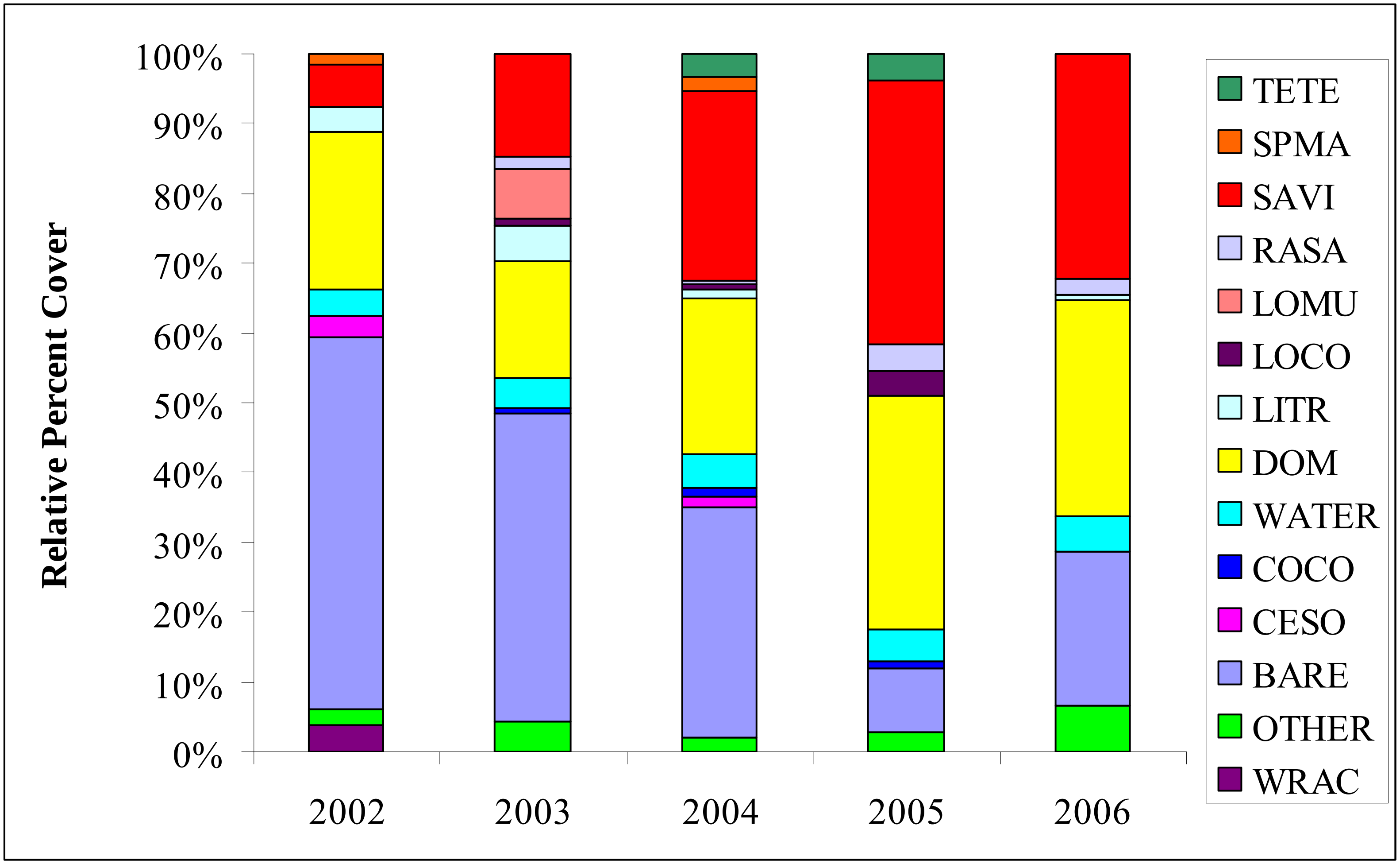


Figure 17. Relative percent cover between August 2002 and August 2006 point intercept vegetation surveys. Pickleweed (*Sarcocornia virginica*) cover has steadily increased in post-breach (1999) years. Category ‘Other’ includes: ALGG, ALGB, ATSE, ATTR, BAPI, BRRA, DISP, FRSA, HYRA, SPFO, and SPRU. Species codes follow those in Table 4.

