The Benicia-Martinez Restoration Project:

2007 Annual Report

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Executive Summary

In 2001, The California Department of Transportation (Caltrans) purchased 9.3 ha of former salt marsh to mitigate impacts caused during the construction of the Benicia-Martinez Bridge. In addition to the creation of 7.1 ha of marsh habitat, this project enhances tidal flow to the California Department of Fish and Game's Goodyear Slough Unit through a connective channel to the Suisun Bay. Restoring tidal flow to the project site required the removal of backfill, the excavation of an intake channel directly to Suisun Bay, and the installation of culverts under the Union Pacific Railroad line. Tidal flow was restored in October 2005.

The USGS San Francisco Bay Estuary Field Station initiated bird surveys in December 2005. In July 2006, the USGS was awarded a contract for comprehensive biophysical monitoring in order to provide information for adaptive management actions and to evaluate restoration success.

Hydrology and water quality

Water level loggers were installed within the project and in the intake channel. Daily maximum water levels within the project were approximately 0.3 ft lower than water levels in the intake channel. Minimum water levels were the same within the project and within the intake channel, indicating full tidal range. From June 2006 to June 2007, sediment pin data showed little change -0.4 $\pm$ 1.6 cm (n = 11, mean $\pm$ SE) and ranged from -14.8 cm (at sediment pin 4) to 4.8 cm (at sediment pins 6 and 9).

Geomorphology

We classified land cover using georeferenced color infrared photographs (ERDAS Imagine software, Leica Geosystems). In May 2006, total vegetative cover (tidal marsh and upland habitat types) comprised 8%, whereas bare land and bare mudflat comprised 90% of the site. We generated a bathymetry map that showed deeper water at the confluence of channels and sloughs into the intake channel (-2.7 – -0.4 ft NAVD88). The deepest portion within the project site is the channel mouth immediately adjacent to the culverts (0.7 – 1.4 ft NAVD88). The side channels are predominately in the elevation range of 2.0 – 4.3 ft NAVD88.

Soils

We measured soil compaction in the upland, marsh plain, and channel habitat types to assess soil condition for plant rooting and growth. The greatest compaction levels were consistently detected in the upland areas (range 1,070.0 – 2,421.3 kPa), followed by the marsh plain (range 97.3 - 785.3 kPa), and channel habitat types (range 17.5 – 211.0 kPa). In channels we detected zero compaction for a depth of 0 – 35 cm and first detected compaction readings at 37.5 cm to 45 cm of depth.

Vegetation

We detected a total of 22 plant species in vegetation quadrat and transect surveys conducted in July 2006 and July 2007. Native vegetation cover has increased from 9% in 2006 to 22% in 2007, while non-native cover increased from 14% to 19%, respectively. Percent cover of common pickleweed (*Sarcocornia pacifica*, formerly *Salicornia virginica*) increased from 3% in July 2006 to 7% in July 2007 and bare ground declined from 73% to 24% (quadrat survey method). Upland areas, which also had the greatest compaction readings, were dominated by invasive weeds, particularly stinkwort (*Dittrichia graveolens*).

Birds

We detected 60 avian species during 35 post-breach surveys from Dec 2005 to June 2007. The greatest number of birds occurred during a single high tide survey in Jan 2007 with 716 birds, of which 84% were shorebirds. Shorebird abundance at other tidal marshes are typically greater during low tide when a greater proportion of mudflats are exposed; however, at BenMar we detected a greater number of shorebirds at high tide (1,793 shorebirds) than at low tide (1,297 shorebirds). The non-vegetated Trichloroethylene-capped upland area was utilized as a breeding area by American avocets (*Recurvirostra americana*), black-necked stilts (*Himantopus mexicanus*), and killdeer (*Charadrius vociferus*).

Small mammals

We captured two mammal species during the Aug 2006 sampling: house mice (*Mus musculus*; 5.9 new captures/100 trap nights) and 1 deer mouse (*Peromyscus maniculatus*; 0.5 new captures/100 trap nights). In September 2007, only house mouse was detected (3.8 new captures/100 trap nights). We have not detected the endangered salt marsh harvest mouse (*Reithrodontomys raviventris*).

Introduction

The San Francisco Bay Estuary (SFBE) forms one of the largest and most urbanized estuaries in the world (Conomos 1979, Sudman 1981). Two-thirds of the remaining salt marsh ecosystems and tidal flat habitats on the Pacific coast are located in this estuary (Josselyn 1983). However, approximately 80% of historical tidal wetlands in the SFBE have been lost to filling and dredging for urban development or agricultural purposes (Nichols et al. 1986). SFBE is a critical resource for humans and biotic communities alike (Harvey et al. 1992, Goals Project 2000). SFBE is home to one of the largest shipping industries on the west coast yet remains a designated Hemispheric Shorebird Reserve Network Site of international importance for migratory shorebirds. The Bay-Delta and Central Valley support more than 18% of the North American wintering population of waterfowl. SFBE is especially renowned for its populations of diving ducks; their numbers comprise more than 50% of the birds counted along the Pacific Flyway during the winter. Many species within our estuary are currently listed as special status species (endangered, threatened, or species of special concern); including, Delta smelt *(Hypomesus transpacificus)*, Sacramento splittail (*Pogonichthys macrolepidotus*), California clapper rail (*Rallus longirostris*), California black rail (*Laterallus jamaicensis*), and salt marsh harvest mouse (*Reithrodontomys raviventris*; CDFG 2007). Ecological functions of remaining wetlands and new restorations are threatened by fragmentation, reductions in available sediment and sea level rise, contaminants, water quality and human disturbance as well as invasive species, predation and disease (Takekawa et al. 2006).

Field Site: Benicia-Martinez Wetland Mitigation

The Benicia-Martinez Wetland Mitigation site is owned by Caltrans and is located in the western shore of Suisun Bay. Suisun Bay is the largest contiguous brackish water marsh on the west coast, receiving freshwater discharges from the Sacramento and San Joaquin Rivers and tidal influence from San Francisco Bay. Suisun Marsh encompasses approximately 10% of California's remaining natural wetlands and provides important habitat for a variety of wildlife including roosting and feeding grounds for migratory waterfowl as well as nursery sites for juvenile fish.

In an effort to mitigate impacts which occurred during the construction of the Benicia Martinez Bridge Project, Caltrans initiated the Benicia-Martinez (BenMar) Mitigation and Monitoring Plan. This plan involved the creation of 7.1 ha of shallow water habitat on a 9.3 ha project site in addition to enhancing tidal flows to the adjacent Goodyear Slough Unit managed by California Department of Fish and Game (CDFG). The BenMar mitigation site is located 5 km east of Benicia on the western shore of Suisun Bay, bounded by Industrial Way and the Union Pacific Railroad (UPRR) line southwest of Lake Herman Road. The Department of Fish and Game lands are located adjacent to the project site, however, separated from the site by the UPRR line (Figure 1).

Figure 1. Benicia-Martinez Mitigation Project is located in Benicia, off Hwy 680 and Lake Herman Road.

Bringing tidal flows to the project site required the removal of fill and the creation of channels within the 9.3 ha project site, the installation of three culverts under the UPRR to reintroduce tidal waters from Suisun Bay, and the excavation of an intake channel from the bay to the project site. The intake channel also enhanced tidal flow to the CDFG property. Elevated groundwater concentration levels of trichloroethylene (TCE) existed in a sand layer on the northern portion of the upland area. This area was compacted and capped and not part of the tidal marsh restoration project.

Tidal flow was re-established in the autumn of 2005 (R. Blizard, pers comm.); however, monitoring of the site did not occur until July 2006 when USGS-Western Ecological Research Center, San Francisco Bay Estuary Field Station was awarded the monitoring contract and established a five year biological and physical monitoring plan (Table 1). This monitoring effort was designed to provide Caltrans with information for adaptive management decisions and evaluation of project success. During the preparation of this report, Caltrans biologist provided USGS with the Benicia-Martinez Mitigation and Monitoring Plan, which outlined three primary criteria for restoration success: (1) long-term tidal channel morphological stability, (2) adequate tidal prism volume and salinity circulation, and (3) establishment of a self-sustaining marshland with a vegetative success criteria of 60-80% cover within 5 years (Morton 2001).

Table 1. USGS sampling schedule and frequency.

Survey	Number of Samples	Frequency	2006	2007
Aerial photo	1 aerial	annual	May	Sept
ERDAS	1 aerial	annual	Aug	--
Photopoints	7 panoramas	annual	Jun, Sep	August
Water Levels	2 loggers	60d download	continuous	continuous
Water Quality	48 hour deployment	annual	Jun, Sep, Dec	Mar, Jun
Sediment pins	11 pins	annual	Jun, Sep, Dec	Mar, Jun
Soil Compaction	6 transects	annual	Sep/Oct	---
Elevation	4 staff gages, 11 sediment pins	biennial	---	Mar
Bathymetry	1 survey	annual	Aug	---
Vegetation	11 transects, 33 quadrats	annual	Jul	Sep
Invertebrates	27 sampled, 9 analyzed	annual	Jun	Aug
Birds	area survey, high and low tides	monthly	monthly	monthly
Small mammals	225 trap nights	annual	Sep	Sep

Here we present our findings from our initial monitoring plan. In addition, we address Caltrans mitigation goals and restoration criteria, if applicable. Discussions are currently underway to coordinate and adapt the monitoring plan to more appropriately address Caltrans mitigation goals and restoration criteria.

Methods

Sampling Framework

We designed the biological and physical monitoring within a 62.5 m x 62.5 m grid system (Takekawa et al. 2002). A grid system is useful in characterizing spatially explicit data (such as bird concentrations) without prior knowledge of where environmental features (such as mudflats or new channels) will develop. Though we assigned grid locations to all bird data, data were pooled across grids for general analyses.

Initial spatial data was collected in Universal Transverse Mercator North American Datum of 1983 Zone 10N meters (UTM NAD83). We georeferenced the aerial photographs to NAD83 in ArcGIS (ESRI, Inc.) using landmarks. These landmarks were surveyed with 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). All elevations were collected and reported in the North American Vertical Datum of 1988 (NAVD88) in feet.

Our biophysical monitoring included photodocumentation (aerial photographs georeferenced using control points, land cover classification analyses, and repeated panoramic photographs at permanent photo stations), hydrology (water level referenced to NAVD88 ft and water quality), geomorphology (surface elevations using sediment pins and bathymetry of channels, sedimentation patterns, soil compaction, soil particle size analyses, soil organic matter content, and channel morphology), vegetation (using transect and quadrat sampling methods), invertebrates (benthic invertebrates), birds (area surveys conducted at low and high tides), and small mammals (Sherman live traps for rodents and shrews) (Takekawa et al. 2002; Table 1, Figure 2).

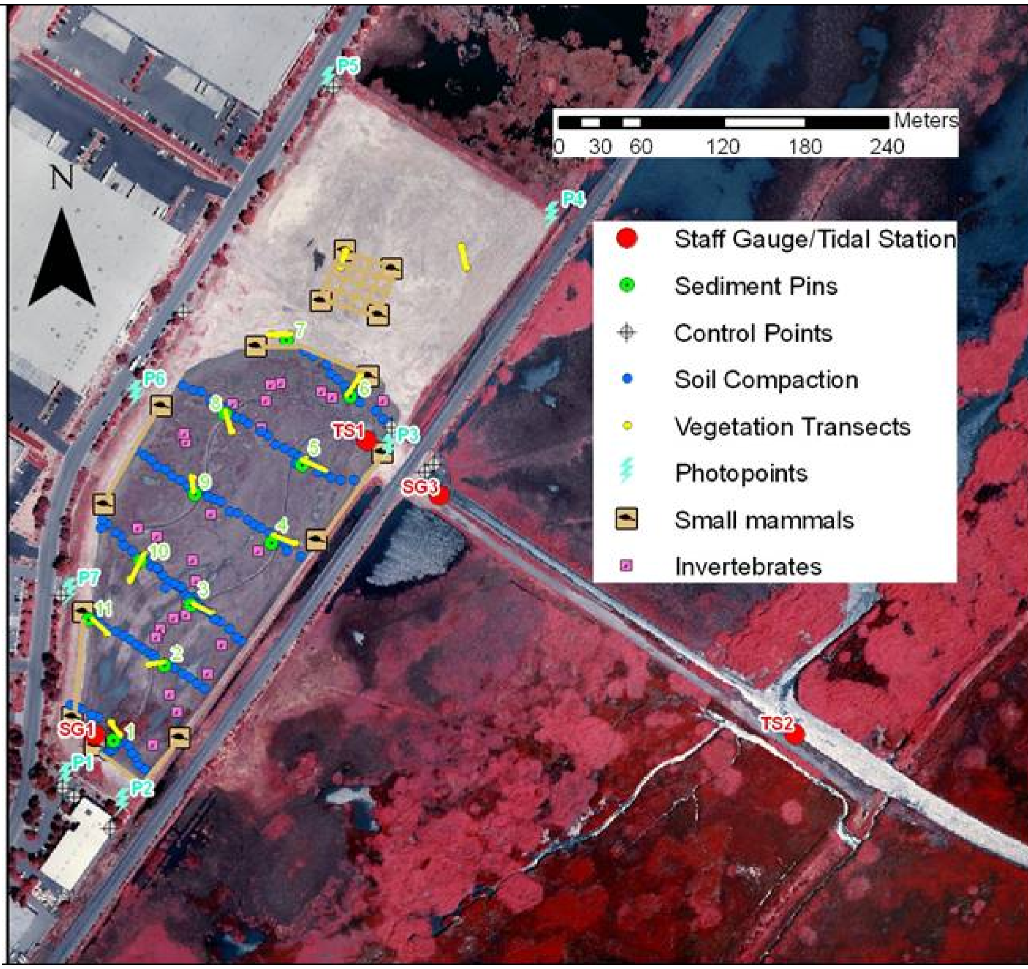


Figure 2. Location of sampling points for staff gages, water level loggers, soil compaction, sediment pins, control points, vegetation transects, photopoints, small mammal traps, and invertebrates.

