Guadalcanal Tidal Marsh Restoration:

2007 Annual Report

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U.S. GEOLOGICAL SURVEY

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Data Summary Report

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EXECUTIVE SUMMARY

- The California Department of Transportation (Caltrans) purchased the 21.4 ha (53 acre) Guadalcanal Village as mitigation for the widening of Hwy 37 at White Slough. Guadalcanal was graded for rapid marsh development and the northern levee breached in October 2001.

- Biological and physical monitoring was conducted by USGS and Ecosystem Restoration Sciences (ERS) from June 2000 to June 2005 under an agreement administered by ERS. In 2006, Caltrans initiated an agreement directly with USGS to provide information for proper adaptive management schemes and assess wetland restoration success. Monitoring efforts focused on hydrology, geomorphology and biology parameters.

- The average daily tidal range within the project was 4.23 $\pm$ 0.06 NAVD88 ft from January to July 2007. The highest recorded tide level occurred during the extreme high tide and flooding event on 1 Jan 2006 at 9.2 ft NAVD88, compared to the highest water level in 2007, which occurred on 15 Jun 2007 at 7.4 ft NAVD88.

- Post-breach dissolved oxygen (DO) levels remained consistently above 5 mg/L, a threshold used by the California Regional Water Quality Control Board as an indicator of aquatic health. Mean DO in 2007 averaged 6.7 $\pm$ 0.05 mg/L, an improvement from 1.4 mg/L recorded in pooled rainwater prior to the restoration in 2000.

- We classified land cover using georeferenced color infrared photographs (ERDAS Imagine software). In Aug 2006, mudflat and tidal marsh vegetation comprised 68% of the site, while open water, bare land and algae comprised 25% of the site, combined.

- Guadalcanal gained 11.03 $\pm$ 9.6 cm of sediment between Feb 2002 and Sep 2007 with the greatest accumulation at Sedpin 7b (114.6 cm) within the main channel. Channels had the greatest amount of sediment accumulation (65.56 $\pm$ 49.09 cm), compared to the low marsh (2.3 $\pm$ 2.2 cm) and high marsh (-3.1 $\pm$ 0.6 cm).

- The bathymetry survey in Sep 2006 quantified a large mudflat at the center of the project with elevation ranging from 3.34 ft to 4.87 ft NAVD88. Primary channel depth characterized by the bathymetric map ranged from 1.84 ft to -5.98 ft NAVD88, while smaller southern channels were much shallower (2.40 ft to 4.23 ft NAVD88).

- Overall, 56 plant species have been detected, of which 21 were native. Point intercept surveys showed pickleweed percent cover increased from 2% in 2002 to 41% in 2007.

- Between 2003 and 2005, non-native plants had greater percent cover than native species. In 2006 and 2007 native species percent cover increased from 14% in 2005 to 28% in 2006 and to 27% in 2007. At the same time, percent cover of non-natives declined from 19% in 2006 to 7% in 2007 such that native species now have almost four times more cover than non-natives.

- We detected 37 invertebrate taxa within 11 taxonomic classes in 2004 and 2006. Although the invertebrate community composition remained relatively similar across sampling years (26 taxa in 7 classes in 2004, 24 taxa in 11 classes in 2006), the overall abundance of pooled taxa declined approximately 80%.

- A total of 67 fish, representing 8 species, were caught during the September 2006 survey and 14 fish (9 species) were caught during the September 2007 survey. During the 2006 survey, three species were encountered for the first time: inland silverside, threadfin shad, and longjaw mudsucker.

- Thirty-one bird species were detected during pre-breach surveys in 2000. We detected 95 bird species during post-breach surveys (Dec 2001 to Sep 2007). The greatest number of birds was recorded at a single high tide survey in Jul 2004 with >16,000 birds, of which 99% were shorebirds.

- Shorebirds were the most abundant bird guild recorded at both high and low tide comprising over 80% of the relative abundance from 2001-2006. Shorebird relative abundance declined to 48% in 2007, reflecting greater detection of passerines. Passerines relative abundance increased from 7% in 2006 to 27% in 2007.

- Three small mammal species have been detected since the restoration; California vole (*Microtus californicus*), house mouse (*Mus musculus*), and salt marsh harvest mouse (*Reithrodontomys raviventris*). Salt marsh harvest mouse numbers decreased from 5.31 new captures per trapnight in 2005 to 0.45 new captures per trapnight in 2006 and 2007.

INTRODUCTION

The San Francisco Bay-Delta 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 the San Francisco Bay Estuary (SFBE) (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). The quality of remaining wetlands is endangered by fragmentation, contaminants, encroaching development, invasive species, sea level rise, water quality, and human disturbances (Takekawa et al. 2006). Despite these challenges, the estuary remains a critical resource for many endemic fish, wildlife, and plant species as well as a major wintering area for migratory waterbirds in the Pacific Flyway. Several animal species of the SFBE are currently listed as federal or state threatened or endangered, under consideration for listing, or of state special concern (Harvey et al. 1992). Many endemic species, such as Mason's lilaeopsis (*Lilaeopsis masonii*), soft bird's-beak (*Cordylanthus mollis*), delta smelt *(Hypomesus transpacificus)*, California clapper rail (*Rallus longirostris*), California black rail (*Laterallus jamaicensis*), San Pablo song sparrow (*Melospiza melodia samuelis*), and salt marsh harvest mouse (*Reithrodontomys raviventris*) benefit from the restoration of tidal wetlands and their characteristic *Spartina foliosa* and *Sarcocornia pacifica* plant communities. In addition, management for specific elements within restoration areas may enhance their value for migratory shorebirds and waterfowl or reduce the incursion of non-indigenous invasive species.

Wetland restoration efforts are currently underway to restore large contiguous areas to improve ecological functions of tidal wetlands. Biological and physical monitoring efforts are critical steps to assess wetland restoration efforts and outcomes (CALFED 2001). Although many wetland restoration projects have been initiated, few have included detailed monitoring for adaptive management of project performance. Baseline biological and physical data is necessary to assess restoration actions and to detect early challenges in achieving project goals.

The Guadalcanal Village (hereafter Guadalcanal) wetland restoration project is a 21.4 ha (53 acre) site that is part of the mitigation for the widening of Highway 37 near White Slough. Guadalcanal is located near the junction of Hwy 37 and the Napa River and is bound by Dutchman's Slough to the north, Pritchard's Marsh (privately owned) to the east, Hwy 37 to the south, and the Cullinan Ranch restoration project (USFWS) to the west. Guadalcanal was formerly used as a naval housing unit and later as a paint ball facility until it was purchased by the California Department of Transportation as mitigation. To facilitate rapid marsh development, Guadalcanal was graded to elevations appropriate for low marsh, marsh plain, high marsh, and upland habitat types. On October 31, 2001, tidal waters were reintroduced to Guadalcanal at the breach to Dutchman's Slough.

Comprehensive monitoring was lead by the U.S. Geological Survey, Western Ecological Research Center (USGS), San Francisco Bay Estuary Field Station. Ecosystem Restoration Sciences (ERS) administered monitoring funds from June 2000 to June 2005. After ERS's contract expired, USGS contributed fieldwork towards bird surveys and tidal data monitoring. In 2006 Caltrans entered an agreement directly with USGS for biophysical monitoring.

METHODS

Sampling Framework

The biophysical monitoring design for Guadalcanal was based on the Biological Monitoring Plan for Cullinan Ranch and Tolay Creek Units (Takekawa et al. 1999). Physical characteristics measured included hydrology (water levels and water quality), photodocumentation (aerial photographs, land cover classifications, and repeated photopoints at the same location), and geomorphology (elevations, sediment erosion and deposition, and mudflat development). Biological monitoring parameters included vegetation (transect surveys, quadrat surveys, land cover classifications), benthic invertebrates (sediment core samples), fish (beach seine and bag seine efforts), birds (observations), and small mammals (Sherman traps; Figure 1, Table 1).

The initial biophysical monitoring agreement terminated with ERS June 2005 and the agreement with USGS was initiated in July 2006. Gaps in data collection are attributed to this interruption in contracting. Many field surveys were not conducted or reduced during the interim period; however, the USGS-SFBE Wetland Restoration Program maintained the photopoints, water level loggers, sediment survey, and bird surveys, in recognition of the value of continuous datasets.

Figure 1. Location of sampling points for benchmarks, dataloggers, start points for vegetation transects, photopoints, sediment pins, invertebrates, fish surveys, and small mammal traps.

Table 1. USGS sampling schedule and frequency.

Survey	**Number of Samples**	**Minimal Frequency**	**Initial Survey**	**2000**[1]	**2001**[2]	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Aerial photo	1 aerial	annual	Feb 02	---	---	Feb	Sept	Sept	---	Aug	Sept	---
ERDAS	1 aerial	annual	Feb 02			Feb	Sept	Sept	---	Aug	scheduled	---
Photopoints	7 panoramas	annual	June 00	June	July	July	July	Oct	Sept	Aug	Aug	---
Water levels	1 logger[3]	74d download	Feb 02	---	---	continuous collection	cont collect	cont collect	cont collect	cont collect	cont collect	cont collect
Water quality	48 hour deployment	annual	Sep 02	---	---	Sept[4]	May[5]	July, Sept, Dec	Mar, June, Dec	Sept, Dec	Mar, June, Sept	Mar
Sediment pins	15 pins	annual	Feb 02	---	---	Feb, May, Jul, Sept	Feb, Jun, Oct	Jan, July, Sept, Dec	Mar, June, Dec	Sept, Dec	Mar, June, Sept	Mar
Soil compaction	9 transects	---	Apr 04	---	---	---	---	April	---	---	Aug	---
Elevation	3 staff guages, 15 sediment pins	---	Mar 04	---	---	---	---	Mar	---	Sept	---	---
Bathymetry	1 survey	---	Jan 04	---	---	---	---	Jan	---	Sept	---	---
Vegetation	24 transects, 72 quadrats	annual	June 00	June	---	May, Aug	May, Aug	Apr, May, Aug	May	Aug	Aug	---
Invertebrates	12 cores	annual	Sept 04	---	---	---	---	Sept	---	Sept	Aug	---
Birds	area survey	monthly	June 00	June	Dec	monthly[6]	monthly[6]	monthly[6]	monthly[6]	monthly[7]	monthly[6]	monthly[6]
Small mammals	225 trap nights	annual	June 00	June	---	---	June	---	May	Sept	Sept	---

[1] Pre-breach surveys

[2] Breached Oct 2001

[3] Two loggers initially; one permanently pulled in Nov 2006.

[4] 6 day deployment

[5] 14 day deployment

[6] High and low tide surveys

[7] All months excluding Feb, May and June

Spatial data were initially collected in UTM NAD27 and NGVD29 ft; however, in 2006 we updated our databases to UTM NAD83 Zone 10N and NAVD88 ft. 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 ft, 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 UTM NAD83 zone 10N / NAVD88 ft, and all locations and elevations in this report will be in these data unless otherwise noted.

Hydrology

Water levels were monitored continuously with water level data loggers to examine the water depth and flow rates. Our tidal station system (R-2100e, Telog Instruments, Inc., New York; Figure 1, Figure 2) 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 readings to an adjacent staff gage that had been surveyed to a known benchmark. Water levels are then converted to water surface elevations.

Figure 2. Water level data logger.

Two water level loggers were initially installed in October 2001. These loggers produced nearly identical hydrographs, so that when the eastern logger failed in November 2006, it was not replaced. 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 environmental conditions in developing wetlands that may be detrimental or advantageous for invertebrates and fish. On June 6, 2000, pre-breach spot readings were taken at locations where water had pooled at Guadalcanal for pH, dissolved oxygen, temperature, and salinity. These readings are used for a baseline comparison with current water quality data.