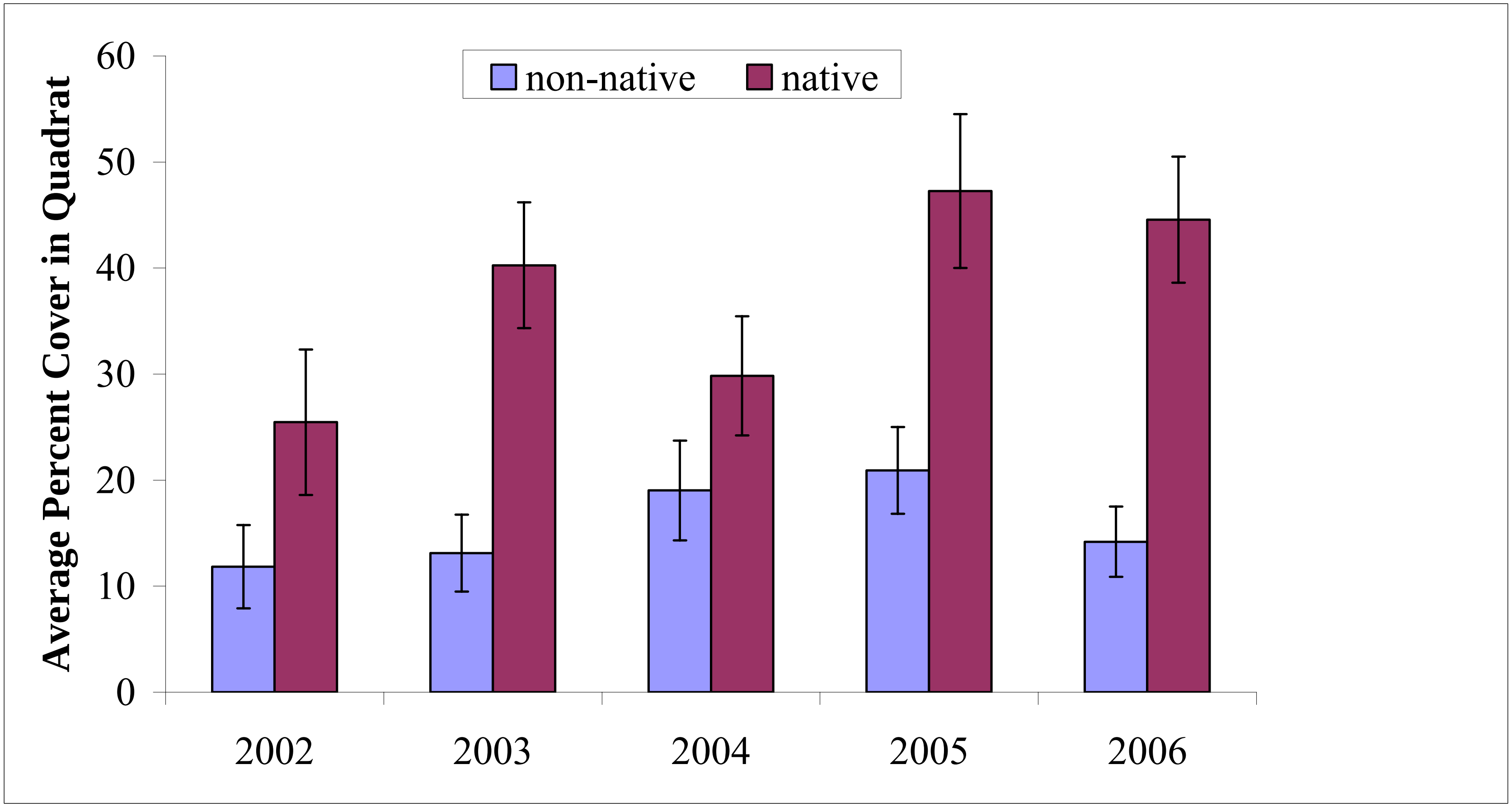
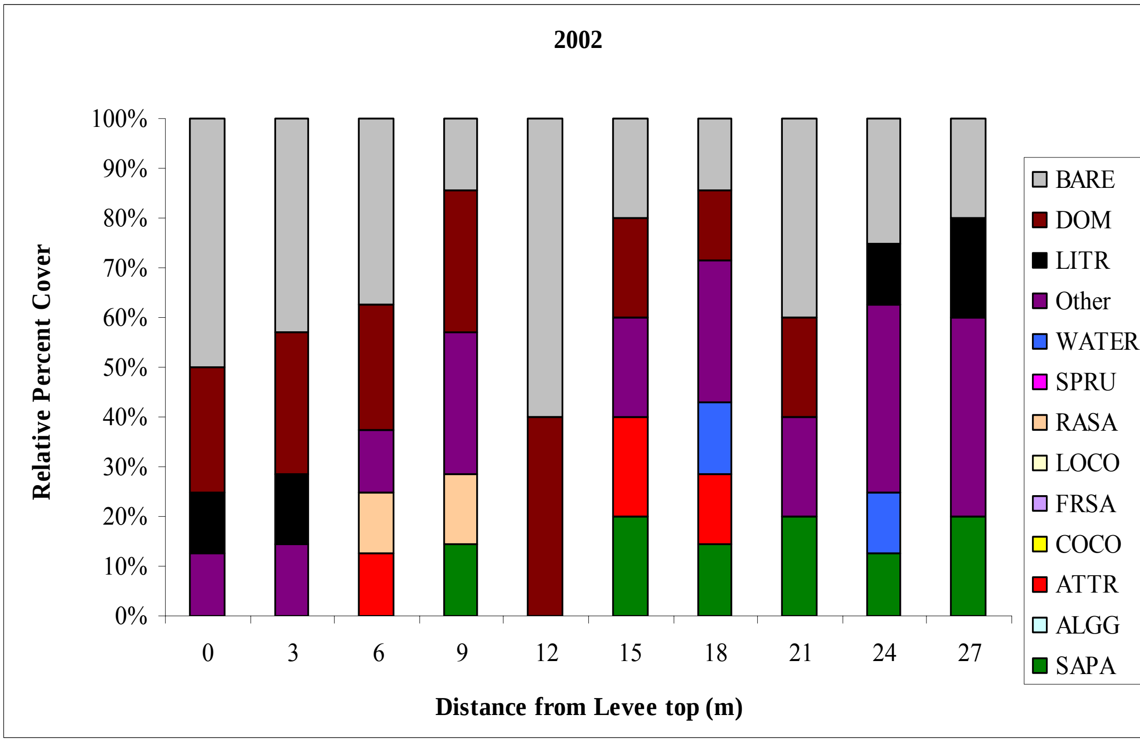


Figure 18. Overall average native and non-native plant cover (mean ± SE, from quadrat surveys) from August 2002 to August 2006.