Hydrology

Two tidal water level stations were installed in the interior of the project near the culvert (TS 1) and one in the intake channel to Suisun Bay (TS 2). The tidal water level system (R-2100e and WLS-31, Telog Instruments, Inc., New York) included a pressure transducer that was placed underwater near the sediment surface, a datalogger that converted water pressure to water depth and recorded data, and a staff gage in which water levels were referenced to NAVD88 ft (Figure 3). Data was downloaded every 60 days and periodic location adjustments were made due to sedimentation patterns and channel development. In addition, periodic spot checks were conducted to test for equipment functioning, sediment buildup near the sensor, and sensor drift. Loggers were moved to deeper water, if possible, when sediment buildup was detected at the sensor. Gaps in the data result from periods when the loggers malfunctioned and were replaced.

Figure 3. Tidal Water Level Station.

Water Quality

Water quality can be used to assess environmental conditions for invertebrates and fish in developing wetlands. We used a Hydrolab Minisonde water quality meter (Hydrolab-Hach Co., Loveland, CO) to record pH, conductivity (internally converted to salinity using the 1978 Practical Salinity Scale), dissolved oxygen, temperature, and turbidity. Data were collected at 15-minute intervals during a 48-hour deployment. The water quality meter was deployed at tidal station 1 (Figure 4) in Jun 06, Sep 06, Dec 06, Mar 07, and Jun 07. Instruments were calibrated prior to deployment and checked upon retrieval. Readings were taken before and after deployment in distilled water to check for any possible fouling effects by algae.

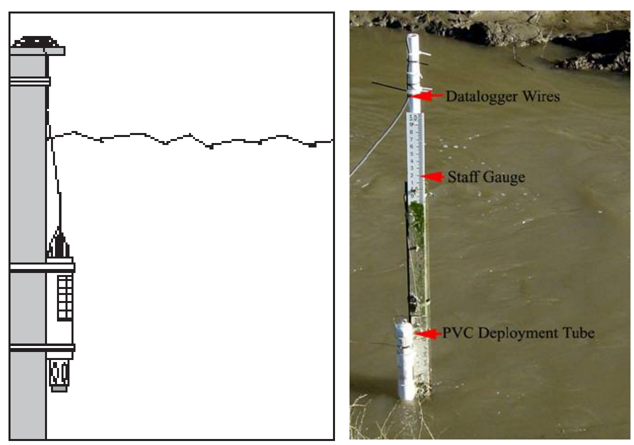


Figure 4. Water quality meter deployment on referenced staff gage within a protective PVC deployment tube.

Geomorphology

The physical features of a tidal wetland, such as land cover, can help track development over time (Mitsch and Gosselink 2000). Low level, color infrared aerial photographs were taken to distinguish land cover types. Panoramic, digital, on-the-ground photographs (photopoints) were taken at established locations annually to qualitatively document changes through time.

Aerial photograph and land cover interpretation

A low-level, color infrared aerial photograph was taken on 16 May 2006 (Figure 2). We georectified the 2006 aerial photograph to UTM NAD83 (ArcGIS; ESRI, Inc.) using permanent visual landmarks (i.e. buildings, cement barriers, etc.). We used a Trimble GeoXT Pocket Global Positioning System unit with a position dilution of precision error of < 3 (the lower the PDOP, the greater the precision) to establish landmark coordinates within the aerial photograph.

Land cover type classifications were conducted on the aerial photograph using ERDAS (Imagine software, Leica Geosystems). We initially ran unsupervised classifications in which the color signature of each pixel was analyzed and systematically grouped into 15 classifications. Unsupervised classifications often resulted in redundant information because of slight differences in color by the same land cover type. For example, vegetated areas consisted of multiple infrared colors and were automatically classified into several groups. Based on the ERDAS image, we were unable to distinguish species because the plant species had variable color signatures. With personal knowledge of the site, we were able to improve the usefulness of the aerial photograph by distinguishing five distinct major land cover types: water/shadow, tidal vegetation, upland vegetation, mudflat, and bare ground.

Photodocumentation

Ground photo points help document and describe qualitative differences in restoration progress. Digital color photographs were taken in July 2006 and August 2007 at seven permanent locations (Figure 2). At each location, several digital pictures were taken and later stitched into a panoramic photograph with Photoshop CS2 (Adobe).

Soils

Soil physical properties

Soil sampling was conducted at invertebrate sampling locations (Figure 2) to relate invertebrate species and composition to soil properties. Soils were collected in tin canisters of a known volume, weighed, and oven dried until a constant mass was achieved for soil moisture and bulk density (Brady and Weil 2001). Additional soil samples were air-dried and analyzed for pH, soil particle size, organic matter content, estimated nitrogen release, salinity, cation exchange capacity, sulfur and soil phosphorus (A & L Western Agricultural Laboratories, Modesto, CA).

Soil compaction

On 28 - 29 September and 10 October 2006, we conducted a soil compaction survey along six transects (Figure 2) using a Field Scout SC 900 digital cone penetrometer (Spectrum Technologies, Plainfield, IL; Figure 5). The penetrometer recorded the cone index or pressure (kPa) needed to push the cone-tipped rod through the soil at 2.5 cm intervals to a depth of 45 cm. Soil depth was measured using an integrated ultrasonic sensor located at the base of the meter. The penetrometer was calibrated according to manufacturer's field manual prior to field use.

Figure 5. Soil compaction meter

Sedimentation

Sediment pins

Eleven sediment monitoring pins (5 cm diameter, schedule-40 PVC) were installed in May 2006 (Figure 2). The length of the sediment pin was measured with a graduated rod (sediment pole) with a flat disk attached to the bottom to minimize sinking into soft substrates. The average of two readings taken at opposite sides of the sediment pin was reported. We surveyed the top of the sediment pins with a SmartPole GPS (Leica Geosystems) with RTKMax Service (Haselbach, Burlingame, CA) for elevations. Sediment surface elevations were calculated by subtracting the length of the sediment pin from the elevation at the top.

Bathymetry

Sediment pins provided rough measurements of sediment accretion; however, readings were limited to the 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 (Woo et al. 2006). A bathymetric survey was conducted on 21 August 2006 in the channels at BenMar. Our bathymetry system consisted of a variable frequency acoustic profiler (Navisound 210; Reson, Inc., Slangerup, Denmark), differential global positioning system unit (DGPS; Trimble, Ag132), and laptop computer mounted on a shallow-draft, flat-bottom boat (Bass Hunter; Cabelas, Sidney, NE; Figure 6). The boat was equipped with an electric trolling motor powered by a 12-v 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. Data were processed in SAS (SAS Institute 1999) and a bathymetric coverage was generated in Geostatistical Analyst (ArcGIS; ESRI, Inc.) using inverse distance weighting maps.

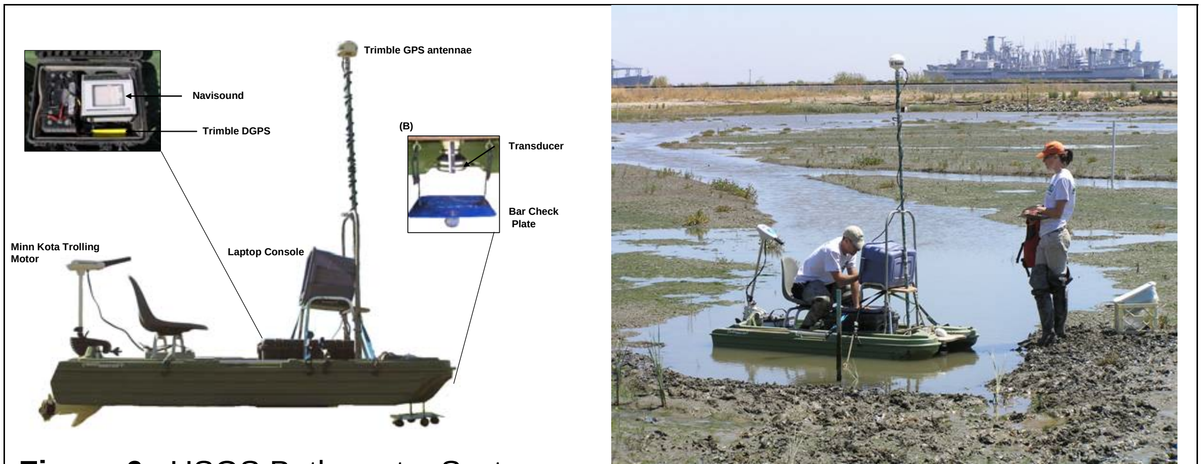


Figure 6. USGS Bathymetry System

Vegetation

Vegetation transect (13 transects) and quadrat (39 quadrats) surveys were conducted in July 2006 and July 2007 (Figure 2). Transect data was used in conjunction with quadrat sampling to increase the likelihood of detecting low-occurrence plant species (Elzinga et al. 1998), as well as decrease observer bias in percent cover estimation from quadrats. Transect surveys were conducted using the point-intercept method at 0.5 m intervals where each “hit” consisted of a plant that was identified and measured for height. Non-vegetated categories included: bare ground, litter, and water. Percent canopy cover was determined by totaling the number of “hits” per species and dividing that number by the total number of point intercepts (Elzinga et al. 1998).

A 0.25 m^2 quadrat (Figure 7) was placed along each transect at 0m, 7.5 m, and 14.5 m. Quadrat measurements consisted of species identification, visual estimates of percent cover (total ≥ 100% due to multiple canopy layers), maximum height, and rooted density (rooted individuals/m^2). Data were analyzed to determine the relative percent cover of each species in quadrants and along transects.

Figure 7. A 0.25 m^2 vegetation quadrat at BenMar.

Invertebrates

Benthic invertebrates were collected at 27 randomly generated points (ArcGIS; ESRI, Inc.) in three stratified substrate types (marsh plain, marsh panne, and channel) on 15 – 16 June 2006 and 16 – 17 August 2007 (Figure 2). At each sampling location, a single benthic core (10 cm diameter, 10 cm depth, for a volume of 785 cm^3) was collected, and then soaked in an Epsom salt solution to “relax” invertebrate parts for easier identification. Benthic cores with a high proportion of clay were soaked in a sodium hexametaphosphate solution (Calgon bath solution; Coty, New York, NY) to help break up clay particles. Samples were then sieved with a 0.5 mm mesh screen and stored in a 70% ethanol and rose-bengal dye solution. The rose-bengal stains invertebrates bright pink to allow for easier sorting. Invertebrates were stored in ethanol/rose-bengal solution and later identified to lowest taxonomic level.

Birds

Area bird surveys were conducted monthly during high (> 4.0 ft) and low tides (< 2.0 ft). Since the site is relatively small and bird species are readily identifiable by sight, we did not supplement area surveys with variable circular plot counts, which incorporate auditory cues for detection and identification. We recorded bird species, number, behavior (i.e., foraging, roosting, calling, flyover, swimming), habitat (i.e., mudflat, marsh plain, open water, aerial, upland or levee), and age class (adult or juvenile) when possible. All species were grouped into guilds for analysis (diver, shorebird, gulls and terns, etc.).

Small Mammals

Small mammal surveys were conducted using Sherman live-traps (7.7 x 9.0 x 23.0 cm) for three consecutive nights on 27 – 29 August 2006 and on 11 – 13 September 2007. We set 5 transects (10 traps per transect; each trap at 10 m intervals) and a 5 x 5 trap grid in the non-tidal portion (25 traps per grid; each trap at 10 m intervals; Figure 2). Dates were selected to avoid extremely high tides that might inundate traps. Polyester batting was placed within each trap for warmth and a wooden shingle was placed above traps to protect captured animals from exposure. Each trap was baited with a mixture of bird seed, chopped walnuts, and dried mealy worms for insectivores. We set and baited traps before dusk and checked each trap within 3 hours of sunrise the following morning. Traps remained closed during the day.

For all individual captures, we identified species, sex, age, mass (g), reproductive condition, and presence of wounds or parasites. We characterized reproductive condition by the presence and development of the testes for males, the presence and development of mammary glands for females, and whether or not the female was pregnant. We measured body length, tail length, left ear, and left hind foot for all new captures. Additional measurements were taken for the genus *Reithrodontomys*: body length, tail length, tail width at 20 mm from the base of the tail, left hind foot length, left ear length, venter coloration pattern, and bi-coloration of tail. Individuals were uniquely color-marked with paint pens to distinguish recaptures.