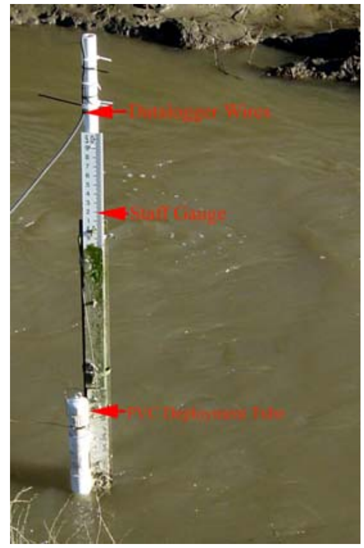


Figure 3. Water quality meter deployment at a tidal station.

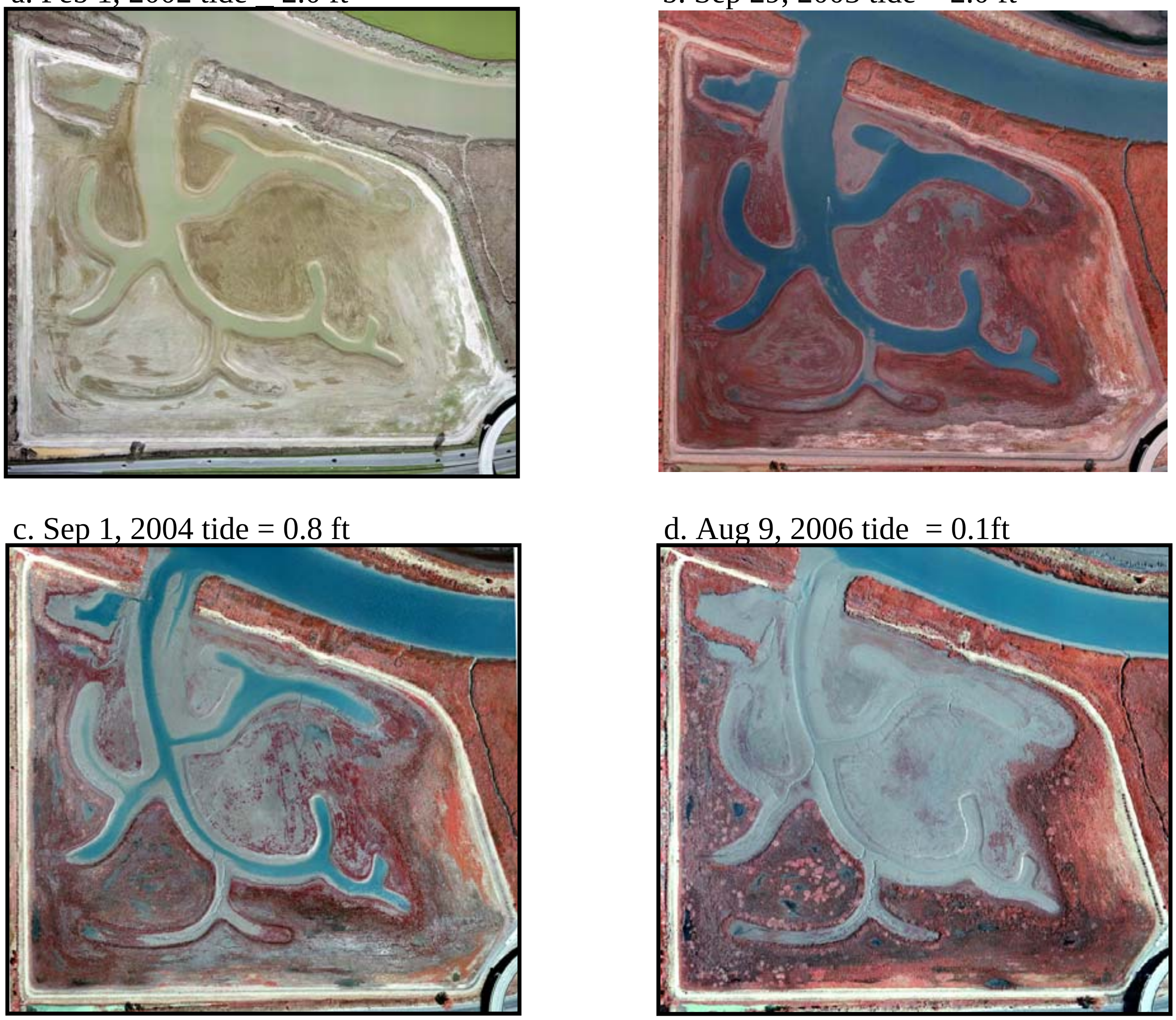
We used a Hydrolab Minisonde water quality meter (Hydrolab-Hach Co., Loveland, CO; Figure 3) to record changes in pH (0.1 pH), conductivity (converted to salinity using the 1978 Practical Salinity Scale), dissolved oxygen (% saturation and mg/L), turbidity (10 NTU), temperature (ºC) and salinity (ppt). Data was collected quarterly in a continuous 48 hr deployment at Guadalcanal’s west datalogger. Prior to deployment, the meter was cleaned and calibrated to standard solutions and programmed to log at 15 min intervals during the 48 hr period. Upon retrieval of the water quality meter, readings were taken in distilled water before and after cleaning to check for any possible fouling effects.

a. Feb 1, 2002 tide ≤ 2.0 ft

b. Sep 29, 2003 tide = 2.0 ft

c. Sep 1, 2004 tide = 0.8 ft

d. Aug 9, 2006 tide = 0.1ft



e. Sep 13, 2007 tide = 2.1ft

Figure 4. Color infrared aerial photographs of the Guadalcanal Restoration Project in (a) February 2002, (b) September 2003, (c) September 2004, (d) August 2006 and (e) September 2007. In 2004, sediment dispersal patterns show the narrowing of the main channel. In 2006 and 2007, the aerial photographs show further sediment accumulation at the channel edges.

Geomorphology

Benchmarks were installed by USGS–WERC in September 2004 throughout the site (Figure 1) and were resurveyed in November 2005 (Shoreline Engineering & Restoration).

Aerial Photograph and Land Cover Interpretation

A low-level, color infrared aerial photograph was taken in 2002, 2003, 2004, 2006 and 2007 (Figure 4). We georectified the 2006 aerial photograph to UTM NAD83 zone 10N (ArcGIS; ESRI, Inc.) using control points. Control points (n = 4) consisted of large white "X's" spray-painted on 1.5 m^2 black plastic sheets 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 to establish control point coordinates. The 2007 aerial photo was flown in September and will be georectified this winter.

We analyzed the August 2006 aerial photograph 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). We were unable to distinguish plant species; however, we refined the ERDAS classifications and used personal knowledge of the site to distinguish six major land cover types: tidal marsh, water, mudflat, upland vegetation, bare ground and algae.

Photodocumentation

Digital ground photographs, along with aerial photographs, help document and describe qualitative differences in restoration progress. Beginning in 2000, digital color photographs of the entire site were taken annually at seven vantage points (Figure 1). At each location, several digital pictures were taken and later stitched into a panoramic photograph.

Sedimentation

Sedimentation: sediment pins

Plastic poles (PVC) pounded into the substrate (sediment pins) are an inexpensive method to asses sedimentation patterns (Siegel 1998, Takekawa et al. 2002; Figure 5). Sediment pins were installed at 14 locations across Guadalcanal (mudflat to high marsh zones) following construction and before the levee was breached. An additional sediment pin (SP 15) was added to the project in 2006 to capture sediment and the elevation was surveyed in September 2006 (Figure 1). Sediment elevations were calculated by subtracting the length of the sediment pin from the elevation of the sediment pin top. A graduated (cm) vertical rod with a flat base was used to determine distance between the pin top and the sediment surface. 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. Sediment pins were taken from February 2002 to September 2007.

Figure 5. Sediment pin measurement.

Sedimentation: bathymetry

Sediment pins provide rough measurements of sediment accretion; however, readings are limited to the pin locations and lack the spatial resolution to adequately detect overall sedimentation patterns. To account for this, we developed a bathymetry system to produce a map of the underwater sediment surface. Our bathymetry system consists 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 echosounder can record water depths as low as 10 cm and is ideal for shallow water systems. 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 min, which was later converted to surface elevations. The echosounder recorded water depth, which was converted to surface elevations using interpolated tide levels. 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 grids (10 m) and contour profiles from elevation datasets.


Figure 6. Bathymetry survey at Guadalcanal

We conducted a bathymetric survey in September 2006 and surveyed the project along both north-south and east-west transects at 25m intervals. We validated our bathymetry elevation recordings using several methods. Prior to data collection, we calibrated the system using a bar check plate and a graduated pole, and adjusted the sound velocity for salinity and temperature differences. Post processing included a comparison with sediment pin elevations to grid cell elevations generated by the bathymetry map.

Vegetation

A 20 m point intercept transect was measured from the center of each vegetation plot (n = 24; Figure 1, Figure 7) in a random direction to determine percent cover of plant species. Plant species were identified and measured for height at 0.5 m intervals along each transect. Percent canopy cover was calculated by dividing the number of "hits" over the total number of point-intercepts (Bonham 1989). In addition, a 0.5 m^2 quadrat was placed along transects at 0, 10 and 19.5 m. Quadrat measurements consisted of species identification, ocular estimates of percent cover, maximum height and density (rooted individuals/m^2) (Elzinga et al. 1998).


Figure 7. Vegetation survey

Invertebrates

Benthic invertebrates were sampled along three elevation gradients in August 2004, August 2006, and August 2007 to examine changes in species diversity and abundance. A single sample core (10 cm diameter, 10 cm depth, for a volume of 785 cm^3) was collected at each habitat zone (channel, mudflat, and marsh plain) along four transects for a total of 12 cores (Figure 1). Samples were screened (0.5 mm mesh) on site and stored in a 70% ethanol and rose-bengal solution for temporary storage until identification. Invertebrates were identified to lowest possible taxa, enumerated, and core volume (785 cm^3) was extrapolated to a 1 m^2 plot at a depth of 10 cm.

Fish

Fish sampling was conducted in September 2006 and September 2007 at Guadalcanal (Figure 1). Fish were collected with a bag seine (5.5 m long and 1.8 m deep, with a 3.2 mm square mesh) and a beach seine (31.5 m long and 1.8 m deep, with 12.5 mm square mesh; Figure 8). A total of four hauls were made at two sites within Guadalcanal: two with the bag seine and two with the beach seine. Site 1 was on the west side of the breach and Site 2 was along the southern border of the channel, east of sediment pin 11 (Figure 1). Captured fish and invertebrates were identified to species, enumerated, measured (standard length and total length; carapace length for crabs), and released on site.

Figure 8. Beach seining at Guadalcanal.

Birds

Beginning in 2002, area surveys were conducted during high (> 4.0 ft) and low tide (< 2.0 ft) each month. Bird species, behavior (foraging, roosting, calling, flyover, swimming, preening, alert, unknown, courtship display, carrying nest material, carrying food, aggression), and 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.).

We also calculated annual species richness (number of species) and species diversity using the Shannon diversity index (Shannon 1948) and Simpson's Index, standardized by the number of surveys conducted. The Shannon index is widely used in ecological studies and accounts for both species richness and evenness: the index will be high if species richness is high, or if evenness is high, or both. Since the Shannon index can be difficult to interpret, we also calculated the Simpson's index of diversity (1-D), which also incorporates both species richness and evenness; however, may be simpler to interpret since the values range from 0 to 1—the greater the value, the greater the sample diversity. Another way to calculate species diversity (using both species richness and evenness) is to standardize the value by the species detected in the sample, as in the N1 transformation of the Shannon index (MacArthur 1965). In other words, if species were distributed completely evenly, then the N1 transformation value would equal the species richness.