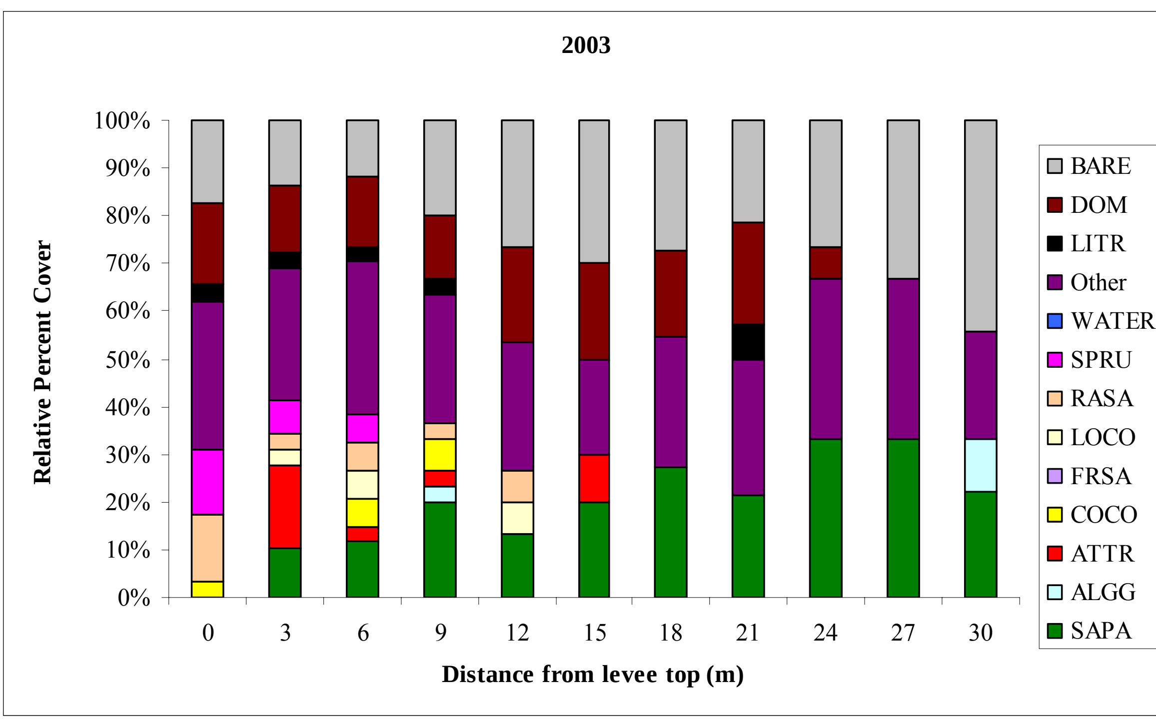
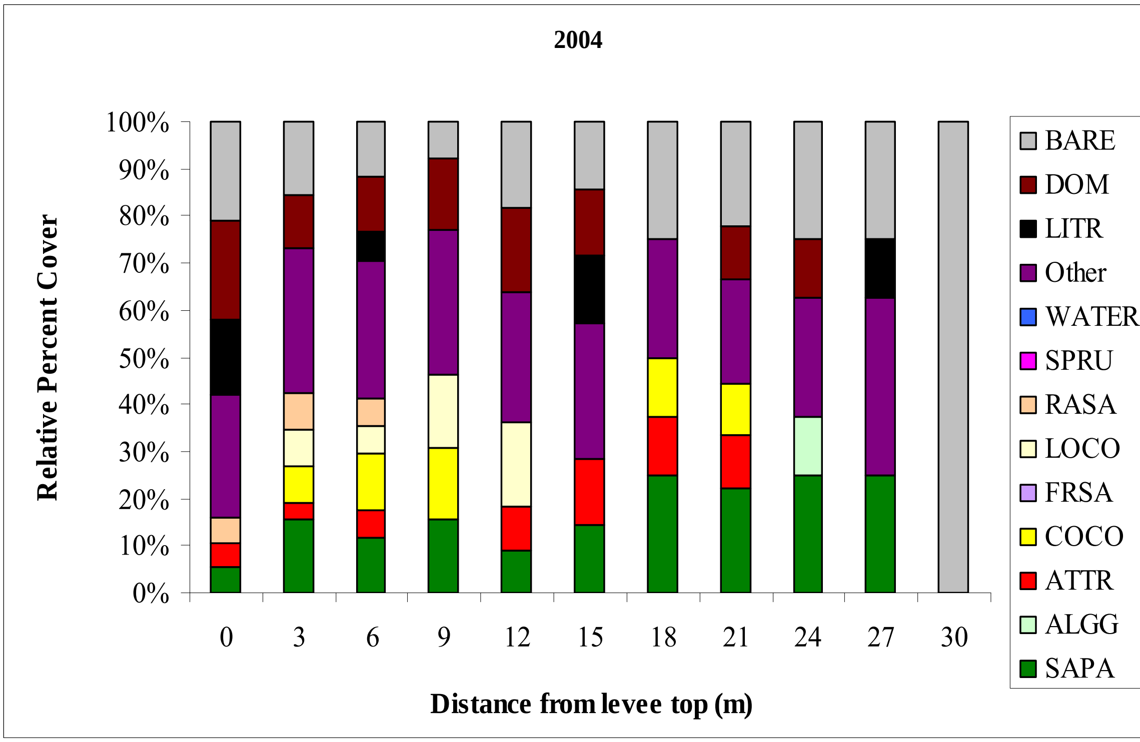


Figure 19. Relative percent vegetated cover from quadrat surveys by distance from the levee top to marsh interior from 2002 to 2006.