Results/Discussion

Hydrology

Tidal data was recorded continuously from 13 July 2006 to present at two locations: the mouth of BenMar at tidal station 1 (TS 1) and within the intake channel to Suisun Bay (TS 2, Figure 2). Here we present a subset of data comparing the water levels at TS 1 and TS 2 from August 2006 and 2007 (Figure 8).

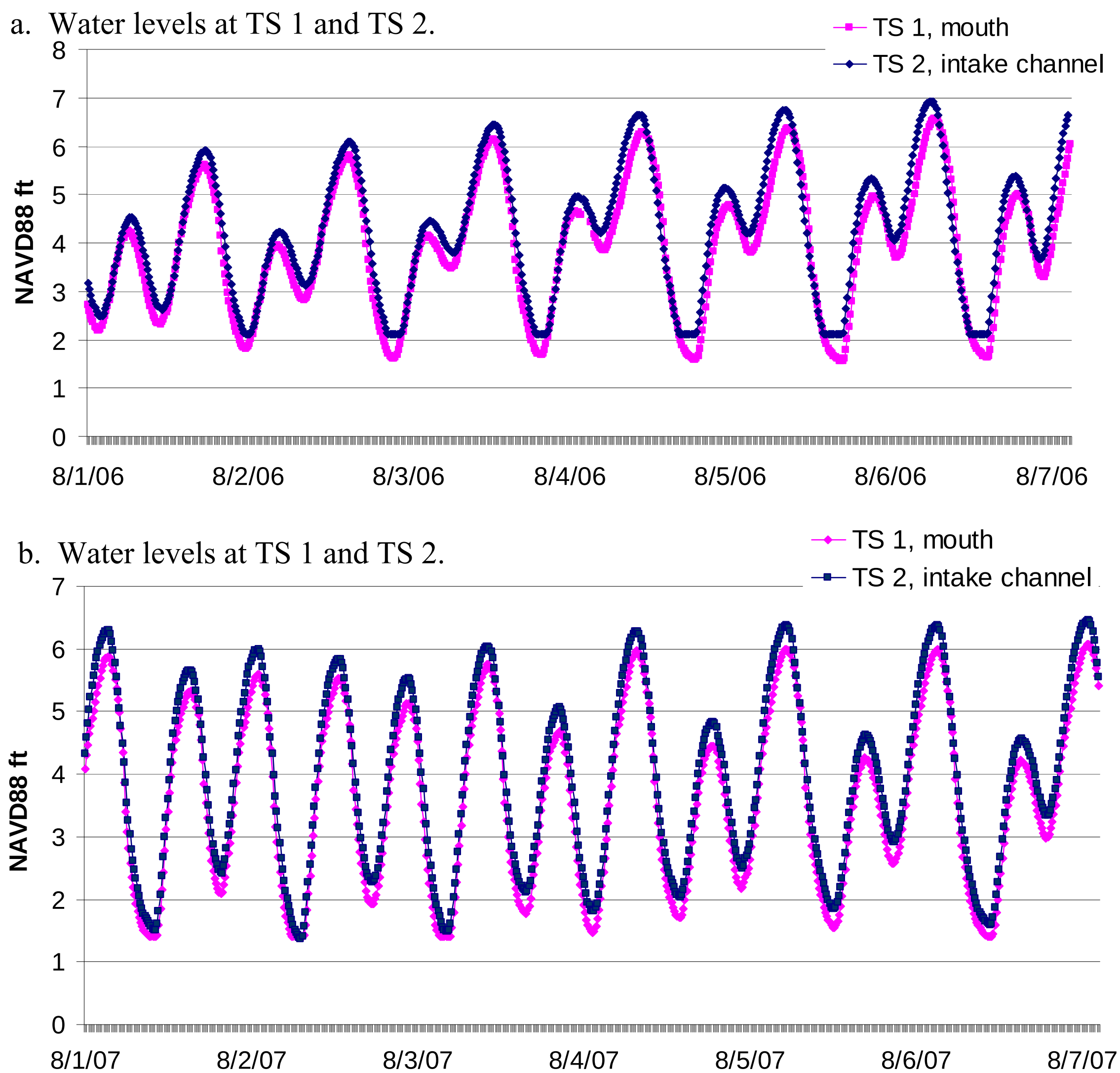


Figure 8. Water levels (NAVD88 ft) at Tidal Station 1 and Tidal Station 2 from 1 – 7 August 2006 (a) and 2007 (b).

Water levels at TS 1 were unobstructed and closely tracked the water levels in the intake channel TS 2 (Figure 8). There was little annual variation from August 2006 to August 2007. The average minimum water level at TS 1 remained constant at 1.5 ft NAVD88 in both August 2006 and August 2007. The average maximum water level was 6.0 ft NAVD88 in August 2006 and 5.8 ft NAVD88 in August 2007 (Figure 9). The daily maximum water levels in the intake channel at TS 2 remained on average 0.3 ft higher than those within the project at TS 1 from August 2006 to August 2007 (Figure 9), whereas the minimum water levels were the same at TS1 and TS2. The time delay from the predicted tides at Benicia (Tides and Currents v 2.5; Nautical Software, Inc.) to BenMar was approximately 60 minutes.

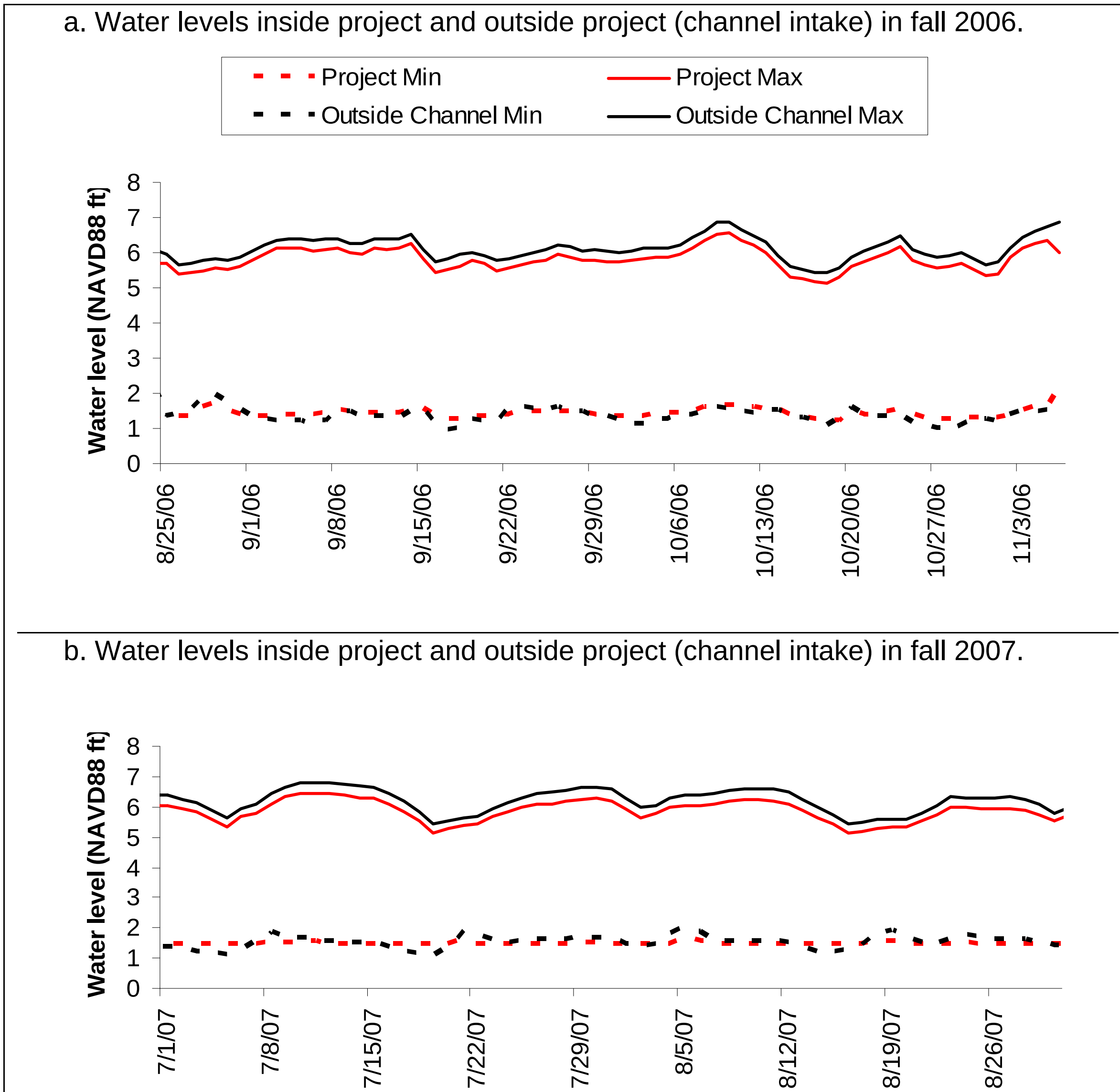


Figure 9. Daily minimum and maximum water levels (NAVD88 ft) at Tidal Station 1 (inside project, red lines) and Tidal Station 2 (outside channel, black lines) in a) fall 2006 and b) late summer 2007.

Water Quality

We deployed a water quality meter for 48-hour continuous logging session in June 2006, Sept 2006, Dec 2006, Mar 2007, and June 2007 (Table 2, Figure 10).
Water temperatures were higher in June 2006 (23.7 ± 0.3 °C) than in June 2007 (20.6 ± 0.3 °C). Daily water temperature varied appreciably in spring (11.1 degrees on 28 March 2007) and summer (14.9 degrees on 22 June 2006 and 11.0 degrees on 18 June 2007) because of warmer afternoon water temperatures, whereas in winter, the daily temperature remained relatively constant (range of 3.2 degrees on 15 Dec 2006; max 13.5 °C, min 10.3 °C). In June 2006 and 2007 maximum water temperatures typically occurred in the late afternoon (between 1600 and 1700), while the coolest water temperatures consistently occurred in the early morning (between 0700 and 0730).

While temperature varied daily and seasonally, salinity varied by season and to a lesser extent by tide. In general, salinity was greatest in summer months (12.1 ± 0.4 ppt in June 2007) due to decreased rainfall and freshwater inflow from rivers; however, the nearly freshwater conditions in June 2006 (1.8 ± 0.0 ppt in June 2006) reflected an above-average rain season with greater freshwater discharge from upstream rivers and dams. Small daily peaks in salinity seem to be more a function of higher high tides (approximately greater than 6.0 ft NAVD88). Daily salinity ranged from 0.8 to 3.2 ppt on 22 June 2006, 8.6 to 14.0 ppt on 13 Sept 2006, 9.4 to 15.1 ppt on 15 Dec 2006, 5.8 to 8.7 ppt on 28 March 2007, and 9.0 to 14.0 ppt on 18 June 2007. At lower tides, salinity levels remained relatively constant. We also detected small freshwater pulses in summer, which may reflect upstream river discharge.

Table 2. Water quality parameters (temperature, pH, specific conductivity, dissolved oxygen, turbidity and salinity) reported as mean ± standard error. Data was collected at Tidal Station 2 from June 2006 to June 2007 (see Figure 2 for locations).

			Temperature	**pH**	**Specific Conductivity**	**DO**	**Turbidity**	**Salinity**
		N	(ºC)	(units)	(mS/cm)	(% saturation)	(ntu)	(ppt)
2006	Jun	192	23.71 ± 0.32	7.45	3.38 ± 0.07	86.03 ± 2.09	46.03 ± 1.43	1.83 ± 0.04
	Sep	188	18.78 ± 0.15	7.71	16.70 ± 0.14	92.39 ± 1.96	---	9.79 ± 0.09
	Dec	164	11.29 ± 0.14	7.54	19.37 ± 0.13	87.03 ± 1.50	56.85 ± 11.20	11.49 ± 0.09
2007	Mar	116	12.69 ± 0.23	7.39	12.64 ± 0.20	94.87 ± 2.32	28.94 ± 1.70	7.27 ± 0.12
	Jun	140	20.63 ± 0.25	7.72	20.34 ± 0.22	85.64 ± 1.22	26.18 ± 5.23	12.12 ± 0.14

Spikes in the turbidity readings were presumably caused by sediment re-suspension with the incoming tide and/or high winds. pH did not vary appreciably by day or season and averaged 7.5 in June 2006 and 7.7 in June 2007. Dissolved oxygen (DO) did not differ in June 2006 and June 2007 (86.0 ± 2.1 and 85.6 ± 1.2, respectively). The California Regional Water Quality Control Board (CRWQCB) has established a DO threshold of 5.0 mg/L as an indicator of aquatic health because prolonged levels below 5.0 mg/L can impair the development of fish larvae and other invertebrates (CWT 2004). Dissolved oxygen levels were consistently above 5.0 mg/L in spring, fall, and winter. We found that daily fluctuations of DO was related to water temperature ($R^2 = 0.66$; $F_{1,190} = 370.567$; $p < 0.01$), and indeed when water temperatures were high in June 2006 and June 2007, DO levels temporarily fell below 5.0 mg/L. On 22 June 2006 we recorded 7 hours of DO levels < 5.0 mg/L (average DO level, 4.6 mg/L) and on 23 June 2006 we recorded only 1 hour of DO levels < 5.0 mg/L (average DO level, 4.8 mg/L). On 18 June 2007, we recorded nearly 2 hours when DO levels averaged 4.8 mg/L.