Small Mammals

Small mammals were surveyed using Sherman live-traps (7.7 x 9.0 x 23.0 cm) at six locations in Guadalcanal. Traps were placed along five transects consisting of 10 traps placed at 10-m intervals and one 5 x 5 grid of 25 traps placed at 10 m intervals (Figure 1). Small mammal surveys occurred for 3 consecutive nights. 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 on each trap to protect captured animals from exposure to the elements. Traps were baited with a mixture of dry seeds, chopped walnuts and dried meal worms. We recorded species identification, sex, age, mass (g), reproductive condition, and presence of wounds or parasites 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 20 mm from the base, left hind foot length, left ear length, venter coloration pattern, bi-coloration of tail, and behavior. Captured individuals were marked by fur clipping to identify recaptures. In September 2007, animals were marked with colored paint pens to identify recaptured individuals. Analyses included a 0.5 trap night correction for sprung but empty traps (Nelson and Clark 1973) and data are presented as the number of new individuals captured per 100 trap nights.

RESULTS AND DISCUSSION

Hydrology

Water level elevations were used to identify patterns of tidal cycles through time and to determine tidal datum, such as the mean higher high water (MHHW). Guadalcanal is fully tidal and experiences tidal amplitude, period and range similar to that of the predicted levels for Mare Island Straight (Tides and Currents Pro; Nautical Software, Inc.; Figure 9). Sedimentation within the main channel limited daily minimum water levels to 1.8 ft NAVD88 at the location of the datalogger (Figure 10). The average daily tidal range from January to July 2007 was 4.2 ± 0.1 ft NAVD88. The highest recorded tide level occurred during the extreme high tide and flooding event on 1 Jan 2006 at 9.2 ft NAVD88, compared to the highest water level in 2007, which occurred on 15 Jun 2007 at 7.4 ft NAVD88.

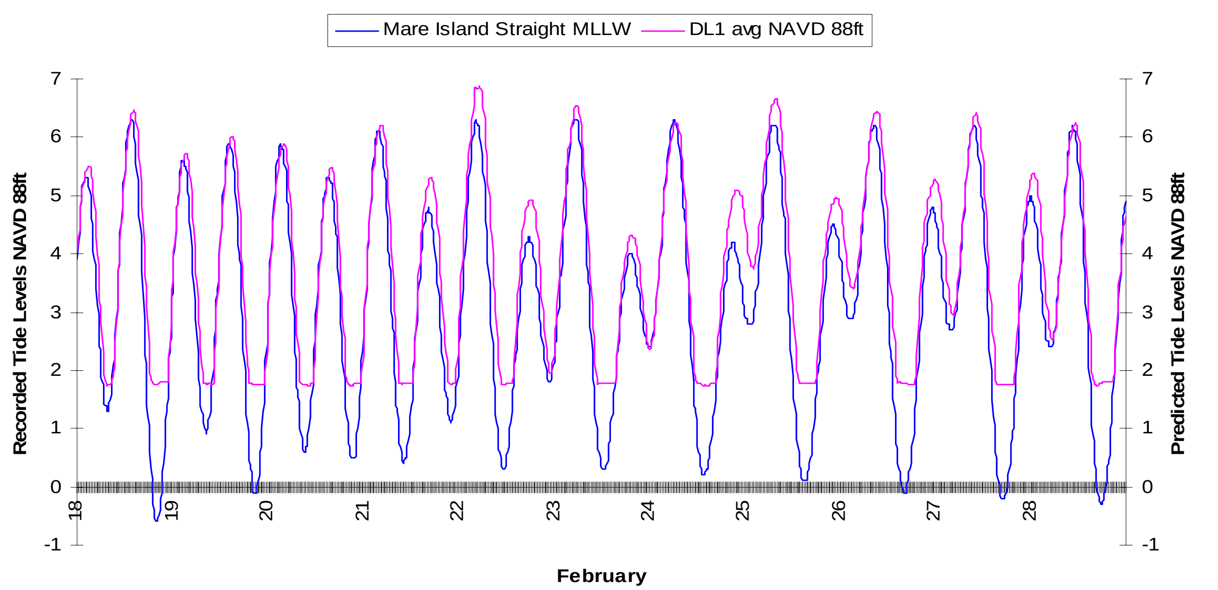


Figure 9. Water levels from 18-28 February 2007 (NAVD88 ft) are compared to the predicted water levels in the Mare Island Straight (MLLW; Tides and Currents v2.5).

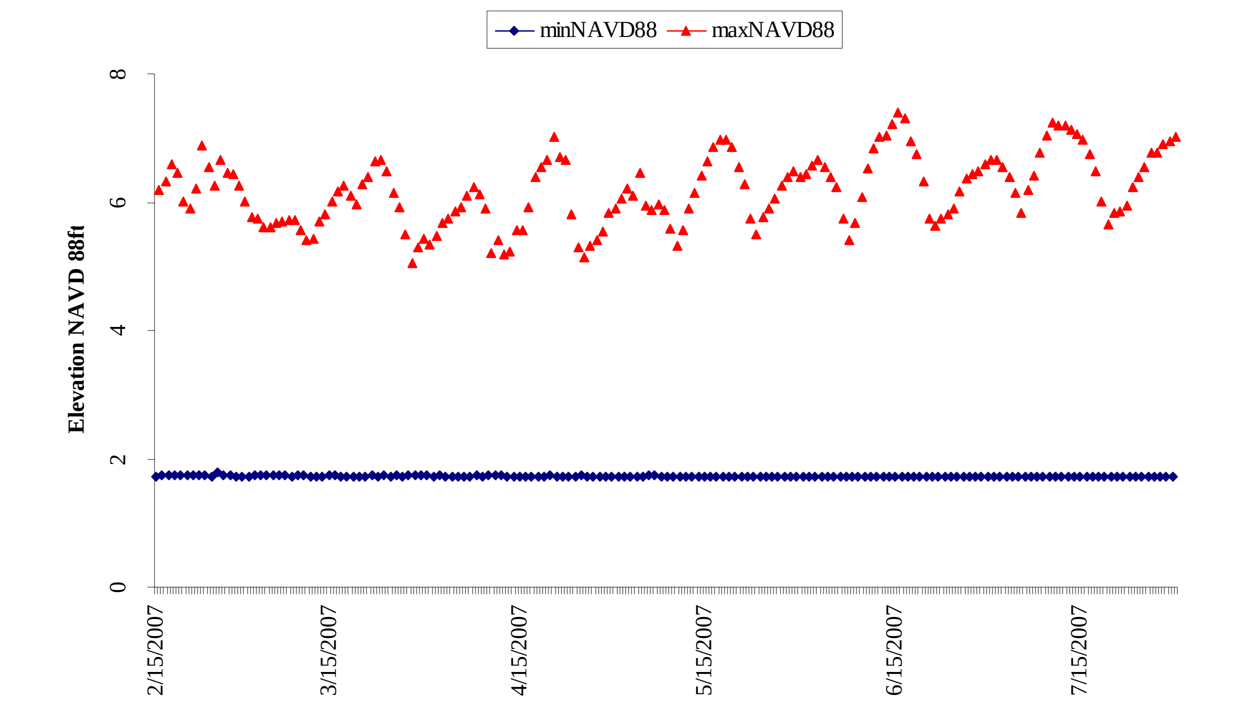


Figure 10. Daily minimum and maximum water levels (NAVD88 ft) from 15 Feb to 30 July 2007 in the Guadalcanal Restoration Site.

Water Quality

Pre-breach water quality measurements reflected pooled rainwater conditions. pH was neutral (7.1), salinity was approximately fresh (0.6 ppt), temperature was typical of summer water temperatures (20.5 C), and dissolved oxygen was low (1.4 mg/L).

Post-breach salinity and dissolved oxygen (DO) averages were typical for this region. The salinity of this estuary generally ranges from 5 to 30 parts per thousand (ppt) depending on the amount of freshwater rain and freshwater release from dams in the upper portions of the estuary. Due to a relatively dry winter in 2006, salinity levels (19.5 $\pm$ 0.1 ppt) were similar to summer values in June 2007 (16.9 $\pm$ 0.0 ppt) (Figure 11, Table 2).

Percent DO did not vary across seasons, but seemed to be more closely linked with temperature (Table 2). At times in the summer months, the percent DO was oversaturated with readings greater than 100%, likely due to high rates of algae photosynthesis during daylight hours. Mean dissolved oxygen has increased from 1.4 mg/L pre-breach to 6.7 ± 0.1 mg/L and is now within the range found at a restored tidal wetland (Tolay Creek, March 2000) of 5.3 to 10.3 mg/L. Post-breach DO levels remained consistently above 5 mg/L, a threshold used by the California Regional Water Quality Control Board as an indicator of aquatic health. Prolonged levels below 5mg/L can impair the development of fish larvae and other invertebrates (CWT 2004).

The mean pH did not vary appreciably from pre-breach in 2000 (7.1 ± 0.2) and post-breach in 2007 (7.6 ± 0.2). Recorded pH values are within the recorded range for this estuary (6.8 to 8.6; Siegel 1998).

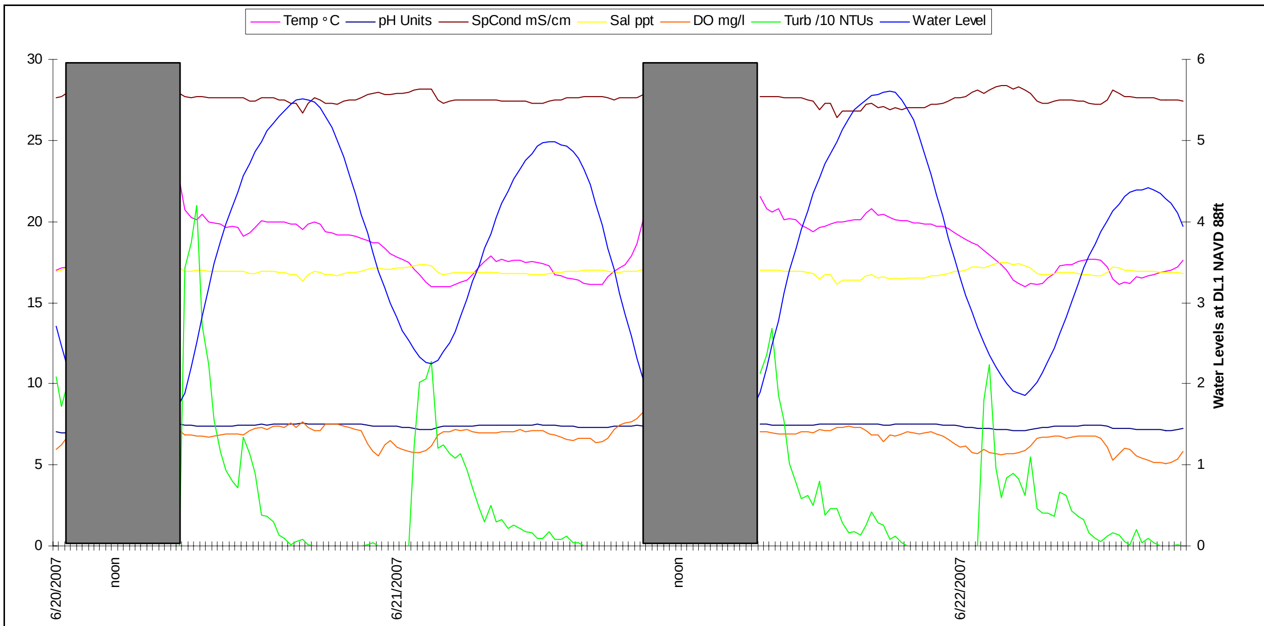


Figure 11. Water quality data from 20 to 22 June 2007. Temperature (°C), pH, specific conductivity (mS/cm), salinity (ppt), dissolved oxygen (mg/L), and turbidity (divided by 10 for scale) are presented on the primary axis and water levels are displayed on the secondary axis (NAVD88 ft). The dark bar shows when water levels were below the sensors.