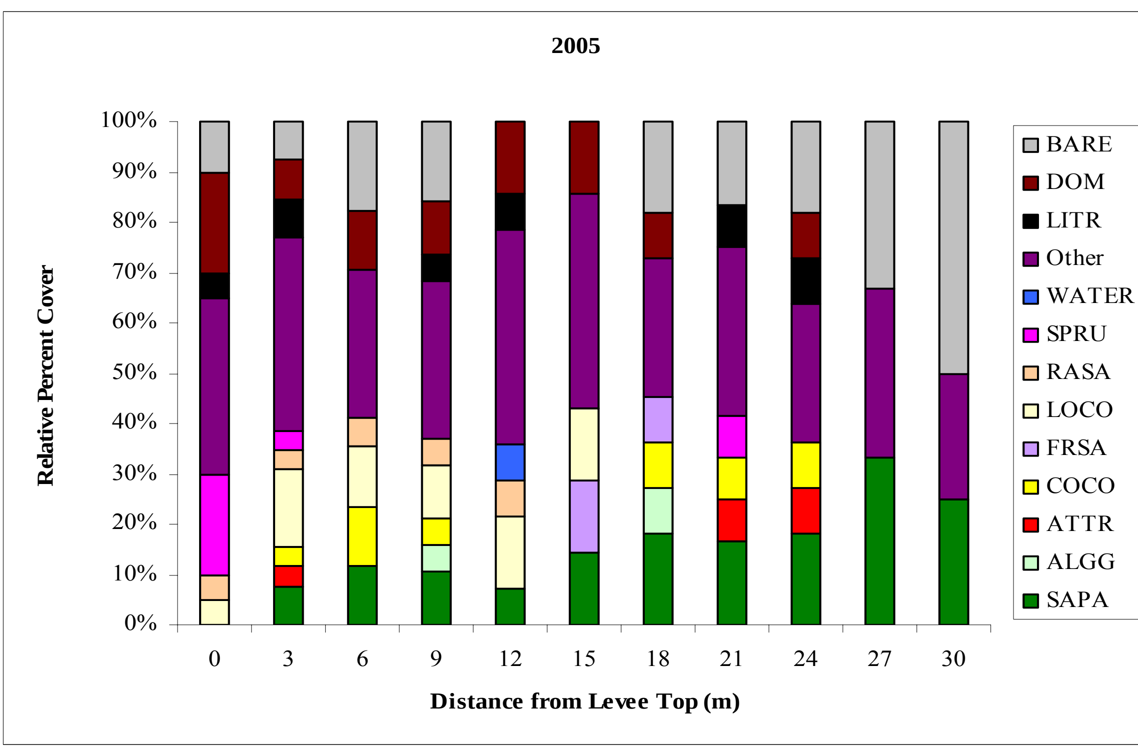


Figure 19. cont'd

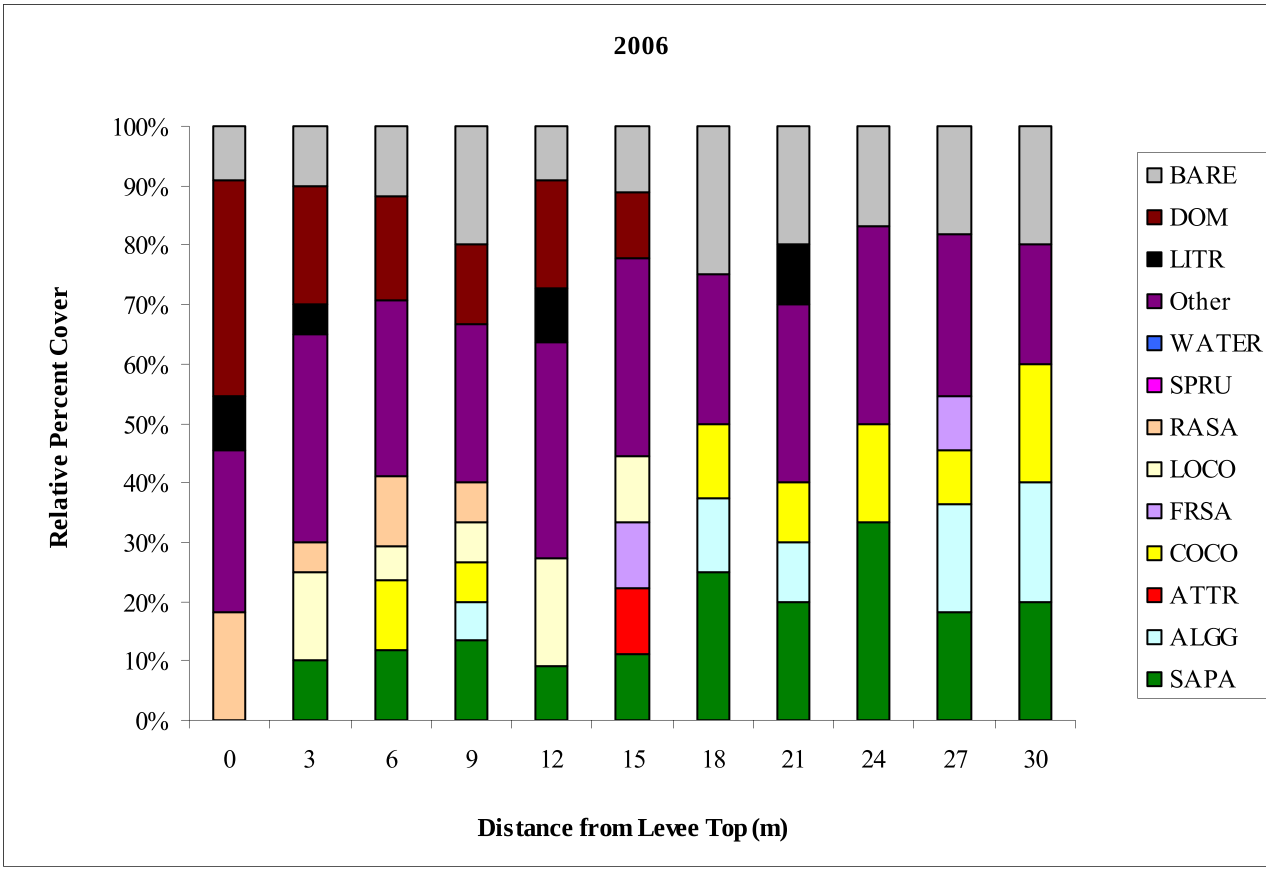


Figure 19. cont'd

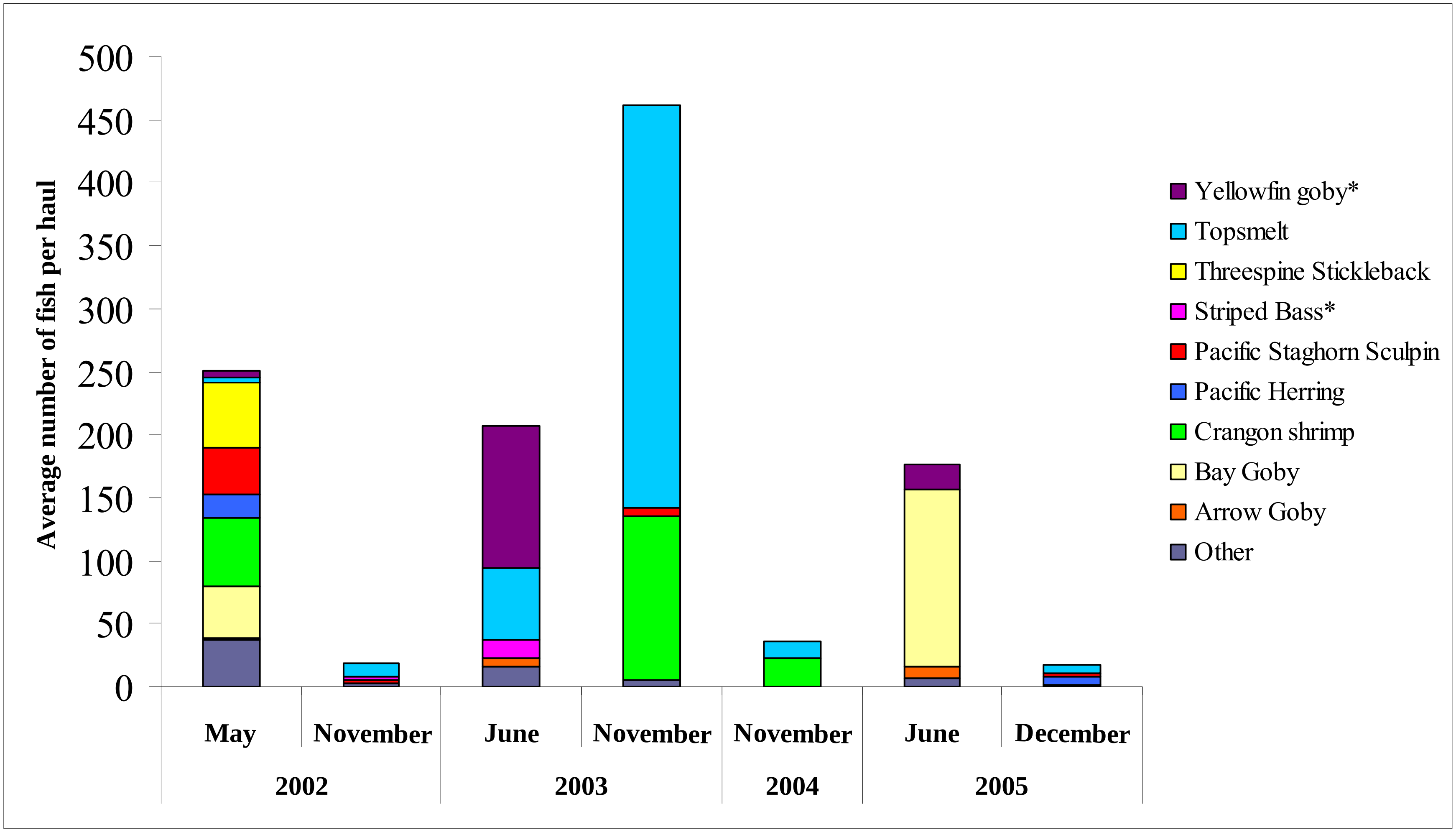


Figure 20. Total numbers of fish caught per haul between 2002 and 2005. Surveys were conducted bi-annually in spring and fall (except for the spring of 2004). Fish were caught with an 80 ft beach seine net. Category “other” captures include: American shad*, Northern anchovy, Bay pipefish, Chinese mitten crab*, Green crab*, Hemigrapsus crab, Jellyfish, Palaemon shrimp*, Rainwater killifish*, Shiner surfperch, and Starry flounder. Asterisk* denotes native fish.