Though the US Environmental Protection Agency established a dissolved oxygen threshold of 5.0 mg/L, dissolved oxygen levels lower than this threshold can naturally occur in estuaries (MD DNR 2002). In recognition of this natural variation, the CRWQCB evaluated the dissolved oxygen compliance in the San Francisco Bay Salt Ponds and revised the trigger threshold for corrective action and reporting if the 10^{th} percentile of discharge waters fell below 3.3 mg/L (CRWQCB 2005). Though this threshold is specific for the South Bay saltponds, dissolved oxygen conditions at BenMar were well above 3.3 mg/L. Over all readings at BenMar, DO levels averaged 8.5 mg/L and fell below the threshold in 39 readings out of 925 readings (4% of the time). The lowest recorded DO level was 3.9 mg/L and the overall average of readings that fell below the threshold was 4.7 $\pm$ 0.04 mg/L.

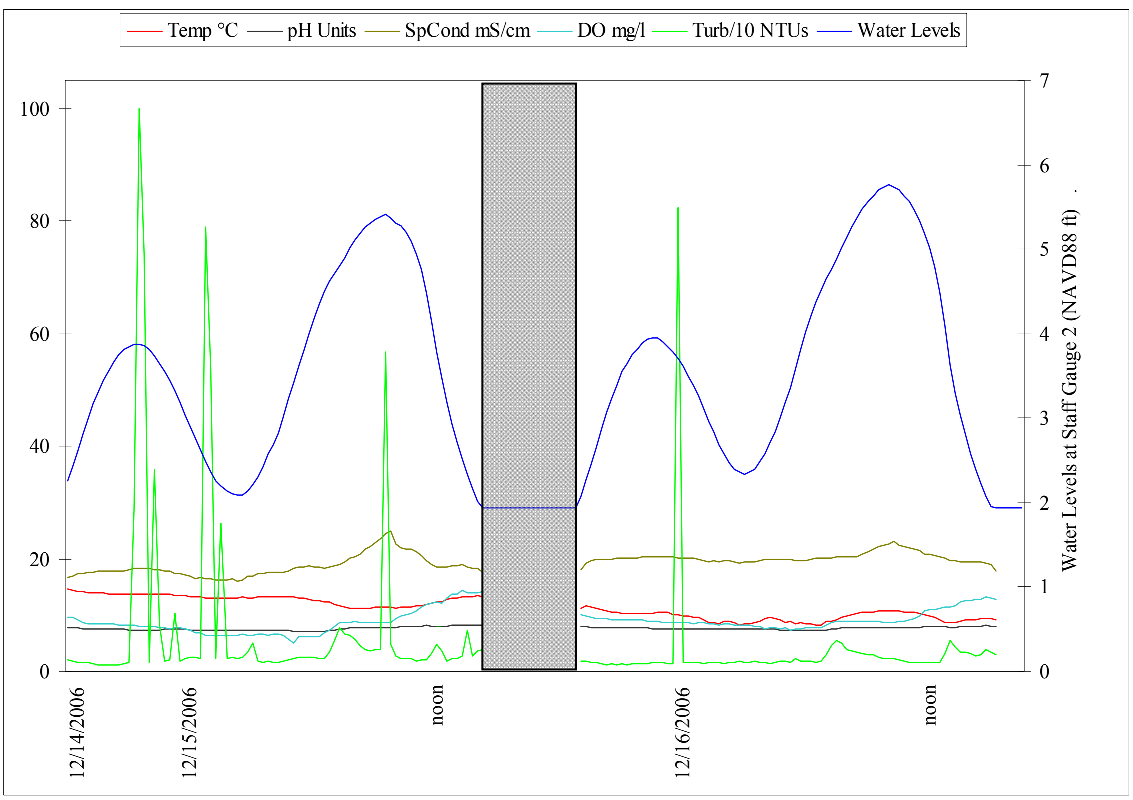


Figure 10. Water quality data from 14 – 16 December 2006. Temperature (°C), pH, specific conductivity (mS/cm), dissolved oxygen (mg/L), and turbidity (divided by 10 for scale) are presented on the primary Y axis and water levels are presented on the secondary Y axis (NAVD88 ft). The dark bar shows a period when water levels were below the level of the water quality sensors.

Geomorphology

Aerial photograph and land cover interpretation

Aerial photographs provide useful information in characterizing and quantifying restoration changes over time. We georeferenced and analyzed the 2006 aerial photograph using ERDAS Imagine software to classify land cover types (Figure 11). Bare areas composed the largest cover type (46%), followed by mudflat (44%), tidal/upland vegetation (5%), tidal marsh vegetation (3%), and water (2%). This method is useful in establishing early baseline of vegetation colonization and quantifying changes in vegetative cover in subsequent years.

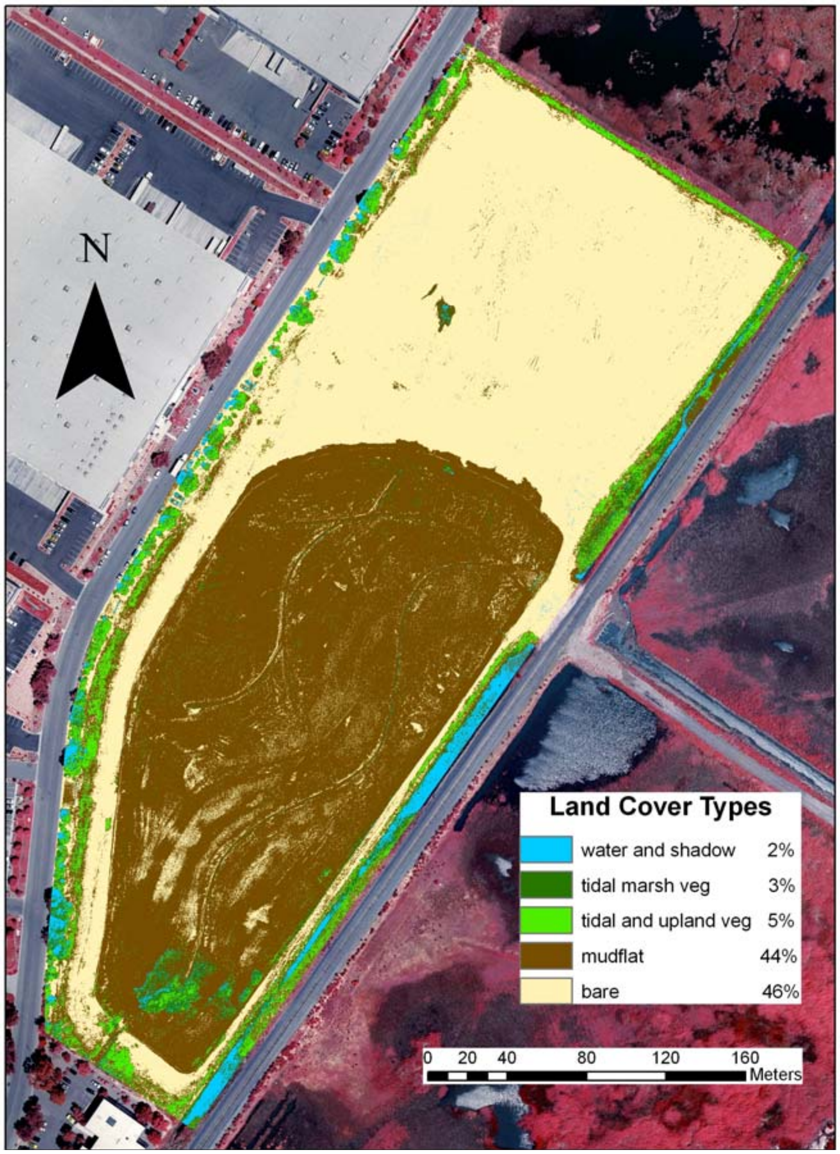


Figure 11. Five main cover classifications were generated from a color infrared photograph in 2006: water and shadow (2%), tidal marsh vegetation (3%), tidal and upland vegetation (5%), mudflat (44%), and bare (46%; ERDAS Imagine software).

Photodocumentation

We took annual panoramic photographs at seven permanent locations in July 2006 and August 2007 (Figure 2). The 2006 images clearly show that the upland portions of the site were dominated by the non-native weed stinkwort (*Dittrichia graveolens*) and that vegetation colonization within the upland TCE-capped area was bare (Figure 12). This largely bare area, was utilized by American avocets for breeding. The 2007 images qualitatively show the amount of vegetation establishment within the marsh plain, which was dominated by common pickleweed (*Sarcocornia pacifica*) and brass buttons (*Cotula coronopifolia*).

Photopoint 4) Northeast corner in 2006

Photopoint 4) Northeast corner in 2007

Figure 12. Photopoints provide qualitative documentation of change over time. At photopoint 4, we see increased vegetative growth in 2007.

Soils

Soil physical properties

Nine soil samples were taken from locations in the channel, marsh plain and marsh panne, adjacent to areas where benthic invertebrate cores were collected. Soil pH was rather neutral within channel and panne sites (6.7 $\pm$ 0.3 and 6.3 $\pm$ 0.1, respectively; Table 3), which is typical of most tidal wetland soils (Ponnamperuma 1972) and areas that are regularly flooded and drained (Mitsch and Gosselink 2000). In contrast, the soil pH within the marsh plain was slightly more acidic (5.1 $\pm$ 0.5) than the channel or panne areas. The process of organic matter decomposition can lower soil pH (Oades 1988); however, BenMar soils are well above a value of pH 4, a level that can be too acidic and detrimental to salt marsh plants (Zedler 2001).

Table 3. Soil analysis (pH, % soil moisture, bulk density, % particle size, organic matter and Phosphorus) reported as mean $\pm$ standard error. Data was collected at invertebrate locations in June 2006 (n = 9; see Figure 2).

	Channel	**Plain**	**Panne**
pH	6.7 $\pm$ 0.3	5.1 $\pm$ 0.5	6.3 $\pm$ 0.7
% Soil moisture	78.8 $\pm$ 21.6	25.0 $\pm$ 4.0	82.4 $\pm$ 28.7
Bulk density[1]	0.8 $\pm$ 0.1	1.3 $\pm$ 0.1	0.9 $\pm$ 0.2
% Particle Size			
Sand	23.7 $\pm$ 3.7	41.0 $\pm$ 8.3	33.3 $\pm$ 1.5
Silt	32.0 $\pm$ 1.2	28.7 $\pm$ 5.9	27.7 $\pm$ 1.9
Clay	44.3 $\pm$ 4.7	30.3 $\pm$ 4.1	39.3 $\pm$ 2.0
Soil Texture	Clay	Sandy Loam	Sandy Loam
Organic Matter			
% Rating	3.4 $\pm$ 0.4	2.5 $\pm$ 0.4	3.2 $\pm$ 0.7
ENR (lbs/A)[2]	97.0 $\pm$ 8.0	80.3 $\pm$ 8.7	94.7 $\pm$ 14.5
Phosphorus (lbs/A P_2O_5)			
P1 (Weak Bray)	9.2 $\pm$ 0.6	25.3 $\pm$ 1.5	14.7 $\pm$ 0.7
$NaHCO_3$-P (Olsen Method)	84.2 $\pm$ 0.3	78.2 $\pm$ 3.8	55.2 $\pm$ 1.2

[1] Based on dry weight (g)
[2] Estimated Nitrogen Release (pounds/acre)

Percent soil moisture varied among all locations with channels and pannes containing greater levels of water than the marsh plain (Table 3). The channels and pannes within BenMar are regularly inundated due to tidal flow, maintaining high soil saturations. Soil bulk density is associated with soil compaction and depends largely on soil particle size, soil organic matter, and interstitial pore space. Plant growth is affected by pore space, which provides space for the storage and transmission of water and air in which roots can grow (Brady and Weil 2001; Oades 1984). Soil bulk density had minor differences among locations with the greatest bulk density detected in the marsh plain (1.3 $\pm$ 0.1 g/cm^3), followed by panne (0.9 $\pm$ 0.2 g/cm^3), and channel (0.8 $\pm$ 0.1 g/cm^3). In comparison, a typical medium-textured mineral soil may have a bulk density of 1.3 g/cm^3 (Brady and Weil 2001).

Natural salt marshes tend to fall within the clay to clay-loam soil particle size categories (Zedler 2001). The soil textures within BenMar consisted of clay (channel) and sandy loam (plain and panne). The marsh plain consisted of more sandy soil particles, which may be insufficient for holding nutrients (cation exchange capacity) for optimal plant growth. Indeed, the cation exchange capacity was greater in the channel substrates (40.4 $\pm$ 1.8) that consisted of fine clay particles as opposed to marsh plain and panne substrates that were more sandy (27.3 $\pm$ 0.1, 31.8 $\pm$ 1.5, respectively). Organic matter and cation exchange capacity will likely improve with time (Brady and Weil 2001).