Table 2. Water quality parameters (mean ± SE for temperature, pH, specific conductivity, dissolved oxygen, turbidity and salinity) collected in June 2000 (pre-breach) and between March 2005 and June 2007 (post-breach).

		N	**Temperature** (ºC)	**pH** (units)	**Specific Conductivity** (mS/cm)	**DO** (% saturation)	**Turbidity** (ntu)	**Salinity** (ppt)
2000	Jun	6	20.5 ± 0.9	7.1	9.7 ± 0.8	-	-	5.5 ± 0.1
2005	Jun	157	18.7 ± 0.1	7.5	6.5 ± 0.1	82.5 ± 0.7	44.0 ± 4.3	3.6 ± 0.0
2006	Sep	198	20.0 ± 0.1	7.8	25.4 ± 0.3	86.4 ± 1.8	-	5.4 ± 0.0
	Dec	154	10.3 ± 0.1	7.7	31.3 ± 0.2	81.7 ± 0.4	-	19.5 ± 0.1
2007	Mar	135	15.6 ± 0.1	7.8	21.8 ± 0.1	83.8 ± 0.7	-	13.0 ± 0.1
	Jun	156	18.3 ± 0.1	7.4	27.5 ± 0.0	78.9 ± 0.7	27.1 ± 3.2	16.9 ± 0.0

Geomorphology

Aerial Photograph and Land Cover Interpretation

Aerial photographs provide useful information in characterizing restoration changes over time. The Guadalcanal aerials documented sediment accretion over the past 5 years. The 2004 aerial shows initial sedimentation and narrowing of the main channel. Further sediment accumulation at the channel edges and algae colonization on the mudflats is evident from the 2006 and 2007 aerial photographs (Figure 4). Sediment dispersal patterns observed from this imagery were confirmed and quantified by sediment pin and bathymetric data.

Once georeferenced, the 2006 aerial was analyzed using ERDAS Imagine software to provide rough estimates of land cover type (Figure 12). Mudflat comprised the largest habitat element (35% at -1.1 MLLW in Mare Island Straight), followed by tidal marsh vegetation (33%), open water (12%), bare/levee top (7%) and algae (6%). This method is useful in establishing early vegetation colonization and spread in subsequent years using remote methods.

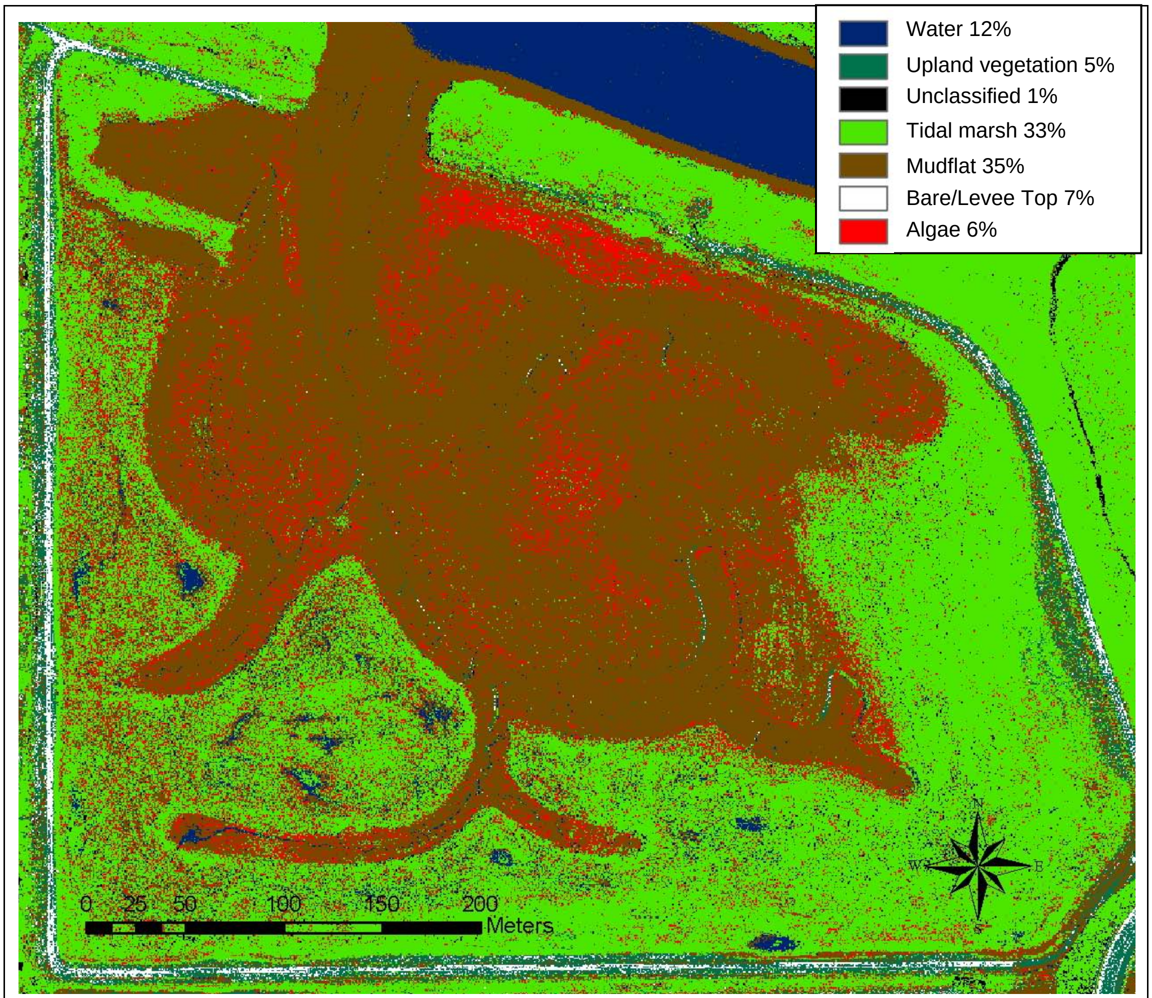


Figure 12. Land cover classifications for September 2006. We grouped pixels based on color signatures and on the ground knowledge into 6 major land cover types: water, upland vegetation, tidal marsh, mudflat, bare, algae, and unclassified.

Photodocumentation

Digital panoramic photographs were taken annually from seven permanent points within the project (Figure 1) to track qualitative changes and to provide reference points for levee erosion, channel width changes, and changes in vegetation. Photographs were first taken in June 2000 to document pre-breach conditions (Appendix A). An increase in pickleweed (*Sarcocornia pacifica*, formerly *Salicornia virginica*) and cordgrass (*Spartina foliosa*) as well as coyote brush (*Baccharis pilularis*) in the upland areas were documented from photopoints taken in the same location from 2000 to 2007 (Figure 13). The latest set of images show increased vegetation development in the marsh plain (Appendix B).

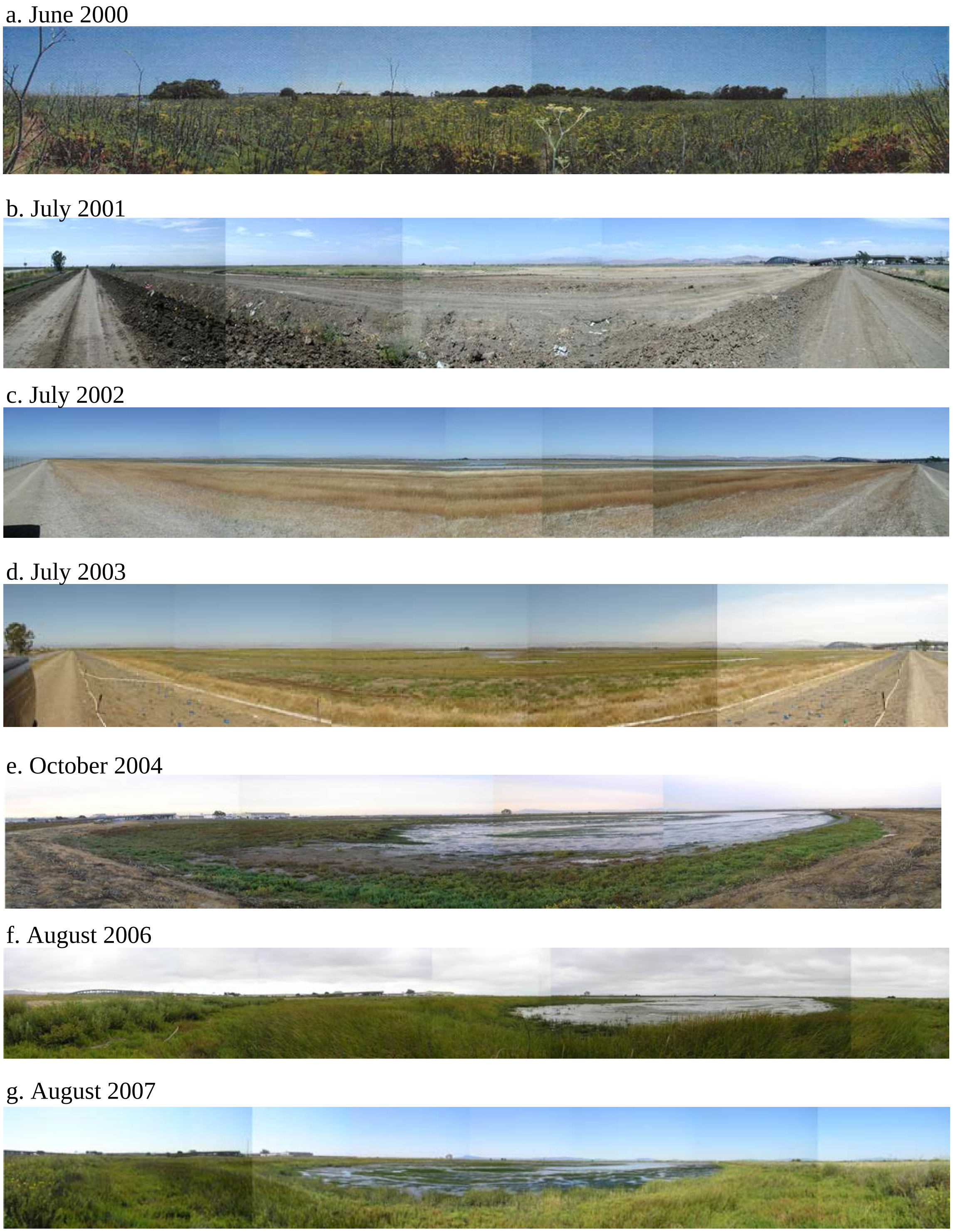


Figure 13. Comparison of panoramic views from photopoint 4 in 2000 (a), 2001 (b), 2002 (c), 2003 (d), 2004 (e), 2006 (f) and 2007 (g).

Sedimentation

Sedimentation: Sediment pins

We measured sediment accumulation seasonally from 2002 to 2007 to the nearest 0.5 cm. Overall, Guadalcanal accumulated 11.0 ± 9.6 cm of sediment between Feb 2002 and Sep 2007 with a gain of 3.7 ± 1.5 cm in the past 12 months. Sediment pins were grouped for analyses by their location in the project as channel (n=5), high marsh (n=4), and low marsh (n=6; Figure 14, Figure 15). The greatest sediment accumulation between Feb 2002 and Sep 2007 occurred in the channels (65.6 ± 49.1 cm). The high marsh (-3.1 ± 0.6 cm) and low marsh (2.3 ± 2.2 cm) experienced little sediment gain or loss with the exception of sedpin 3 (10.9 cm) which is located in the NW corner of the project. Due to the high sedimentation rates within the channels, water is completely drained out of Guadalcanal during low tide and the channel thalweg is visible. Vegetation (*Spartina*) has also colonized the southernmost channel.