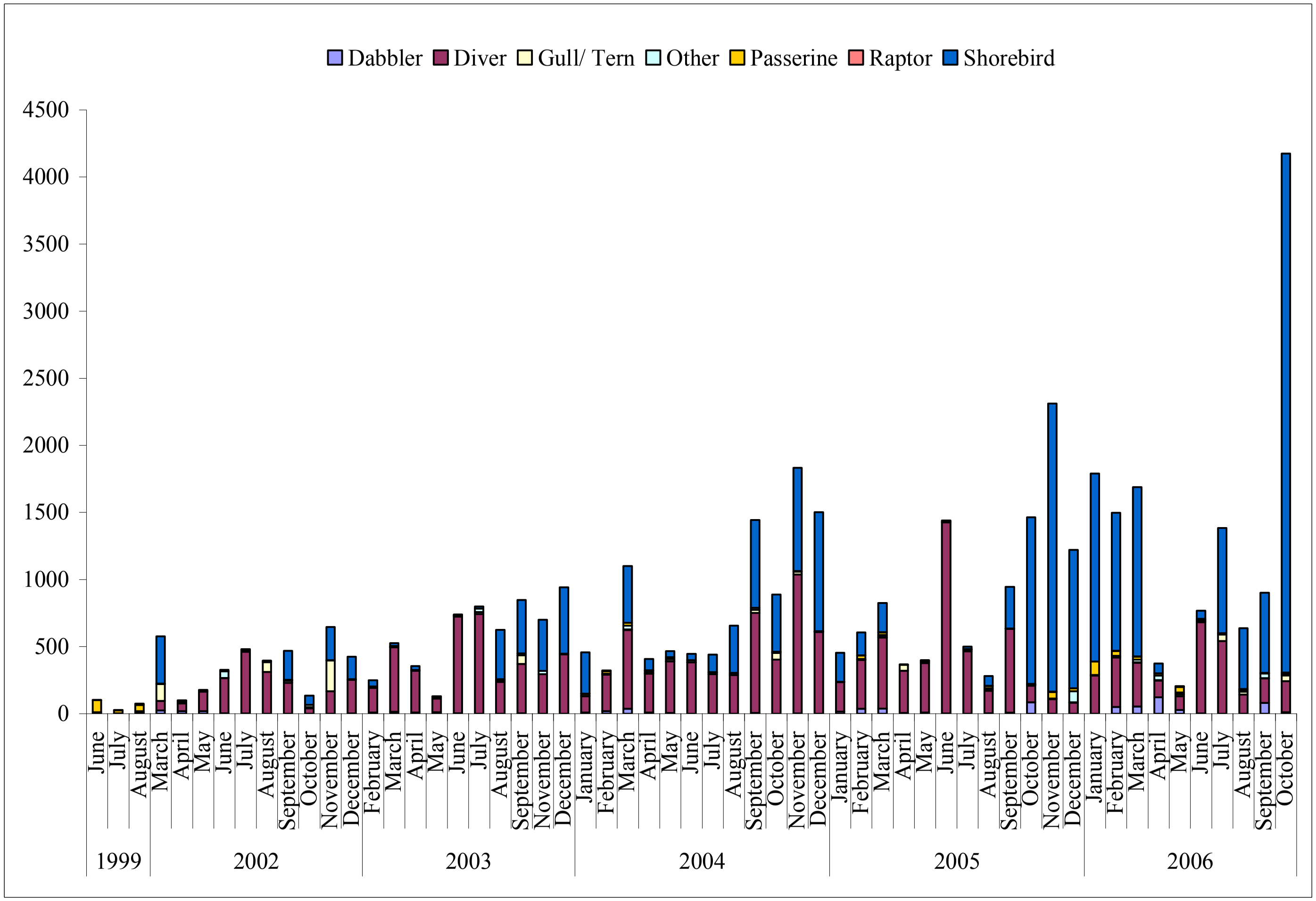
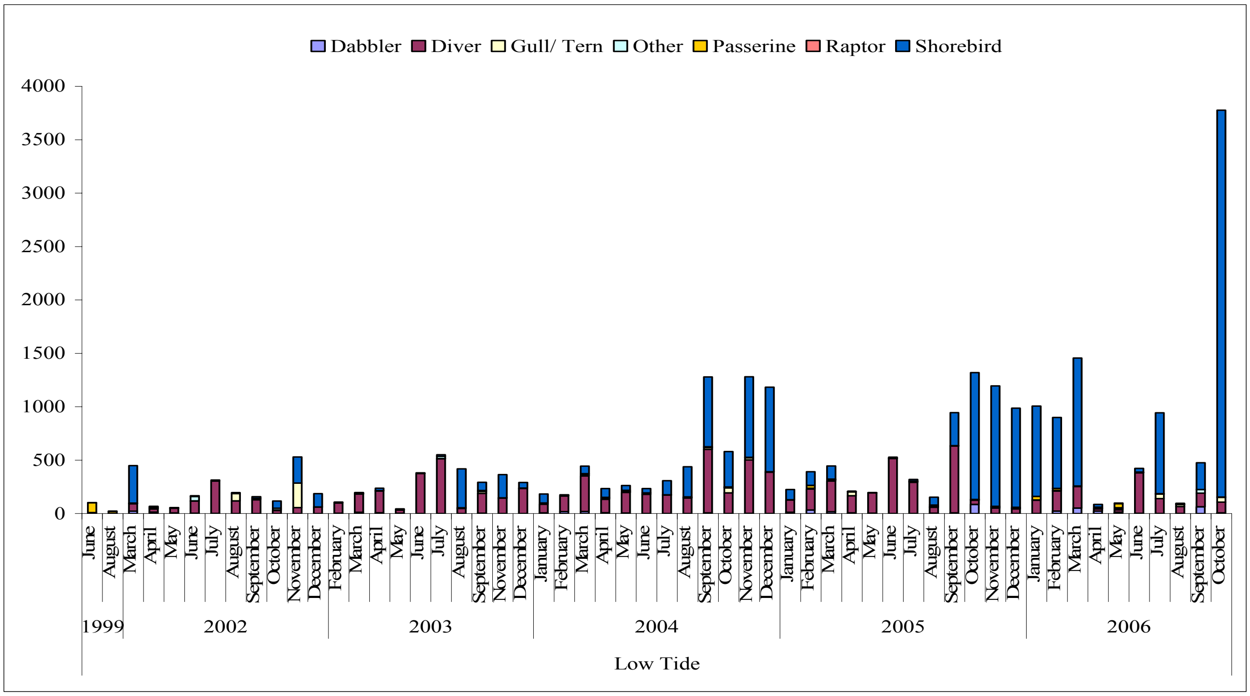


Figure 21. The total number of birds observed at Tubbs Setback is presented by guild and month. Shorebird numbers peak during the fall through spring migration, while divers are more abundant during summer months.