Organic matter is important in the formation and stabilization of soil aggregates and in the enhancement of plant growth during decomposition when nitrates and phosphates are made available (Brady and Weil 2001). The estimated release of nitrogen into the soil for channels, plains and pannes are 97.0, 80.3 and 94.7 lbs/A^2, respectively. Phosphorus was found in very low levels within all three strata based on the Weak Bray P1 soil test (Table 3; Buchholz 1983). BenMar soils are new and as the restoration progresses, we expect to find increased levels of organic matter and cation exchange capacity.

Soil compaction

Significant soil compaction can reduce interstitial pore space, reduce soil water content, and create an environment that can restrict root growth and nutrient uptake in plants (Hammit 1998; Brady and Weil 2001). To determine optimal soil conditions for plant growth, we conducted a soil compaction survey in 2006. Soil compaction profiles were measured from 0 to 45 cm deep in four different substrate types: upland (n = 3), marsh plain (n = 80), and channel (n = 3). The greatest compaction levels were consistently detected in the upland areas (range 1,070.0 to 2,421.3 kPa; Figure 13). The marsh plain areas had much lower and less variable soil compaction readings (range 97.3 to 785.3 kPa) and the channels showed no compaction from 0 - 35 cm, but from 37.5 - 45 cm of depth we were able to detect compaction readings (range 17.5 to 211.0 kPa). When soils are compacted, soil particles are pushed closer together and pore space is reduced. Soil compaction makes it difficult for roots to penetrate through the soil. In general, soil compaction values > 2,000 kPa inhibit root growth. Increased soil compaction can also lead to a lower rate of water infiltration into the soil. The upland areas are highly compacted, even within the top 15 cm of plant rooting depth, which may limit plant growth or promote the growth and spread of weedy vegetation.

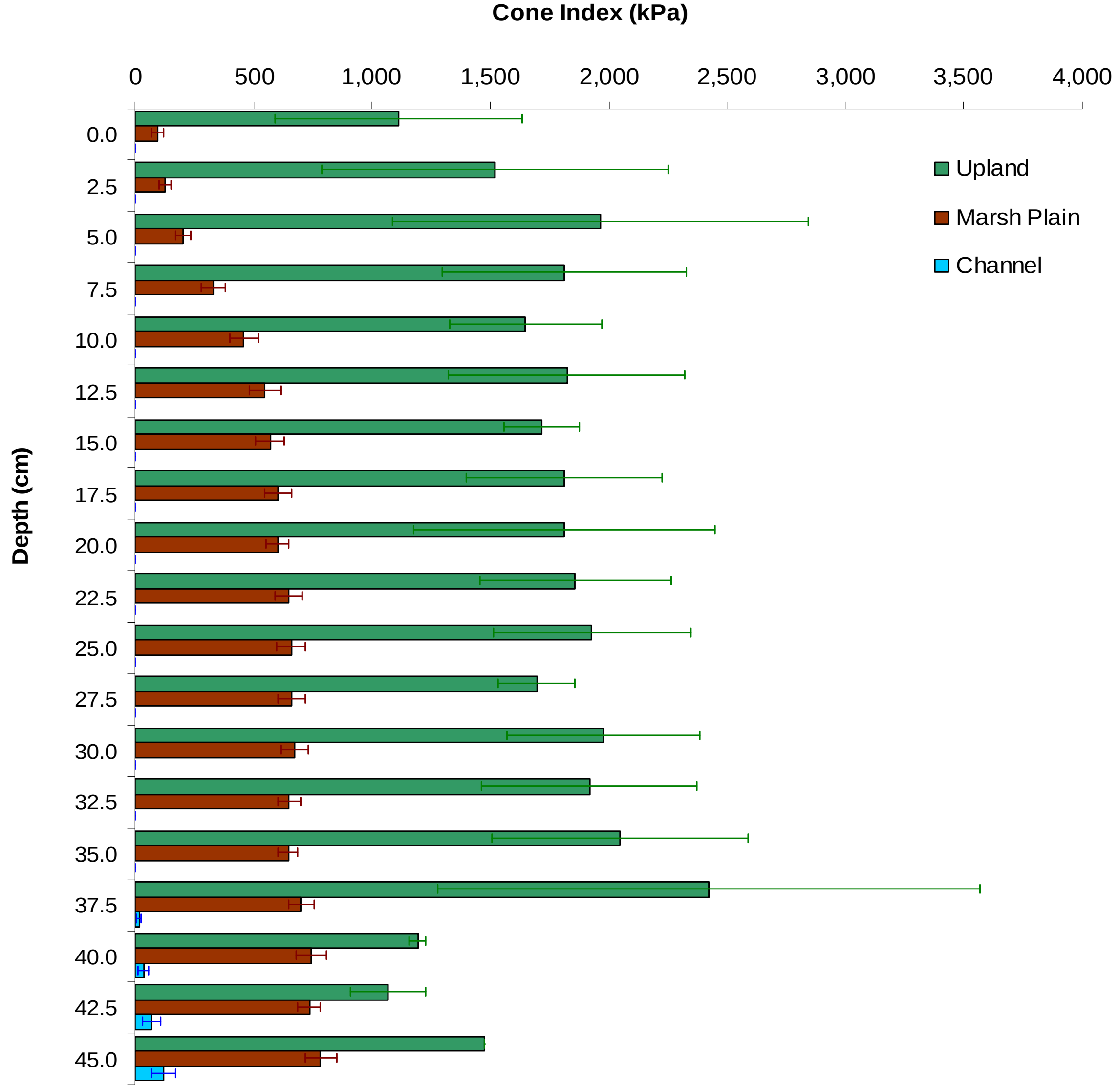


Figure 13. Soil compaction levels (kPa) by depth and substrate type: upland, marsh plain and channel.

Sedimentation

Sediment pins

We measured sediment accumulation using sediment pins during the summer, fall, and winter of 2006 and spring and summer of 2007 (n = 11) to the nearest 0.5 cm. Sediment elevations did not change dramatically in any of the three groups of sediment pins (marsh plain, channel and upland) from June 2006 to June 2007 (Figure 14). Sediment levels in the marsh plain (4.5 $\pm$ 0.3 ft NAVD88 in June 2006 and June 2007), channel (3.1 $\pm$ 0.2 ft NAVD88 in June 2006; 2.8 $\pm$ 0.2 ft NAVD88 in June 2007), and upland (6.2 $\pm$ 1.1 ft NAVD88 in June 2006 and June 2007) did not vary significantly in one year. Overall sediment change averaged -0.4 $\pm$ 1.6 cm using sediment pin data (n = 11) and ranged from -14.8 cm (at sediment pin 4, channel) to 4.8 cm (at sediment pins 6, marsh plain; and 9, channel) from June 2006 to June 2007. Elevation data were not obtained before or soon after the restoration of tidal flow (USGS contract was initiated approximately 1 yr after construction was completed). However, soil compaction data within the channels indicate that initial sedimentation rates may have been significant. We did not detect any soil compaction readings within channels until a depth of 37.5 cm. Assuming that the excavated channels would have a hard, detectable bottom, loose unconsolidated sediment may have accumulated within channels by 37.5 cm within a year (Figure 13, Figure 14). Sediment deposition and changes through time are critical parameters that help determine the progress of tidal marsh restoration projects. USGS developed a shallow water bathymetry system for increased spatial resolution for sedimentation patterns.

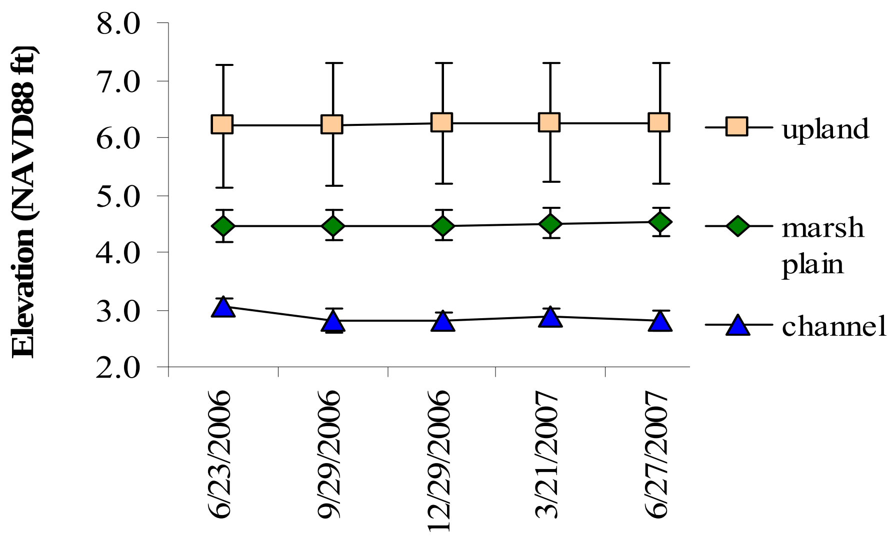


Figure 14. Average sediment elevations (± SE; NAVD88 ft) by habitat type from Jun 2006 to Jun 2007.

Bathymetry

Our August 2006 bathymetry surveys quantified channel elevations that were not detected using sediment pins. The bathymetry map (Figure 15) shows that the deepest area of the mitigation site was near the culverts leading under the railroad tracks to the outer channel (0.7 ft NAVD88). The intake channel is approximately 0.5 km from the bay to the mitigation site and the thalweg ranges from -2.7 – 0.7 ft NAVD88. Deeper water areas are located at the confluence of sloughs as they enter the intake channel. In contrast, the channel thalweg within the site range from 0.7 – 4.3 ft NAVD88. The deepest portion within the project site is the channel mouth immediately adjacent to the culverts (0.7 ft – 1.4 ft NAVD88). The side channels are predominantly in the elevation range of 2.0 ft – 4.3 ft NAVD88.

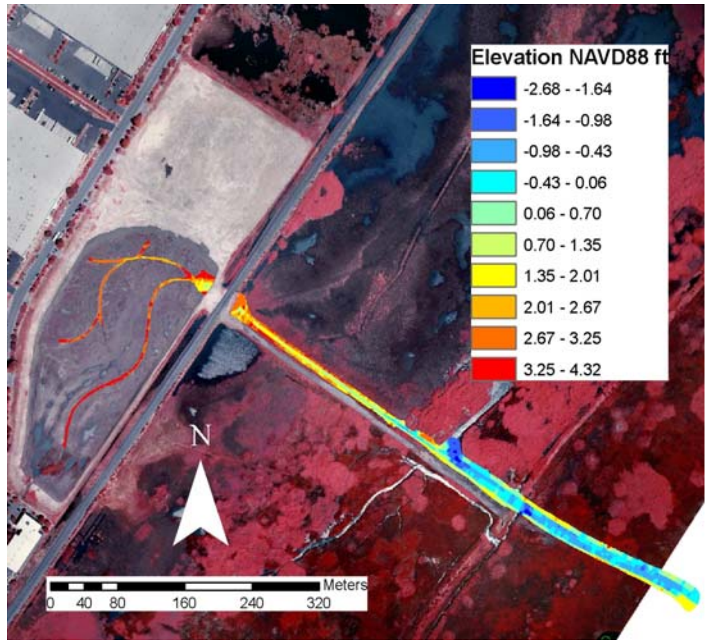


Figure 15. Bathymetric surveys at the BenMar in Aug 2006 show sediment surface elevation (NAVD88 ft). The bathymetric map was restricted to the channels where there was sufficient water.

Vegetation

Twenty-two plant species were detected within the BenMar Restoration Site between July 2006 and 2007 (Table 4). Common plant species found included *Atriplex triangularis*, *Cotula coronopifolia, Dittrichia graveolens, Lepidium latifolium, Sarcocornia pacifica,* and *Typha sp.,* of which two are native: *Atriplex triangularis* and *Sarcocornia pacifica.* Increasing pickleweed (*S. pacifica*) cover is an important outcome of restoration because it functions as cover and a food resource for tidal marsh species. We used both quadrat and point intercept transect methods to assess percent cover. Relative percent cover of pickleweed increased from 3% in July 2006 to 7% in July 2007 (quadrat survey methods). Brass buttons (*C. coronopifolia*) and cattail (*Typha sp.*) also increased over the same period from <1% to 6% and 5% to 6% respectively. Bare ground declined from 73% to 24% (Figure 16). In the point intercept transect method, pickleweed increased from 3% to 7% between 2006 and 2007. Brass buttons increased from <1% to 8%, and bare ground decreased from 69% to 22% (Figure 17). The point intercept method is not well suited to detect rare or low cover species due to a low probability that the pole will hit one. However, when combined with quadrat sampling, the likelihood of detecting low-occurrence plant species increases (Elzinga et al. 1998).