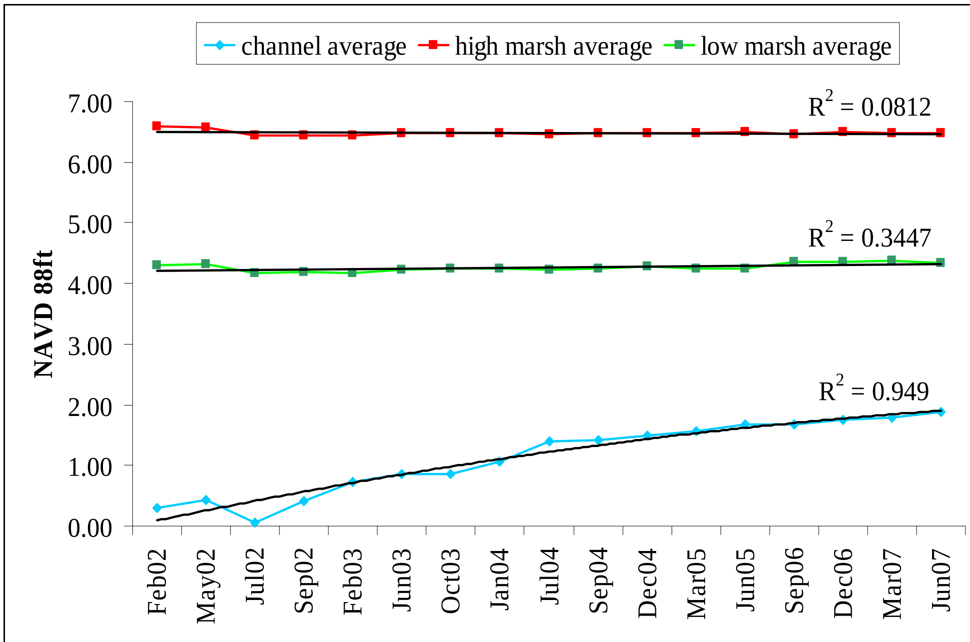


Figure 14. Average sediment elevations (NAVD88 ft) for channel, high marsh and low marsh between February 2002 and June 2007.

Sedpin 7b, located in the channel, accrued the most sediment (114.6 cm) from Feb 2002 to Sept 2007 (Figure 15; Figure 16). Sedpin 6, located in the marsh plain, had the greatest elevation loss (-4.0 cm), where soils may have settled. Sedpin 5, located in the low marsh area, lost 3.84 cm of elevation. From Sep 2006 - Sep 2007 the channel gained 9.7 ± 2.9 cm of sediment but the high marsh (0.8 ± 0.2 cm) and low marsh (0.7 ± 0.6 cm) remained relatively stable.

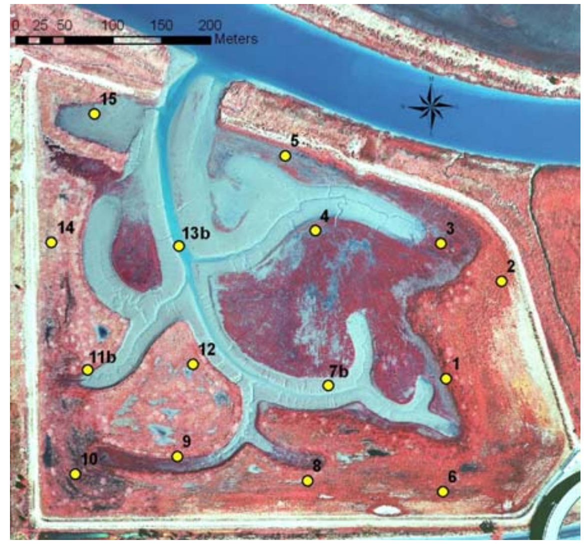


Figure 15. Sediment pin locations

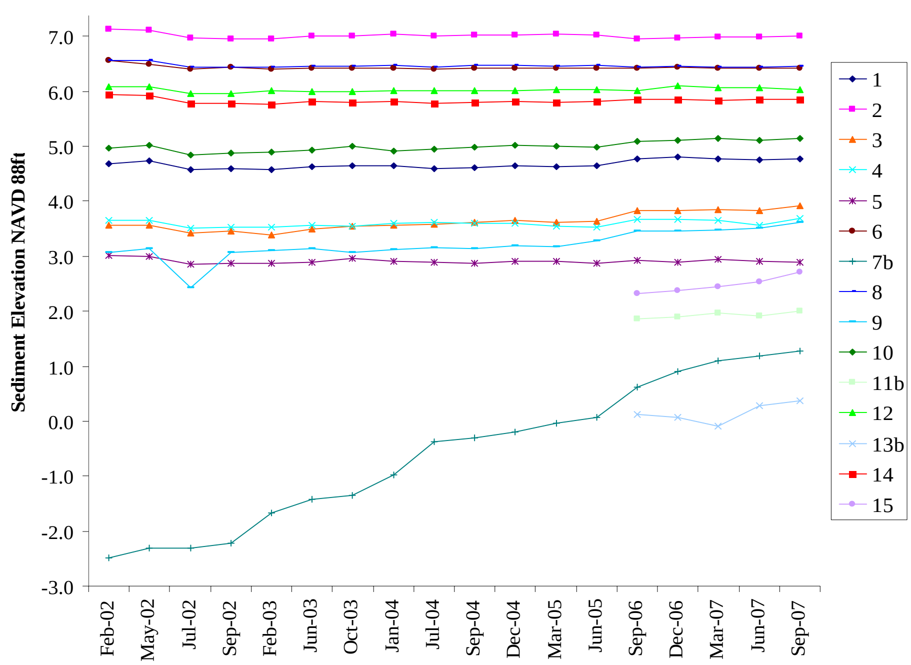


Figure 16. Sediment elevation (NAVD88 ft) at 15 sediment pin locations from February 2002 to June 2007.

Sedimentation: bathymetry

The bathymetric map showed the large mudflat at the center of the project (elevation ranged from 3.3 to 4.9 ft NAVD88) and the primary channels (1.8 to -6.0 ft NAVD88), but it also captured more discreet areas of sediment accretion in the project (Figure 17) where sediment pins are lacking. Areas of high elevation include the mudflat on the west side of the project and northwest of sedpin 4. The southernmost channels are much shallower (2.4 to 4.2 ft NAVD88) compared to other channel elevations. Sedpin 9, which is located within the southernmost channel, showed a gain of 16.5 cm with a year (Sept 2006 to Sept 2007).

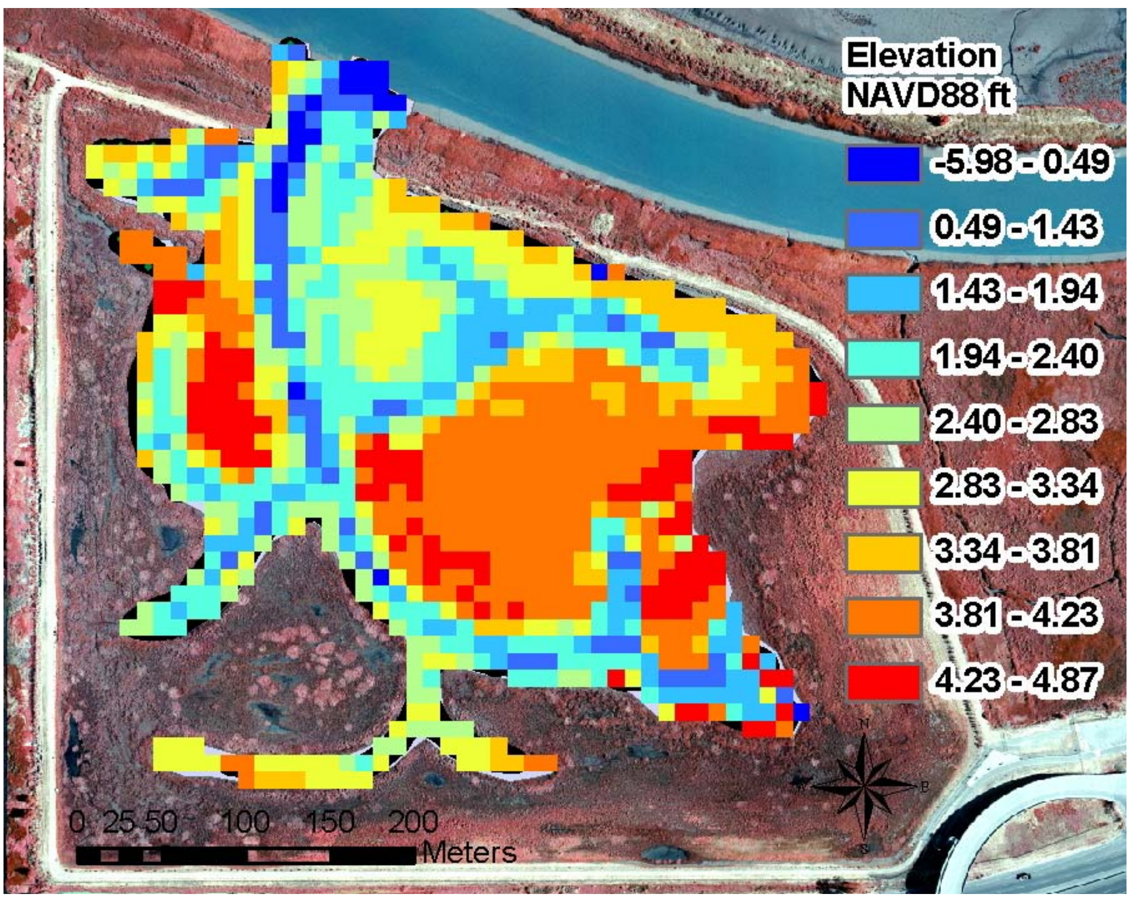


Figure 17. Bathymetric survey at Guadalcanal in September 2006 show sediment surface elevations (NAVD88 ft).

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 sediment surface elevations measured by sediment pins and bathymetry interpolations was 6.6 $\pm$ 4.3 cm. Sources of error may be attributed to difference in survey timing, accuracy of sediment pin measurements, 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 datapoints to 10 m grids.

Vegetation

Fifty-six plant species have been detected within the Guadalcanal Restoration Area, 21 of which are native (Table 3). Pre-breach surveys recorded 25 plant species with only 3 native species.

Prior to the breach, the site was dominated by nonnative plants and grasses: common fennel (*Foeniculum vulgare*), wild oat (*Avena fatua*), Mediterranean barley (*Hordeum marinum*), perennial ryegrass (*Lolium perenne*), Sydney golden wattle (*Acacia longifolia*), annual beardgrass (*Polypogon sp.*), fat hen (*Atriplex triangularis*) and curly dock (*Rumex crispus*). Eucalyptus trees (*Eucalyptus camaldulensis*) were present at 16 $\pm$ 6% cover but were removed prior to the breach. Common fennel comprised 37 $\pm$ 10% cover of the site and Sydney golden wattle was at 15 $\pm$ 8% cover (quadrat method).

Table 3. List of native and non-native plant species detected during vegetation surveys.