A. Bird numbers by month and guild during low tide.



B. Bird numbers by month and guild during high tide.

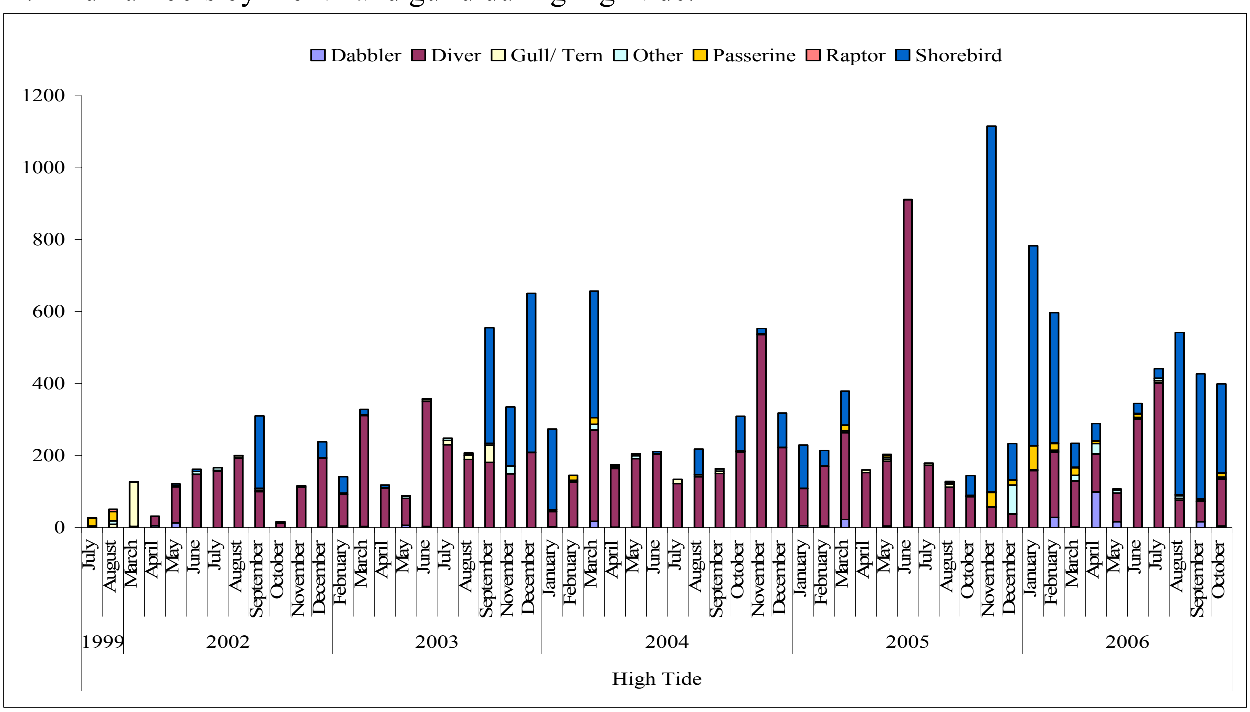
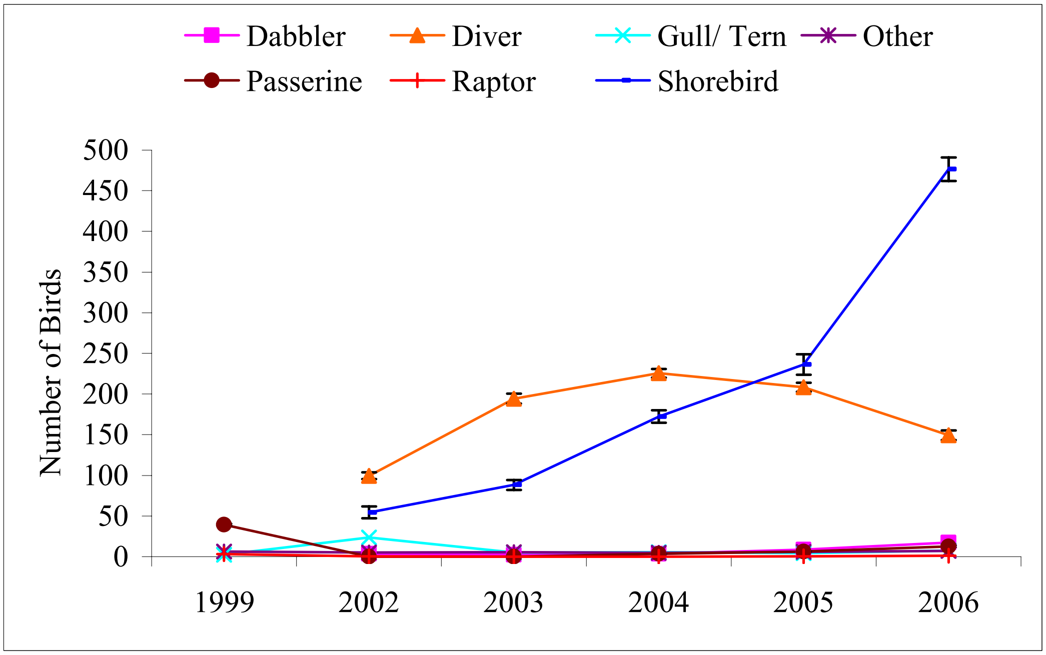


Figure 22. Monthly bird abundances by guild at Tubbs Setback at low tide (A) and high (B) tide. Other includes: American White Pelican, Black-crowned Night Heron, Canada Goose, Double-crested Cormorant, Great Blue Heron, Great Egret, Ring-necked Pheasant, Snowy Egret, and Turkey Vulture.