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

Spp. Code	Common Name	Scientific Name	Native[1]	Invasive[1]
ATTR	Fat hen	*Atriplex triangularis*	Y	N
BRHO	Soft chess	*Bromus hordeaceous*	N	N
RASA	Wild radish	*Raphanus sativus*	N	N
CESO	Yellow star thistle	*Centaurea solstitialis*	N	Y
CIVU	Bull thistle	*Cirsium vulgare*	N	Y
COCO	Brass buttons	*Cotula coronopifolia*	N	N
CYCA	Artichoke thistle	*Cynara cardunculus*	N	Y
FOVU	Common Fennel	*Foeniculum vulgare*	N	Y
DIGR	Stinkwort	*Dittrichia graveolens*	N	N
LELA	Perennial pepperweed	*Lepidium latifolium*	N	Y
LOMU	Italian rye grass	*Lolium multiflorum*	N	Y
LOPE	Perennial rye grass	*Lolium perenne*	N	N
PHAU	Common reed	*Phragmites australis*	Y*	Y
PIEC	Bristly oxtongue	*Picris echioides*	N	N
POMO	Rabbitfoot beardgrass	*Polypogon monspeliensis*	N	N
POSP	Knotweed	*Polygonum sp.*	N	N
RASA	Common wild radish	*Raphanus sativus*	N	N
SAPA	Pickleweed	*Sarcocornia pacifica*	Y	N
SCPU	Common threesquare	*Schoenoplectus pungens*	N	N
SCSP	Bulrush	*Schoenoplectus sp.*	Y	N
SPMA	Sand spurrey	*Spergularia macrotheca*	Y	N
SPSP	Sand spurrey	*Spergularia sp.*	Y	N
TYAN	Narrow-leaved cattail	*Typha angustifolia*	N	N
TYSP	Cattail	*Typha sp.*	N	Y
ALGB	Brown algae	*N/A*		
ALGG	Green algae	*N/A*		
BARE	Bare ground	*N/A*		
DOM	Dead & standing	*N/A*		
LI	Litter (dead & not standing)	*N/A*		
MF	Mudflat	*N/A*		
OPWA	Open water	*N/A*		
UNKN	Unknown	*N/A*		
WR	Wrack	*N/A*		

[1]Y = yes, N =no

*Native or non-native not determined, but both potentially invasive.

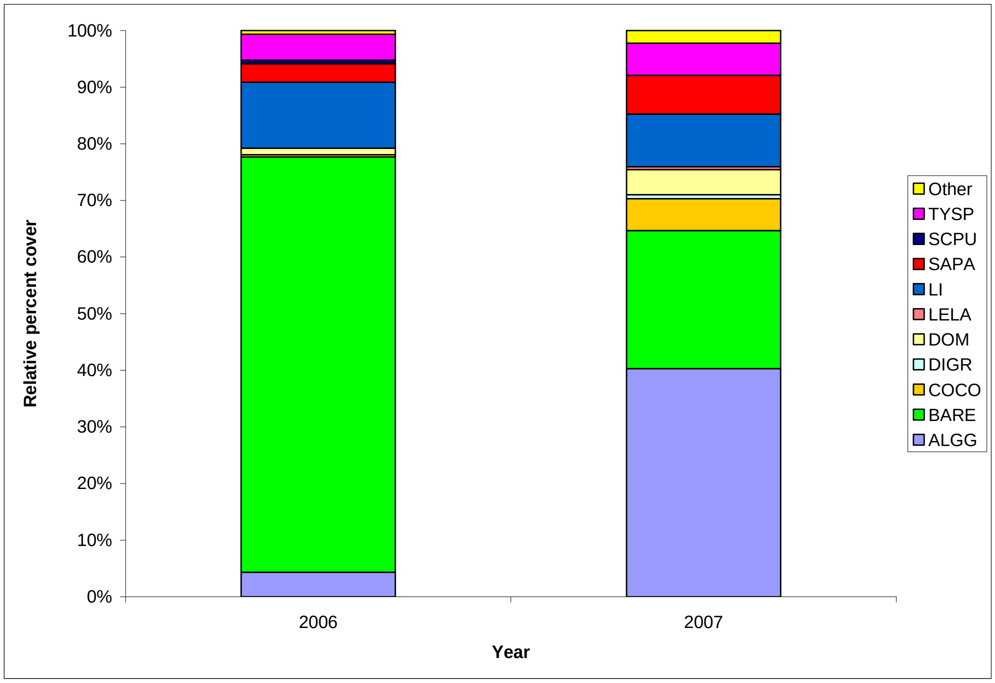


Figure 16. Relative percent cover of major plant species (quadrat surveys) postbreach at BenMar Restoration Site, Summer 2006-2007. Plant codes follow Table 4. *Other* includes unknown, DOM and *Scirpus* spp.

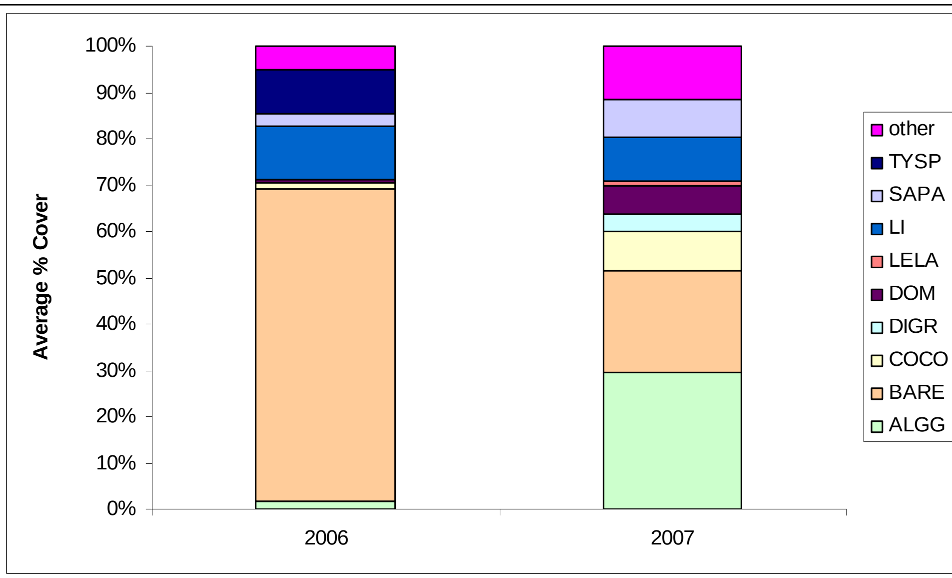
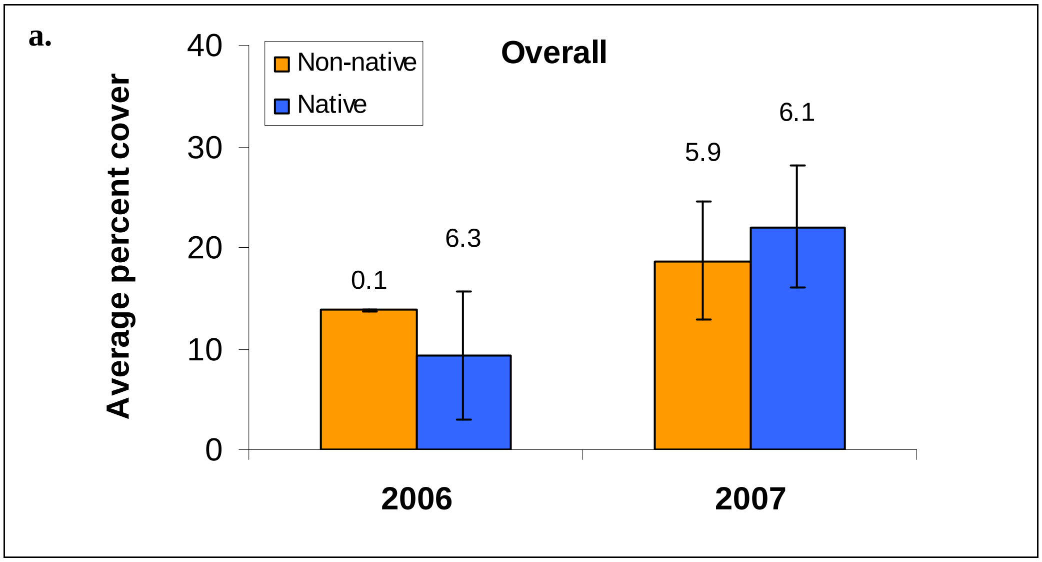
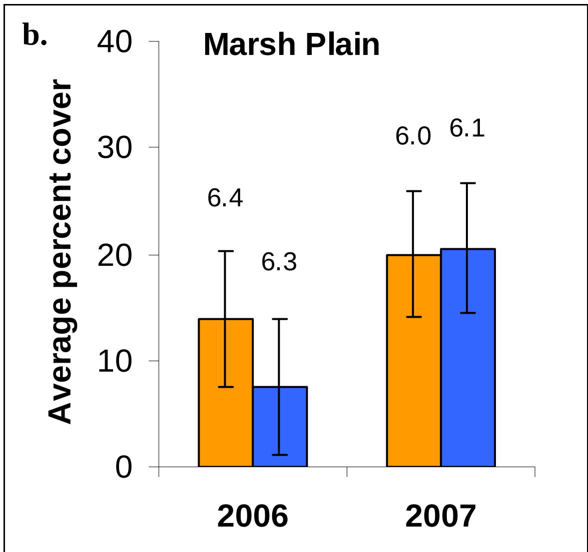


Figure 17. Relative percent cover of plant species derived from transect surveys, summer 2006 - 2007. Plant codes follow Table 4. *Other* includes brown algae, ATTR, PIEC, *Polygonum sp., Scirpus spp.*, and *Spergularia* spp.

The majority of plants we detected in 2006 were non-native with an average relative percent cover of 14%, and increased to 19% in 2007 (quadrat surveys). Native species coverage averaged 9% in 2006 and rose to 22% in 2007 (Figure 18a). Overall, native cover increased at a greater rate than non-native, with pickleweed comprising most of the average native cover. Marsh plain native cover rose an average 13% (pickleweed) from 2006 surveys while non-native cover rose 6% (brass buttons). Upland native cover increased by 8%, whereas, non-natives increased 9%. Brass buttons is a non-native perennial and is considered a wetland indicator species. It is a pioneer plant that colonizes bare ground and can establish large monocultures at new restoration sites (van der Toorn 1980); however, in similar restoration sites such as Guadalcanal, it is eventually outcompeted by native marsh species such as common pickleweed (Woo et al. in prep).





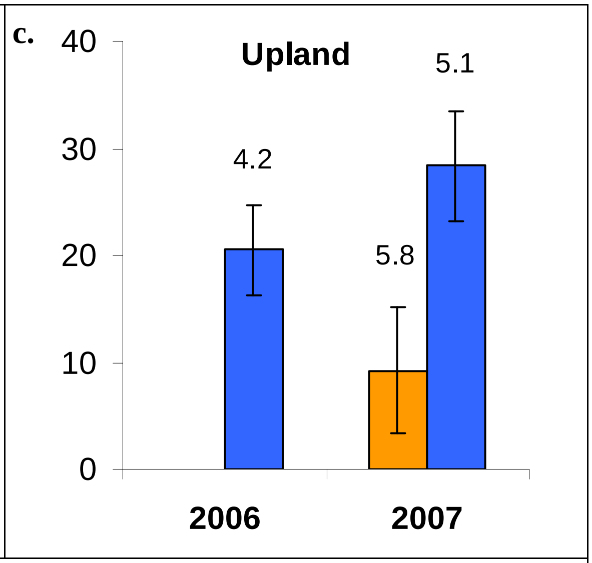


Figure 18. Average percent cover (+ SE) of (a) native and non-native plants across entire site, (b) within the marsh plain, and (c) in the upland habitat type.

Perennial pepperweed (*L. latifolium*) is a non-native invasive plant of concern that produces dense monospecific stands. Perennial pepperweed invades a variety of ecosystems including: riparian, wetland areas, estuaries, floodplains, roadsides and rangelands. Stems can grow up to 1.5 m in height, almost one meter taller than pickleweed canopies (Renz and Randall 2000). Dense pepperweed can displace native plant species as well as alter salt marsh habitat by changing the soil ions (Blank and Young 1997). Pepperweed was detected in our July 2007 survey on the NE corner of the mitigation site, in sparse patches.

Stinkwort, *Dittrichia graveolens,* is an invasive annual native to the Mediterranean region that has recently invaded California. In 2006 point intercept transects, it was detected in only 1 transect at 3% cover. The following year it was detected in three transects with up to 32% cover. Though not detected in vegetation transects, stinkwort dominated the upland areas (pers. obs., Figure 18). Stinkwort is drought tolerant and can produce an estimated 15,000 seeds per adult plant, which may be viable for 3 years in the soil (Parsons and Cuthbertson 1992). Stinkwort also contains composites that are linked to allergic contact dermatitis in humans and can also harm livestock that ingest it. The barbed pappus bristles can puncture the small intestine of livestock, resulting in mortality (Eflora 2007). Stinkwort is spreading rapidly in California, especially along roadways, with wind dispersed seeds that can also stick to hair, feathers, vehicles, equipment, and clothing (DiTomaso 2004).

Figure 18. Upland dominated by stinkwort in the foreground.