Common Name	Scientific Name	Code	Native[1]
alkali heath	*Frankenia salina*	FRSA	Y
American bulrush	*Bolboschoenus maritimus*	BOMA	Y
arrowgrass	*Triglochin maritima*	TRMA	Y
barley	*Hordeum murinum*	HOMU	N
bird’s-foot trefoil	*Lotus corniculatus*	LOCO	N
common brass buttons	*Cotula coronopifolia*	COCO	N
bristly ox-tongue	*Picris echioides*	PIEC	N
buckhorn plantain	*Plantago coronopus*	PLCO	N
California burrclover	*Medicago polymorpha*	MEPO	N
California poppy	*Eschscholzia californica*	ESCA	Y
California tule	*Schoenoplectus californicus*	SCCA	Y
cattail species	*Typha spp.*	TYSP	-
cheeseweed	*Malva parviflora*	MAPA	N
cocklebur	*Xanthium strumarium*	XAST	Y
common fennel	*Foeniculum vulgare*	FOVU	N
common knotweed	*Polygonum arenastrum*	POAR	N
common sowthistle	*Sonchus oleraceus*	SOOL	N
common vetch	*Vicia sativa*	VISA	N
common wild radish	*Raphanus sativa*	RASA	N
cordgrass	*Spartina foliosa*	SPFO	Y
coyote brush	*Baccharis pilularis*	BAPI	Y
curly dock	*Rumex crispus*	RUCR	N
Eleocharis species	*Eleocharis spp.*	ELSP	Y
English plantain	*Plantago lanceolata*	PLLA	N
fat hen	*Atriplex triangularis*	ATTR	Y
fescue	*Vulpia microstachys*	VUMI	Y
gum-plant	*Grindelia stricta*	GRST	Y
Hordeum species	*Hordeum spp.*	HOSP	N
horseweed species	*Conyza spp.*	COSP	-
Italian ryegrass	*Lolium multiflorum*	LOMU	N
Lolium species	*Lolium spp*	LOSP	N
longbeak stork’s bill	*Erodium botrys*	ERBO	N
Marin knotweed	*Polygonum marinense*	POMA	Y
meadow barley	*Hordeum brachyantherum*	HOBR	Y
Mediterranean barley	*Hordeum marinum*	HOMA	N
perennial rye grass	*Lolium perenne*	LOPE	N
pickleweed	*Sarcocornia pacifica*	SAPA	Y
plantago species	*Plantago spp.*	PLSP	Y
prickly lettuce	*Lactuca serriola*	LASE	N
purple star thistle	*Centaurea calcitrapa*	CECA	N
rabbitfoot beardgrass	*Polypogon monspeliensis*	POMO	N
red clover	*Trifolium pratense*	TRPR	N
red sandspurry	*Spergularia rubra*	SPRU	N

Common Name	Scientific Name	Code	Native[1]
ripgut brome	*Bromus diandrus*	BRDI	N
Russian thistle	*Salsola soda*	SASO	N
salt grass	*Distichlis spicata*	DISP	Y
saltmarsh daisy	*Jaumea carnosa*	JACA	Y
scarlet pimpernel	*Anagallis arvensis*	ANAR	N
sea lavender	*Limonium californicum*	LICA	Y
soft chess	*Bromus hordeaceous*	BRHO	N
sour clover	*Melilotus indica*	MEIN	N
Spanish clover	*Lotus purshianus*	LOPU	Y
spikeweed	*Hemizonia pungens*	HEPU	Y
sticky sandspurry	*Spergularia macrotheca*	SPMA	Y
stinkwort	*Dittrichia graveolens*	DIGR	N
wild oats	*Avena fatua*	AVFA	N
yellow star thistle	*Centaurea solstitialis*	CESO	N
algae	*n/a*	ALGA	-
bare ground	*n/a*	BARE	-
dead	*n/a*	LITR	-
open water	*n/a*	OPWA	-

[1]Yes or No

Post breach surveys showed that the relative percent cover of pickleweed increased from 1% in 2002 to 32% in 2006 but decreased slightly to 26% in 2007 (quadrat surveys method; Figure 18). There has been an increase in percent cover of algae from 0% in 2002 to 18% in 2007, which is also visible from the aerial photos (Figure 4). In point intercept surveys, similar patterns were observed for pickleweed where relative percent cover increased from 2% in 2002 to 41% in 2007 (Figure 19).

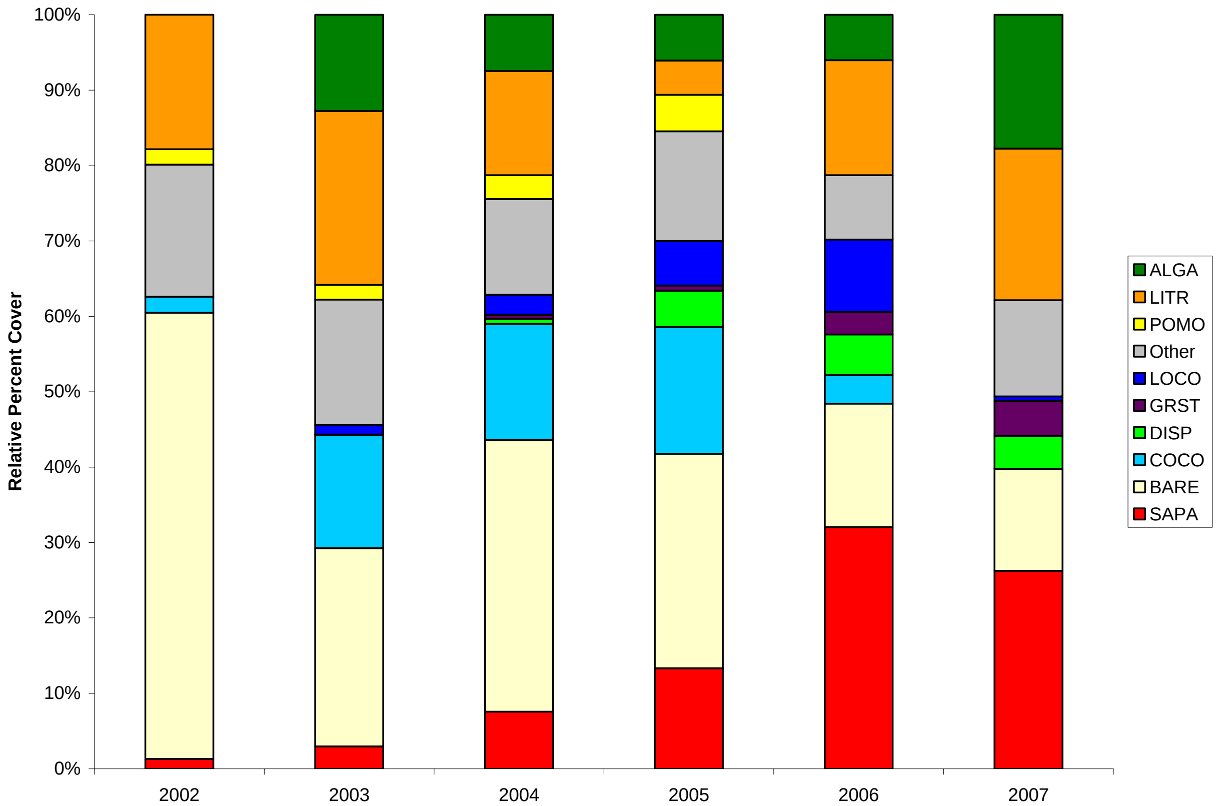


Figure 18. Relative percent cover between August 2002 and August 2007 for quadrat surveys. Category "other" includes: DISP, POMA, RUCR, SPMA, ATTR, JACA HOBR, BAPI. Species codes follow those in Table 4.

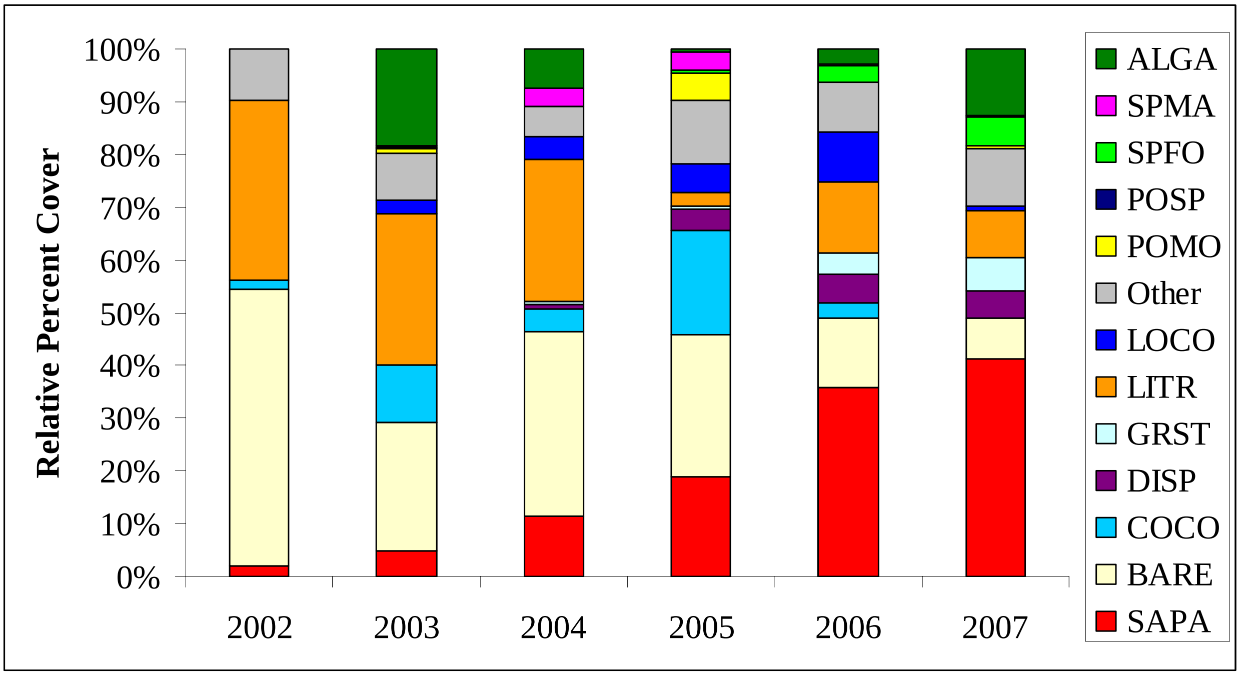


Figure 19. Relative percent cover between 2002 and 2007 for point intercept surveys. Surveys were conducted in August, except in 2005 when surveys were conducted in May, prior to the contract termination. Category "other" includes: POMA, RUCR, ATTR, JACA HOBR, BAPI. Species codes follow those in Table 4.

Between 2003 and 2005, non-native plants had greater percent cover than native species. In 2006 and 2007 native species percent cover increased from 14% in 2005 to 28% in 2006 and to 27% in 2007 (Figure 20). At the same time, percent cover of non-natives declined from 19% in 2006 to 7% in 2007 such that native species are now almost four times more abundant than non-natives. Non-native species included brass buttons (*Cotula coronopifolia*), which declined (Figure 19, Figure 20)

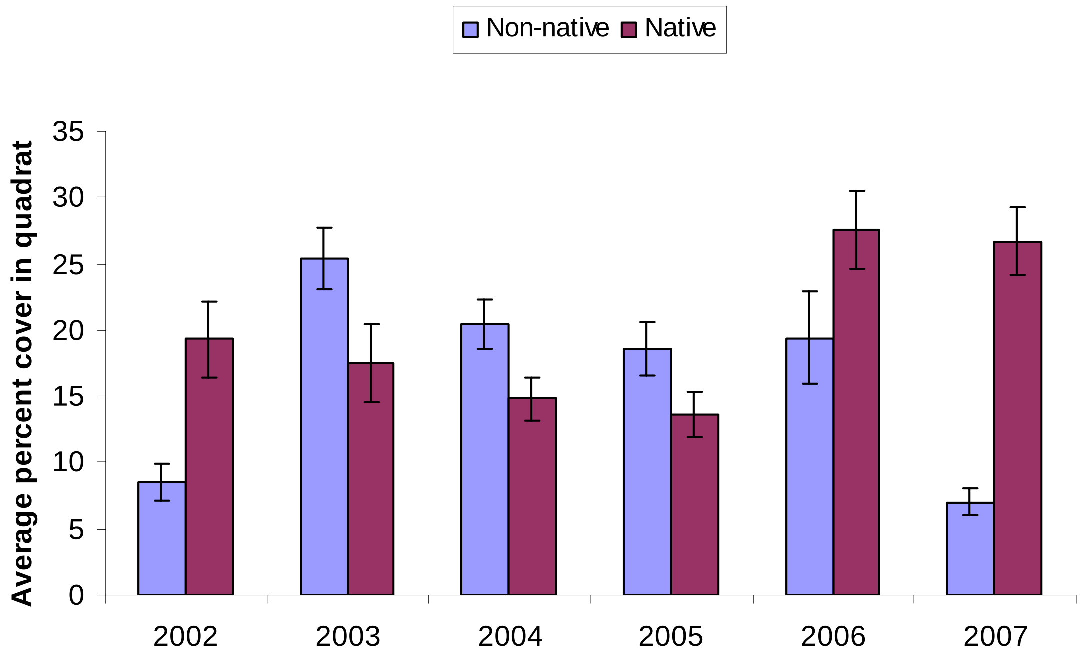


Figure 20. Overall average native and non-native plant cover (mean ± SE, from quadrat surveys) conducted annually in August from 2002 to 2007.