A. Overall average number of birds per survey.



B. Average number of birds per survey during the fall and winter migratory season.

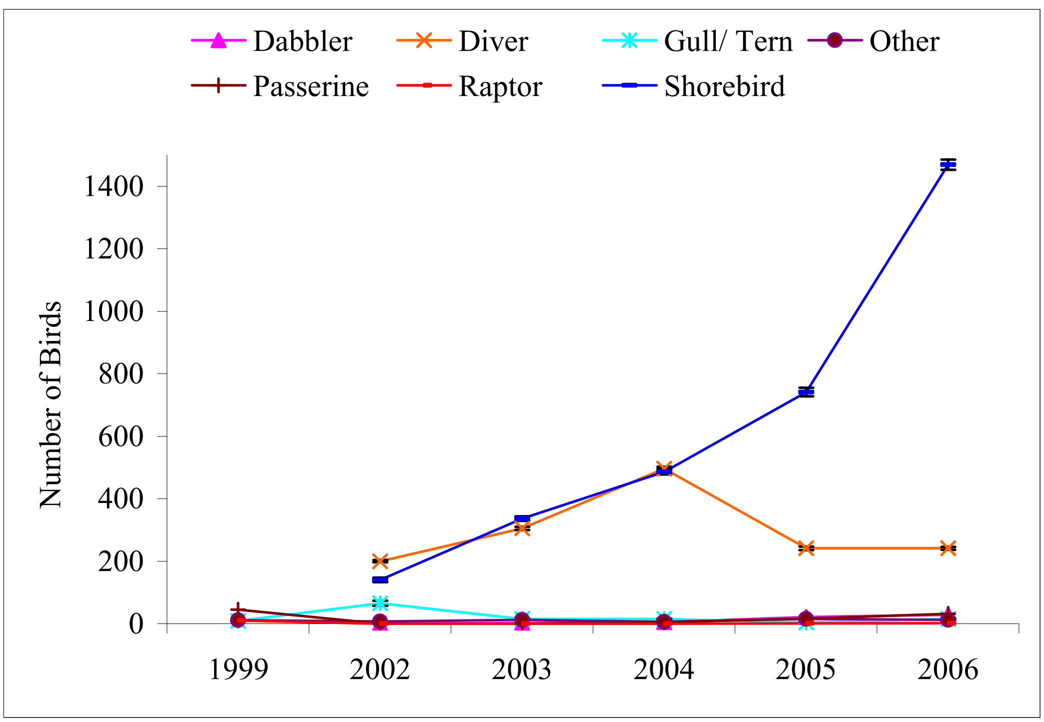


Figure 23. Average number of birds per survey (mean + standard error) detected (A) over all months and (B) during the migratory season (August – February) for 1999, and 2002 through 2006. Note different scale on each chart.

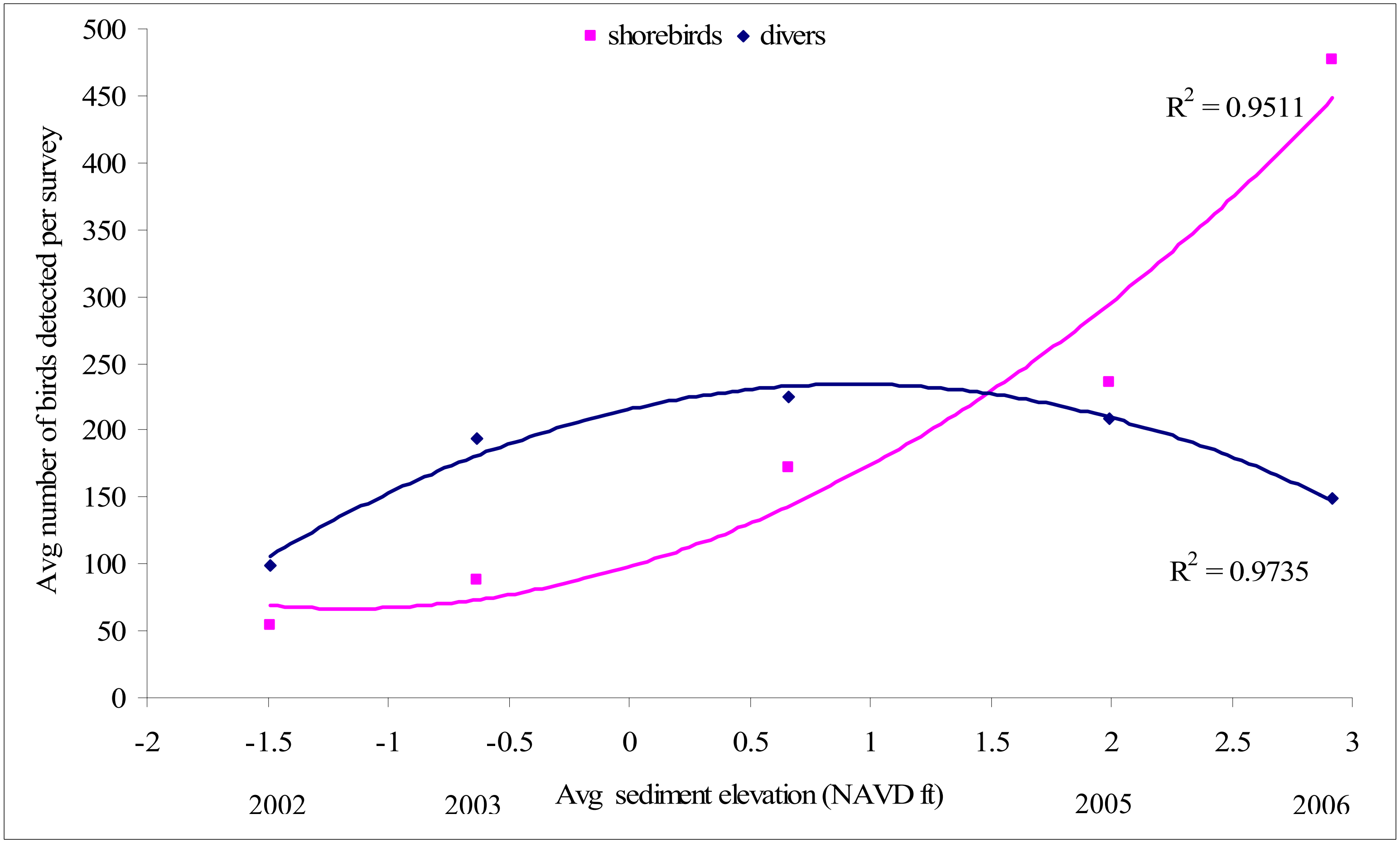


Figure 24. Average numbers of shorebirds and diving birds detected per survey as related to sediment elevation (NAVD ft) at Tubbs Setback. All data is presented as yearly averages from 2002 to 2006, and sediment data excludes land and channel sediment pins. Average numbers of diving birds peaked in 2004 and then declined while shorebird numbers increased with additional sediment deposition.