Common reed (*Phragmites australis*) is a perennial that forms extensive monospecific stands, up to a square kilometer or more. Stands can reproduce vegetatively and spread up to 5 m or more per year by horizontal 'runner' stems. The invasive weed displaces other plant species and can threaten wildlife because they alter the structure and function of relatively diverse marshes (Marks et al. 1993). Patches of *Phragmites* was detected within the marsh plain of BenMar restoration site on the eastern and southern sides. Control and management of this weed within the site boundaries will need to consider the extensive stands of *Phragmites* on adjacent Department of Fish and Game lands. Other notable non-native species detected within BenMar and its surrounding areas include yellow star thistle (winter annual, *Centaurea solstitialis*), bull thistle (biennial, *Cirsium vulgare*) and artichoke thistle (perennial, *Cynara carduncul*us).

Invertebrates

Invertebrates are important indicators of water quality and ecological integrity of marsh habitats (US EPA 2002). They can provide useful information for tracking the progression of restoration at the BenMar restoration site. We collected benthic invertebrates in June 2006 and

August 2007 at randomly selected sites within three substrate types (channel, marsh panne, and marsh plain). The 2006 data are summarized below. Invertebrate samples from 2007 are currently being sorted, identified, and enumerated.

Table 5. Invertebrate abundance per m^3 (1 m^2 area with 10 cm depth) for channel, marsh panne and marsh plain.

Taxon	Channel			Marsh Panne			Marsh Plain		
	A	B	C	A	B	C	A	B	C
Chironomidae	3,057	3,694	7,261	1,911	764	3,312	-	-	-
Dolichopodidae	127	-	-	127	-	-	637	-	-
Muscidae	-	-	-	892	-	-	-	637	127
Nematoda	-	-	-	255	-	-	-	-	-
Oligochaeta	-	-	-	255	-	-	-	-	-
Diptera	-	-	-	-	127	-	255	-	-
Ave # of taxa/sample		**1.33**			**2.67**			**1.33**	

Invertebrate specimens from six taxa were present in the sub-sample of sediment cores analyzed (Table 5). The taxa are as follows: Chironomidae (non-biting midges), Dolichopodidae (long-legged flies), Muscidae (house flies), Nematoda (roundworms), Oligochaeta (earthworms) and Diptera (true flies). Samples taken from the marsh panne had the highest average number of taxa (2.7 taxa), as compared to the channel (1.3 taxa) and the marsh plain (1.3 taxa). Chironomids (family Chironomidae) were present in all the channel and marsh panne samples, but not the marsh plain samples. They had significantly higher abundance than the other five taxa within the two substrate types in which they were found, with an average of 4,671 individuals/m^3 for marsh channel, and 1,996 individuals/m^3 for marsh panne (Table 5). Fly larvae in the Dolichopodidae family were present in 1 sample of each substrate at an average abundance of 42 individuals/m^3 for marsh channel, 42 individuals/$m^3$for marsh panne and 212 individuals/m^3 for marsh plain. The greatest invertebrate taxa abundance was found in a sample collected in the marsh panne (5 taxa) while 5 of the 9 analyzed samples contained only 1 taxon.

Birds

During the 35 post-breach area surveys from December 2005 to June 2007, we detected 61 bird species. We conducted 10 bird surveys prior to the initiation of our contract (December 2005 to July 2006): from December 2005 to March 2006 only low tide bird surveys were conducted, and thereafter high and low tide surveys were conducted. Shorebirds were the most common guild (i.e., American avocet, western sandpiper, black-necked stilt), followed by passerines (i.e., red-winged blackbird, song sparrow), dabbler (i.e., mallard, American widgeon), piscivore (i.e., snowy egret), other (birds with other foraging guilds, i.e. Anna’s hummingbird, Virgina rail), raptor (i.e., northern harrier, turkey vulture), and diver (i.e., ruddy duck; Table 6).

Table 6. Bird species, bird type, and average number of birds observed per survey (35 surveys).

Bird Type	Common Name	Total
Shorebird	American Avocet	26.62
	Black-bellied Plover	1.50
	Black-necked Stilt	6.71
	Dowitcher	3.41
	Dunlin	4.32
	Killdeer	9.91
	Least Sandpiper	13.97
	Semipalmated Plover	0.41
	Western Sandpiper	21.12
	Willet	2.32
	Yellowlegs	0.41
Shorebird Total		*90.88*
Passerine	American Crow	1.79
	American Goldfinch	0.06
	American Pipit	0.03
	Barn Swallow	0.50
	Black Phoebe	0.32
	Brewer's Blackbird	0.44
	Bushtit	0.12
	Cliff Swallow	0.56
	Common Raven	0.06
	Common Yellowthroat	0.29
	Golden-crowned Sparrow	0.18
	House Finch	0.18
	Marsh Wren	0.82
	Mourning Dove	0.29
	Northern Mockingbird	0.32
	Red-winged Blackbird	11.18
	Rock Dove	0.24
	Say's Phoebe	0.03
	Song Sparrow	2.79
	Tree Swallow	0.21
	Western Meadowlark	0.12
	Western Scrub Jay	0.03
	White-crowned Sparrow	0.88
	Yellow-rumped Warbler	1.32
Passerine Total		*43.56*
Dabbler	American Widgeon	2.76
	Cinnamon Teal	0.91
	Gadwall	0.74
	Green-winged Teal	0.97
	Mallard	3.12
	Mute Swan	0.03
	Northern Shoveler	0.41
Dabbler Total		*9.12*

Piscivore	Belted Kingfisher	0.06
	Double-crested Cormorant	0.12
	Great Blue Heron	0.03
	Great Egret	0.18
	Snowy Egret	0.88
Piscivore Total		*1.26*
Other	American Bittern	0.15
	Anna’s Hummingbird	0.09
	Canada Goose	0.50
	Ring-billed Gull	0.09
	Ring-necked Pheasant	0.03
	Virginia Rail	0.03
Other Total		*0.85*
Raptor	American Kestrel	0.06
	Cooper's Hawk	0.03
	Northern Harrier	0.24
	Red-tailed Hawk	0.06
	Turkey Vulture	0.09
	White-tailed Kite	0.03
Raptor Total		*0.50*
Diver	Ruddy Duck	0.03
Diver Total		*0.03*
Grand Total		**146.21**

Bird abundances were dominated by shorebird and passerine guilds and varied seasonally, with greater abundances of passerines in the spring and summer months (June – Nov) and greater abundances of shorebirds during the fall and winter migratory season (Aug 2006 – Feb 2007; Figure 20). The maximum number of birds detected within a month occurred in Jan 2007, where we detected 806 birds from 17 species.

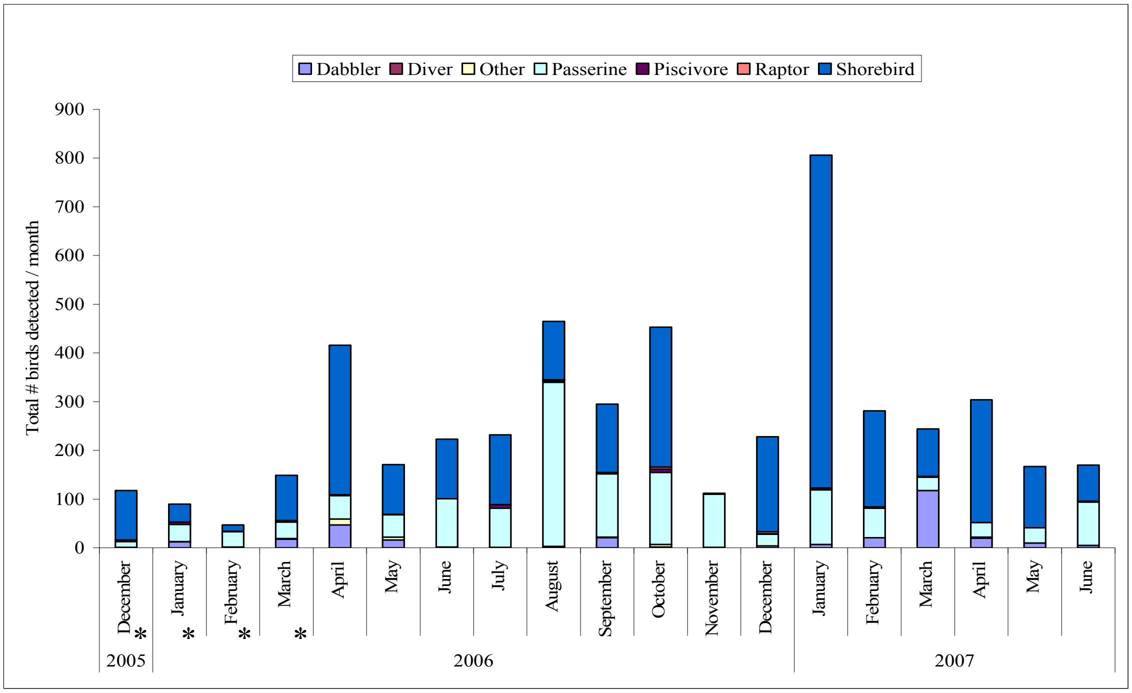
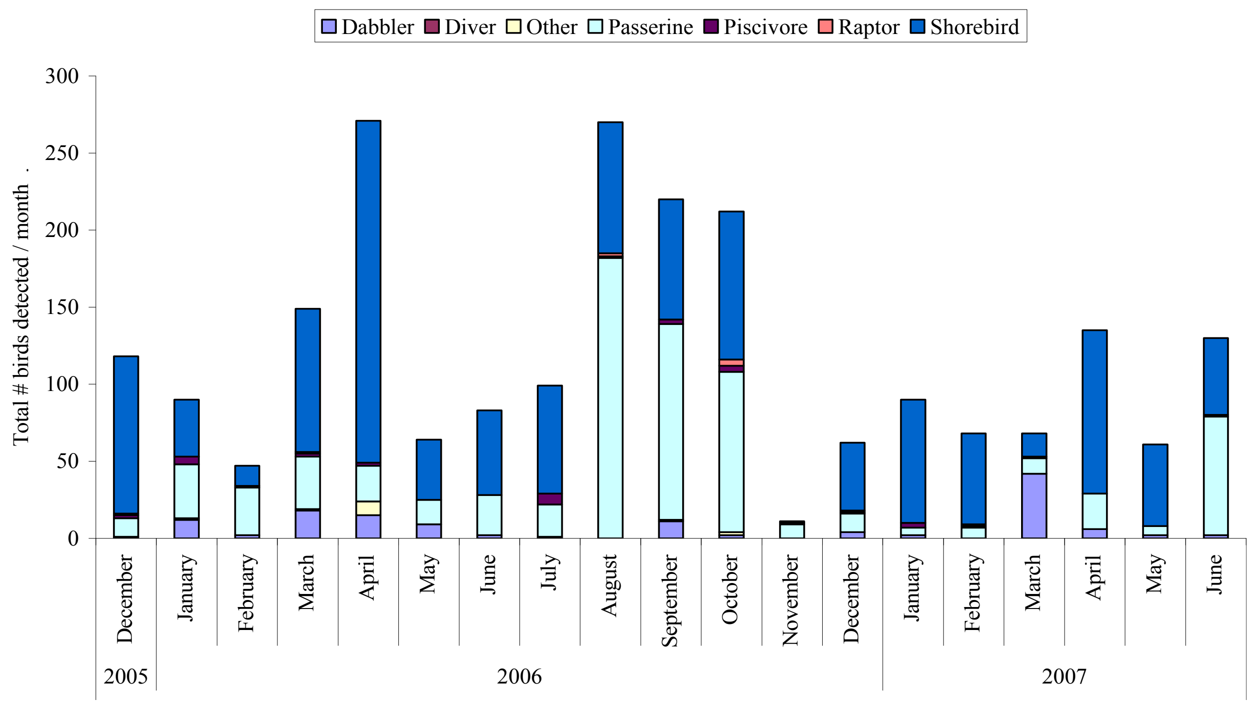


Figure 20. Total number of birds by guild observed from Dec 2005 to Jun 2007. Other includes: American Bittern, Canada Goose, Ring-billed Gull, Ring-necked Pheasant, and Virginia Rail. *The Dec 2005, January, February, and March 2006 surveys were conducted only at low tide. Subsequent surveys include high and low tides.

Bird composition and abundance typically vary by tide, with greater numbers of shorebirds utilizing mudflats as they become exposed during low tide as in the Guadalcanal (Bias et al. 2005) and Tubbs Setback Restoration sites (Woo et al. 2006; Woo et al. in prep). However, at BenMar we detected similar overall abundance at high and low tide and a greater number of shorebirds at high tide (1,793 shorebirds) than at low tide (1,297 shorebirds, Figure 21). Shorebirds utilization varied by tide: during high tide, shorebirds were primarily observed roosting (59%), followed by foraging (26%), alarm (5%), and flyover (5%); while during low tide, shorebirds were primarily foraging (77%), followed by roosting (11%), and alarm (7%).