Invasive, non-native species detected in Guadalcanal include yellow star thistle (*Centaurea solstitialis*), purple star thistle (*Centaurea calcitrapa*), and common fennel. These weeds mainly occur along the tops of the levee and were not normally detected within our surveys, since we focused on vegetation within the project boundaries. Physical removal of these species has been necessary to minimize their impact on the project. A regular mowing schedule has controlled fennel; however yellow starthistle and purple starthistle plants are capable of flowering at short heights. A continued effort of invasive species removal will be required in order to maintain a low density of invasive species. Russian thistle (*Salsola soda*) is an exotic halophyte that is located along the eastern marsh plain and upland transition zone. It is a summer annual and although the seed longevity is unknown, it is thought that the seeds do not remain viable in the soil for three years or more, like other members of the same genus (Brusati and DiTomaso 2007).

Several *Spartina* plants were observed, which were taller and more robust looking, similar to characteristic found in the non-native *Spartina alterniflora* and hybrids. These plants were located north of sediment pin 8 directly in line with the flow of the main channel. We contacted the Invasive Spartina Project (ISP) which conducted two field surveys. *Spartina* plants in question were collected for further analysis. Genetic analysis confirmed that these plants were native *Spartina foliosa*.

Invertebrates

Benthic invertebrates were collected on Aug 31, 2004 and Sep 5, 2006. Invertebrate abundances were extrapolated from cores to number of individuals/m^2 within a depth of 10 cm. In 2004 and 2006, 37 taxa within 11 taxonomic classes were detected. Although the invertebrate community composition remained relatively similar across sampling years (26 taxa in 7 classes in 2004, 24 taxa in 11 classes in 2006), the overall abundance of pooled taxa declined approximately 80% (Table 4). Despite an overall decline in invertebrate abundance, some taxa increased from 2004 to 2006: Nematoda, Gastropoda, Oligochaeta, Ostracoda and Sipuncula. These declines may indicate a change in the benthic conditions at the restoration site, or reflect predation by shorebirds.

Table 4. Abundance of invertebrate taxa (per m^2) detected at Guadalcanal in 2004 and 2006.

Class	Name	2004	2006
Annelida	Tubificidae	13,885	255
Bivalvia	Corbiculidae	-	1,147
	Corbuculidae	1,019	-
	Macoma	4,586	255
	Myidae	9,045	3,822
	Potamocorbula	-	1,656
Gastropoda	Assiminea	-	764
Hirudinea	Hirudinea	127	510
Insecta	Chironomidae	-	127
	Diptera	127	127
	Formicidae	127	-
Malacostraca	Copepoda	-	127
	Corophiidae	-	127
	Corophium	39,618	5,605
	Cumacea	155,415	2,675
	Ericthonius	127	-
	Grandidierella	127	-
	Isopoda	892	3,822
	Mysidae	255	-
	Pancolus	56,815	255
Nematoda	Nematoda	-	255
Oligochaeta	Oligochaeta	-	7,898
Ostracoda	Ostracoda	9,299	22,803
Polychaeta	Capitella	-	2,166
	Capitellidae	19,618	-
	Glycinde	1,656	127
	Nereidae	127	-
	Opheliidae	1,656	-
	Orbiniidae	1,911	-
	Polychaeta	7,134	255
	Spionidae	4,331	-
	Terebellidae	-	4,331
Sipuncula			

Amphipods (genus *Corophium*) and marine crustaceans (order *Cumacea*) were the only taxa present in all 2004 samples. In the 2006 samples, crustaceans in the class *Ostracoda* were the most abundant taxa. Cumacean crustaceans were the dominant group in 66% of cores sampled in 2004. The greatest average density of amphipods was in the mudflat (104,969 amphipods/m^2) (Table 5), as compared to the mudflat transition (31,465 amphipods/m^2), and vegetated margins (18,981 amphipods/m^2).

Table 5. 2004 invertebrate taxa detected /m^2 by habitat type

Taxon	Channel				Panne				Plain			
	A3	B3	C3	D3	A2	B2	C2	D2	A1	B1	C1	D1
Amphipoda	255	127	-	-	-	-	382	-	-	-	-	255
Balanus	-	-	-	-	-	127	-	-	-	-	-	-
Bivalvia	-	-	-	2930	382	-	-	764	-	382	127	127
Brachyura	-	-	-	-	-	127	-	-	-	-	-	127
Capitellidae	1274	2293	127	1656	2803	255	-	382	8153	-	255	2420
Corbuculidae	-	-	-	-	-	892	-	-	127	-	-	-
Corophium	2038	510	2293	1911	7389	1019	5987	10955	2420	1147	3567	382
Cumacea	43694	15414	13248	32612	2293	1529	10955	16688	637	10573	637	7134
Diptera	-	-	-	-	127	-	-	-	-	-	-	-
Ericthonius	-	127	-	-	-	-	-	-	-	-	-	-
Formicidae	-	-	-	-	-	-	-	127	-	-	-	-
Glycinde	127	255	255	382	-	-	-	-	637	-	-	-
Grandidierella	-	-	-	-	-	-	127	-	-	-	-	-
Hirudinea	-	-	-	-	-	-	-	-	127	-	-	-
Isopoda	127	-	-	-	-	-	-	-	637	-	-	127
Macoma	382	892	510	-	637	-	892	127	-	-	1147	-
Myidae	1656	4713	-	382	127	-	2038	-	-	-	-	127
Mysidae	-	-	-	-	-	-	-	-	-	-	255	-
Nereidae	-	-	-	-	-	-	-	-	-	-	127	-
Opheliidae	1656	-	-	-	-	-	-	-	-	-	-	-
Orbiniidae	510	-	-	-	-	-	-	-	1401	-	-	-
Ostracoda	3949	510	-	-	2038	382	-	-	2420	-	-	-
Pancolus	382	892	-	255	25223	21911	-	510	4841	2038	255	510
Polychaeta	1656	-	-	-	-	764	-	382	2675	764	255	637
Spionidae	2675	892	382	-	-	-	-	255	-	-	127	-
Tubificidae	-	1019	-	3567	892	-	-	7261	-	-	1147	-

The same taxa did not have a dominant presence in 2006 samples, with densities in mudlflat (1,147 amphipods/m^2), mudflat transition (1,147 amphipods/ m^2) and vegetated margin (382 amphipods/m^2) were significantly lower (Table 6). The gastropod, *Assiminea californica*, a native snail found from Vancouver to Baja, CA, was detected in low abundances (764/m^2) in only one marsh sample in 2006.

Table 6. 2006 invertebrate taxa detected (per m^2) by habitat zone.

Taxon	Channel				Panne				Plain			
	A3	B3	C3	D3	A2	B2	C2	D2	A1	B1	C1	D1
Assiminea	255	6242	-	-	255	1147	-	-	764	-	127	-
Bivalvia	382	-	-	-	127	-	382	255	-	-	127	-
Capitella	-	-	1401	510	-	-	-	255	-	-	-	-
Chironomidae	-	-	-	-	-	-	-	-	-	-	127	-
Copepoda	-	-	-	-	-	-	127	-	-	-	-	-
Corbiculidae	-	764	-	-	-	-	382	-	-	-	-	-
Corophiidae	-	-	-	-	127	-	-	-	-	-	-	-
Corophium	255	-	1019	637	510	-	510	637	127	1529	127	255
Cumacea	255	-	255	637	764	-	382	-	127	255	-	-
Diptera	-	-	127	-	-	-	-	-	-	-	-	-
Glycinde	-	-	-	-	-	-	-	127	-	-	-	-
Hirudinea	-	-	-	-	-	-	-	127	-	255	-	127
Isopoda	127	510	382	255	-	127	-	510	1401	-	255	255
Macoma	-	-	-	-	-	-	255	-	-	-	-	-
Myidae	-	-	-	3567	-	-	-	255	-	-	-	-
Nematoda	-	-	255	-	-	-	-	-	-	-	-	-
Oligochaeta	510	-	-	-	2675	764	892	127	1401	1147	382	-
Ostracoda	1401	1019	-	-	1147	1656	-	892	15924	382	-	382
Pancolus	-	-	-	255	-	-	-	-	-	-	-	-
Polychaeta	-	-	127	-	-	-	-	-	-	-	127	-
Potamocorbula	-	-	510	892	-	-	-	-	255	-	-	-
Sipuncula	-	-	127	-	-	-	-	127	-	-	-	-
Terebellidae	-	-	-	-	-	4331	-	-	-	-	-	-
Tubificidae	-	-	-	-	-	-	-	255	-	-	-	-

Bivalves (class *Bivalvia*) reached their highest average density in the mudflats (8,535 bivalves/m^2), as compared to the mudflat transition (4,713 bivalves/m^2), and the vegetated margin (1,401 bivalves/m^2) in 2004. *Macoma balthica* comprised 31% of bivalves in sediment cores. The invasive Asian clam, *Corbula amurensis*, was present in 3 samples but comprised only 6% of those samples.

In 2006, bivalves exhibited similar patterns of decline in abundance, reaching their highest average density in the mudflats (1,401 bivalves/m^2), as compared to the mudflat transition (255 bivalves/m^2), and the vegetated margin (255 bivalves/ m^2) in 2004. *Macoma balthica* comprised 4% of bivalves in sediment cores. The invasive Asian clam, *Corbula amurensis*, was present in 3 samples but comprised only 17% of those samples.

Fish

A total of 67 fish, representing 8 species, were caught during the September 2006 survey and 14 fish (9 species) were caught during the September 2007 survey (Table 7). In 2006, bag seining yielded 37 fish, whereas beach seining yielded 30 fish. Each seine type captured five species.

Table 7. Fish and invertebrate species in 2006 and 2007 using bag seine and beach seine methods. Crangon and Paleamon species were not detected in 2006.