BenMar is largely exposed or shallowly inundated, even at high tide. The greatest number of birds recorded in a single high tide survey occurred in January 2007 when we detected 716 birds (603 shorebirds). High numbers of birds were also noted using the site for roosting at high tide (Figure 21). We also recorded behavior during our surveys. Shorebirds utilized the site for both foraging (46%) and roosting (39%) while dabblers used the site for swimming (43%), foraging (36%), and roosting (11%). Most divers may be absent because the site is too shallow even during high tide. Breeding American avocets and killdeer utilized bare ground in the TCE-capped upland areas for nesting in 2006 and 2007. A number of hatchling American avocets, killdeer, and black-necked stilts were observed on site. These birds use depressions in the ground with minimal nesting material and eggs blend in with the surrounding habitat (Ehrlich et al. 1988; Rintoul et al. 2003).

a. Bird abundance at low tide by month and guild



b. Bird abundance at high tide by month and guild

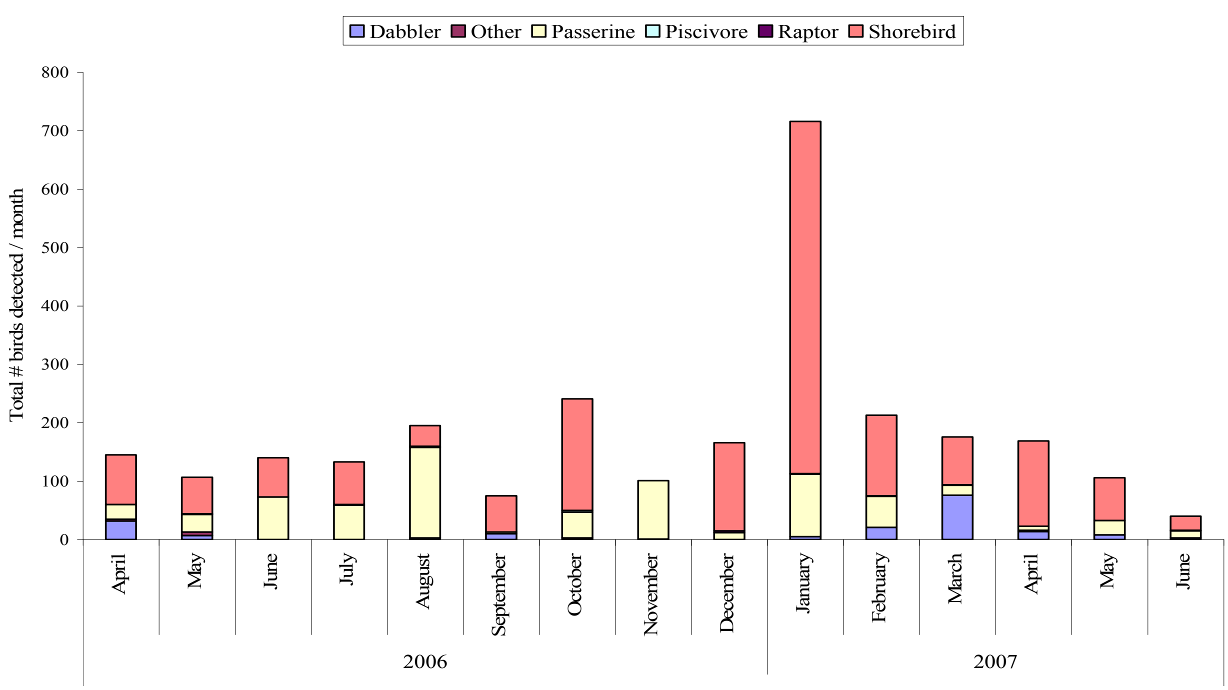


Figure 21. Number of birds by guild at a) high tide and b) low tide from Dec 2005 to Jun 2007. Other includes: American Bittern, Canada Goose, Ring-billed Gull, Ring-necked Pheasant, and Virginia Rail. *The Dec 2005, January, February, and March 2006 surveys were conducted only at low tide. Subsequent surveys include high and low tides.

Small Mammals

The small mammal trapping effort in Aug 2006 consisted of 225 trap nights. Two species were detected: 13 house mice (*Mus musculus*; 5.9 new captures/100 trap nights) and 1 deer mouse (*Peromyscus maniculatus*; 0.5 new captures/100 trap nights; Table 7). We corrected the trapping effort to 221 nights due to eight closed but empty traps (Nelson and Clark 1973). Fifty percent of the house mice were in adult reproductive condition. In September of 2007, our small mammal trapping effort consisted of 225 trap nights, with an adjusted trapping effort of 209.5 trap nights to account for the 31 closed but empty traps (Nelson and Clark 1973). High winds contributed to the large number of closed but empty traps. During the 3 day sampling effort, only house mouse was detected (8 new captures; 3.8 new captures/100 trap nights; Table 7). Twenty-five percent of the house mice were in adult reproductive condition. Incidental mammal observations at the site included tracks and sign of river otter (*Lutra canadensis*), raccoon (*Procyon lotor*), dog (*Canis familiaris*) and jackrabbit (*Lepis californicus*). Based on track observations, a river otter may have been responsible for some of the closed but empty traps in 2007.

Table 7. List of small mammal species and abundance index (new captures per 100 trap nights).

Common Name	Scientific name	2006	2007
House mouse	*Mus musculus*	5.8	3.8
Deer mouse	*Peromyscus maniculatus*	0.4	0

We have not detected the endangered salt marsh harvest mouse (*Reithrodontomys raviventris*). Salt marsh harvest mice are found in dense cover of pickleweed and salt marsh plants (Sacramento Fish and Wildlife Service 2004; Shellhammer et al. 1982). This species may have been present in numbers too low for detection or the salt marsh harvest mouse has not yet colonized the site. At the Guadalcanal restoration site, salt marsh harvest mouse were detected three years after the restoration of tidal flow. This species may not be present at this time because of inadequate vegetative height, percent cover, or density, or because of a lack of an abundant source population nearby due to natural population fluctuations. However, in a 2000 small mammal survey, conducted by the California Department of Water Resources and Fish and Game, 20 salt marsh harvest mice (4 new captures/100 trap nights) were captured at Goodyear Slough, east of BenMar (CDWR 2003). Continued monitoring of the vegetative cover may help explain the habitat use of the salt marsh harvest mouse.

Conclusion

The BenMar restoration site has rapidly progressed over the last year. Native vegetation cover has increased from 9% in 2006 to 22% in 2007, while non-natives have increased from 14% to 19%, respectively. Tidal waters inside the site were 0.3 ft lower than the tides in the intake channel. The site is utilized by 61 bird species, including breeding American avocets, black-necked stilts, and killdeer. Two small mammal species were detected during our trapping sessions (deer mouse and house mouse), and tracks of dogs, raccoon, jackrabbit, and river otter have been detected. The continued development of new monitoring technologies and methods has allowed the USGS to better describe changing environments. Utilization of remote sensing techniques, such as ERDAS Imagine software to classify land cover types and LiDAR to calculate surface elevations, can be useful in quantifying vegetation colonization and morphologic changes to the landscape.

Restoration Goals

Though our five year biological and physical monitoring plan was established prior to our knowledge of Caltrans mitigation plan, here we attempt to address Caltrans mitigation goals and restoration criteria, if applicable. Discussions are currently underway to coordinate and adapt the monitoring plan to more appropriately address Caltrans mitigation goals and restoration criteria. The mitigation goal of the BenMar restoration site was to restore and enhance tidal brackish marsh habitat for the benefit of endangered and threatened species, migratory birds and other estuarine dependent wildlife. More specifically, the restoration objectives were to create: (1) long-term tidal channel morphological stability, (2) adequate tidal prism and salinity circulation, and the (3) establishment of a self-sustaining marshland (Morton 2001).

Long-term tidal channel morphological stability

Our monitoring contract was initiated approximately one year after the restoration of tidal flow and we did not capture initial sedimentation events. Sediment pin data did not show any sedimentation within the channel; however, soil compaction data within the channels indicate that initial sedimentation rates may have been approximately 37.5 cm. The bathymetry map shows the location of the channel thalweg at the confluence of channels. Water levels within the site closely tracked the water levels within the intake channel from Suisun Bay. Potential challenges include high sedimentation rates that can reduce channel capacity, site drainage and available habitat for fish; however, we established sediment elevations to form a baseline from which to compare future changes. The bathymetry of the intake channel and the channel network within the project will be closely monitored for changes that may threaten channel stability.

Adequate tidal prism and salinity circulation

Challenges in achieving adequate tidal prism will likely be similar to challenges in sustaining channel stability, as increased sediment can cause channel in-filling and reduce tidal prism. The tidal range inside the project site closely followed the water levels in the outer intake channel to Suisun Bay. Our water level loggers did not detect any signs of significant muted tide levels or impedance to drainage, indicating fully tidal conditions. The water levels in the outer channel were consistently 0.3 ft higher than those within the project interior.

We detected a range of salinities from 1.8 $\pm$ 0.0 ppt in June 2006 to 12.1 $\pm$ 0.4 ppt in June 2007, which are within the range for a diverse assemblage of brackish marsh plant species, natives and non-natives alike (Peterson 2006). Dissolved oxygen (DO) levels may be of concern in summer months. Prolonged DO levels below 5.0 mg/L may harm invertebrates and developing aquatic organisms. We detected DO levels temporarily below 5.0 mg/L in June 2006 and June 2007. Though the US Environmental Protection Agency established a dissolved oxygen threshold of 5.0 mg/L, DO levels below this threshold can occur naturally in estuaries (MD DNR 2002). Over all readings, DO levels averaged 8.5 mg/L and fell below the threshold only 4% of the time. The lowest recorded DO level was 3.9 mg/L and the average of readings that fell below the threshold was 4.7 $\pm$ 0.0 mg/L.

Establishment of a self-sustaining marshland

BenMar is rapidly becoming vegetated and has a diverse assemblage of plant species. Non-native plants have increased from 14% in 2006 to 19% in 2007. The site is also utilized by a large number of birds for roosting, foraging and breeding. It is this early stage of restoration that will influence the trajectory of the restoration. A self-sustaining, high quality marsh is an unrealistic goal without maintenance; however, adaptive management relies on consistent monitoring for quick identification of problem areas before solutions become cost prohibitive. Challenges to establishing a self-sustaining marshland, include factors that reduce habitat value for wildlife. Unrestricted public use of the site and invasive plant species can be detrimental to wildlife. On several occasions, we observed people throwing rocks at juvenile avocets, driving remote control cars, and running their dogs in the same area where birds were nesting. In addition, numerous golf balls were found in the upland TCE-capped area, indicating use as a driving or putting range. Signs may help restrict detrimental public activities and encourage the protection of the restoration site for wildlife value.

In cases where natural plant colonization may be lengthy or areas of bare ground may encourage undesirable weeds, it may be beneficial to actively encourage native plant growth. New wetlands are especially vulnerable to the colonization of weed species because of the large extent of available bare ground. In addition, upland transition zones are common places for invasive plants to establish because of poor soil organic matter and high soil compaction. Once established, invasive species are likely to spread if left alone. Invasive plant management can be minimized by matching weed removal strategies with the specific biology and ecology of the weed. Risk analyses that incorporate current species distribution, life cycle (annual, biennial, or perennial), seed production, seed dispersal, seed longevity, competitive ability and source populations can help prioritize invasive plant control (Pennings and Callaway 1992). At BenMar, the adjacent lands contain extensive stands of *Phragmites*, a highly invasive wetland plant. Fragmented control efforts will be limited if there is a constant input from nearby source populations. Priorities may be more realistically set on species that can remain clear with lower maintenance. Stinkwort has become the dominant upland invasive plant. As an annual, with a seed longevity of three years, it may be controlled by continued physical removal or chemical control prior to seed production. If seeds are produced, they stick to clothing and vehicles and can be unwittingly spread from one site to another. BenMar hosts a diverse assemblage of plants and wildlife. Continued monitoring can help identify early challenges to reaching project success criteria and help increase the value for wildlife.

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Abbreviations and Acronyms

°C	degrees Celsius
ArcGIS	Arc Geographical Information System
BenMar	Benicia-Martinez Restoration Site
Caltrans	California Department of Transportation
CDFG	California Department of Fish and Game
CDWR	California Department of Water Resources
cm	centimeter
CRWQCB	California Regional Water Quality Control Board
CWT	Clean Water Team
DGPS	Differential Global Positioning System
DO	dissolved oxygen
DOM	Dead Organic Matter
ENR	Estimated Nitrogen Release
ERDAS	Earth Resources Data Analysis System
ESRI	Environmental Systems Research Institute
ft	feet
g	grams
ha	hectares
Hwy	highway
km	kilometers
kPa	kilopascal
lbs/A	pounds/acre
LiDAR	Light Detection and Ranging
m	meter
MD DNR	Maryland Department of Natural Resources
mg/L	milligrams/liter
mm	millimeter
n	sample size
NAVD88	North American Vertical Datum of 1988
NTU	Nephelometric Turbidity Unit
PDOP	position dilution of precision error
ppt	parts per trillion
PVC	polyvinyl chloride plastic pipe
SAS	Statistical Analysis System
SE	standard error
SFBE	San Francisco Bay Estuary
sp.	one species
spp.	more than one species
SWRCB	California State Water Resources Control Board
TCE	trichloroethylene
TS	tidal station
UPRR	Union Pacific Railroad
US EPA	US Environmental Protection Agency
USGS	US Geological Survey
UTM	Universal Transverse Mercator
v	volt

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