Common name	**Scientific Name**	**Native**	**2006**	**2007**
Corbula species	*Corbula spp.*	No	--	2
Crangon species	*Crangon spp.*	Yes	--	1
Hemigrapsus species	*Hemigrapsus spp.*	n/a	--	1
inland silverside	*Menidia beryllina*	No	33	2
longjaw mudsucker	*Gillichthys mirabilis*	Yes	1	--
Macoma species	*Macoma spp.*	Yes	--	1
Palaemon species	*Palaemon spp.*	No	--	1
rainwater killifish	*Lucania parva*	No	1	--
Sacramento splittail	*Pogonichthys macrolepidotus*	Yes	8	--
shimofuri goby	*Tridentiger bifasciatus*	No	3	--
starry flounder	*Platichthys stellatus*	Yes	--	1
striped bass	*Morone saxatilis*	No	18	2
threadfin shad	*Dorosoma petenense*	No	1	--
yellowfin goby	*Acanthogobius flavimanus*	No	2	3
Total			**67**	**14**

The bag seine captured mostly inland silverside (*Menidia beryllina*), followed by shimofuri goby (*Tridentiger bifasciatus*), then by striped bass (*Morone saxatilis*), and lastly by longjaw mudsucker (*Gillichthys mirabilis*) and rainwater killifish (*Lucania parva*). By comparison, the beach seine captured mostly striped bass, followed by Sacramento splittail (*Pogonichthys macrolepidotus*), inland silverside, yellowfin goby (*Acanthogobius flavimanus*), and threadfin shad (*Dorosoma petenense*). Although not caught in our seines, we observed a dead adult Chinook salmon (*Oncorhynchus tshawytscha*) at site 2 near the western edge of the marsh.

During the 2006 survey, three species were encountered for the first time: inland silverside, threadfin shad, and longjaw mudsucker. Our 2006 results closely resembled the species assemblages present in the Napa-Sonoma salt ponds, which were dominated by inland silverside, rainwater killifish, and three-spine stickleback (*Gasterosteus aculeatus*) captured in bag seines and striped bass, splittail, common carp (*Cyprinus carpio*), and topsmelt (*Atherinops affinis*) captured in variable-mesh gill nets at salinity ranges similar to those found at our study area (Takekawa et al. 2006). Water quality at the two sampling locations showed little variation during the 2006 survey. Water temperature ranged from 16.9 to 17.6°C and dissolved oxygen ranged from 6.2 mg/L to 6.8 mg/L, whereas pH (7.3) and salinity (15.7 ppt) did not differ.

In 2007, there was a marked decrease in fish captures with only 14 individuals caught, 6 of which were shrimp and mollusk species (Table 7). Water temperature ranged from 21.5 to 22°C, dissolved oxygen ranged from 6.9 mg/L to 7.1 mg/L, and pH ranged from 7.3 to 7.5. Salinity (19.8 ppt) was the same at the two fish sampling locations. Fish species have specific tolerances for sediment loads (Moyle 2002). Sediment samples from August 2007 were sent to a soils laboratory for particle size analysis. Annual variation is common in fish assemblages in the San Francisco Bay Estuary (Matern et al. 2002). Guadalcanal also drains out almost entirely at very low tide providing temporary habitat for fish other than mudsuckers.

Birds

We detected 31 bird species in point-count surveys (n = 20 species) and area surveys (n = 22 species) at Guadalcanal in June 2000 (pre-breach). Bird species listed as threatened or endangered were not observed at Guadalcanal prior to the breach. Observations of Federal and/or California listed Species of Special Concern (FSC/CSC) included double-crested cormorant (*Phalacrocorax auritus)*, snowy plover (*Charadrius alexandrinus*), and northern harrier (*Circus cyaneus*). Double-crested cormorants were only observed flying over the area. Of the 31 bird species observed, only 6 were recorded flying over the area: Caspian tern (*Sterna caspia*), cliff swallow (*Hirundo pyrrhonota*), double-crested cormorant, Forster's tern (*Sterna forsteri*), great egret (*Casmerodius albus*) and gull species (*Larus sp.*).

We detected a total of 95 bird species post-breach at Guadalcanal (Table 8). We grouped species into 8 guilds for analyses: shorebirds, raptors, piscivores, passerines, gulls/terns, diving ducks, dabbling ducks and other (other includes: black rail, Canada goose, ring-necked pheasant, and Virginia rail).

Table 8. Bird Species found at Guadalcanal.

Guild	**Common Name**	**Scientific Name**
Dabbler	American coot	*Fulica americana*
	American wigeon	*Anas americana*
	blue-winged teal	*Anas discors*
	cinnamon teal	*Anas cyanoptera*
	gadwall	*Anas strepera*
	green-winged teal	*Anas crecca*
	mallard	*Anas platyrhynchos*
	Northern pintail	*Anas acuta*
	Northern shoveler	*Anas clypeata*
Diver	bufflehead	*Bucephala albeola*
	canvasback	*Aythya valisineria*
	common goldeneye	*Bucephala clangula*
	redhead	*Aythya americana*
	ruddy duck	*Oxyura jamaicensis*
	scaup	*Aythya spp.*
	Western grebe	*Aechmophorus occidentalis*
Gull/Tern	black skimmer	*Rynchops niger*
	California gull	*Larus californicus*
	Caspian tern	*Sterna caspia*
	Forster's tern	*Sterna forsteri*
	herring gull	*Larus argentatus*
	ring-billed gull	*Larus delawarensis*
	Western gull	*Larus occidentalis*
Passerine	Allen's hummingbird	*Selasphorus sasin*
	American crow	*Corvus brachyrhynchos*
	American goldfinch	*Carduelis tristis*
	American pipit	*Anthus rubescens*
	American robin	*Turdus migratorius*
	Anna's hummingbird	*Calypte anna*
	barn swallow	*Hirundo rustica*
	belted kingfisher	*Ceryle alcyon*
	black phoebe	*Sayornis nigricans*
	Brewer's blackbird	*Euphagus cyanocephalus*
	brown-headed cowbird	*Molothrus ater*
	bushtit	*Psaltriparus minimus*
	cliff swallow	*Petrochelidon pyrrhonota*
	common raven	*Corvus cryptoleucus*

Guild	Common Name	Scientific Name
	common yellowthroat	*Geothlypis trichas*
	European starling	*Sturnus vulgaris*
	golden-crowned sparrow	*Zonotrichia albicollis*
	horned lark	*Eremophila alpestris*
	house finch	*Carpodacus mexicanus*
	loggerhead shrike	*Lanius excubitor*
	marsh wren	*Cistothorus palustris*
	mourning dove	*Zenaida macroura*
	Northern mockingbird	*Lanius excubitor*
	red-winged blackbird	*Agelaius phoeniceus*
	rock dove	*Coluba livia*
	savannah sparrow	*Passerculus sandwichensis*
	say's pheobe	*Sayornis saya*
	song sparrow	*Melospiza melodia*
	Western kingbird	*Tyrannus verticalis*
	Western meadowlark	*Sturnella neglecta*
	white-crowned sparrow	*Zonotrichia leucophrys*
	yellow-rumped warbler	*Dendroica coronata*
Piscivore	American white pelican	*Pelecanus occidentalis*
	double-crested cormorant	*Phalacrocorax auritus*
	great blue heron	*Ardea herodias*
	great egret	*Ardea alba*
	snowy egret	*Egretta thula*
Raptor	American kestral	*Falco sparverius*
	Northern harrier	*Circus cyaneus*
	osprey	*Pandion haliaetus*
	peregrine falcon	*Anas cyanoptera*
	red-tailed hawk	*Buteo jamaicensis*
	turkey vulture	*Cathartes aura*
	white-tailed kite	*Elanus leucurus*
Shorebird	American avocet	*Recurvirostra americana*
	black-bellied plover	*Pluvialis squatarola*
	black-necked stilt	*Himantopus mexicanus*
	Clark's greebe	*Aechmophorus clarkii*
	common snipe	*Gallinago gallinago*
	dowitcher	*Limnodromus spp.*
	dunlin	*Calidris alpina*
	greater yellowlegs	*Tringa melanoleuca*
	killdeer	*Charadrius vociferus*

Guild	Common Name	Scientific Name
	least sandpiper	*Calidris minutilla*
	lesser yellowlegs	*Tringa flavipes*
	long-billed curlew	*Numenius americanus*
	long-billed dowicher	*Limnodromus scolopaceus*
	marbled godwit	*Limosa fedoa*
	semipalmated plover	*Charadrius semipalmatus*
	semipalmated sandpiper	*Calidris pusilla*
	snowy plover	*Chradrius alexandrinus*
	spotted sandpiper	*Actitis macularia*
	Western sandpiper	*Calidris mauri*
	whimbrel	*Numenius phaeopus*
	willet	*Catoptrophorus semipalmatus*
Other	black rail	*Laterallus jamaicensis*
	Canada goose	*Branta canadensis*
	ring-necked pheasant	*Phasianus colchicus*
	virginia rail	*Rallus limicola*

Species richness and species diversity was calculated between 2000 and 2007 using the Shannon diversity index, the N1 transformation of the Shannon index, and the Simpson's index (Table 9). Though avian species richness was lowest in 2001 (17 species) and greatest in 2002 (67 species), the species diversity from the three indices showed a greater species diversity in 2001 than in 2002 (Table 9). Species richness alone can be misleading because it also does not consider the relative abundance of individuals among species (species evenness). Only 17 species were detected in 2001; however, since the relative abundance of each species were more evenly distributed than in 2002 (despite the 67 species detected), the overall species diversity was greater in 2001 than in 2002.

Species richness increased from pre-breach (range 17-21 species) to post-breach (range 54-67 species). Conversely, species diversity values do not clearly differ from pre-breach to post-breach, mainly because evenness is low (few species with high abundances, such as migratory shorebirds).

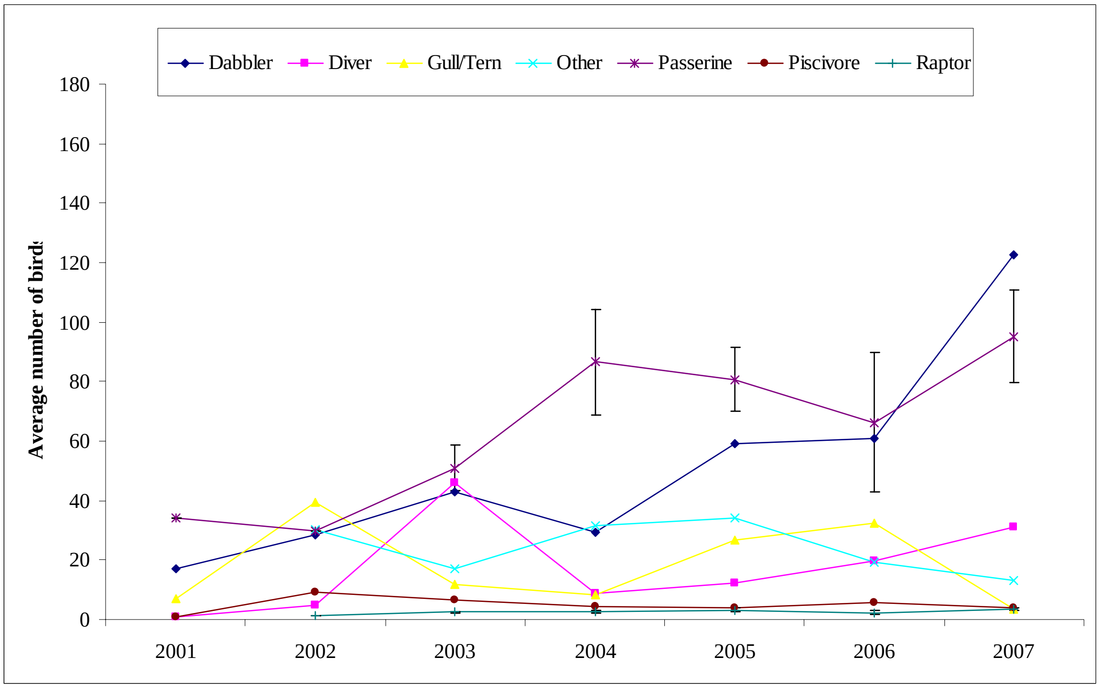
Shannon diversity is more sensitive to rare species detected in low abundance and indeed values were greatest in 2006 (2.77, when 63 species detected), but was lowest in 2002 (2.0, when 21 species detected). Values of the Shannon diversity index typically fall between 1.5 and 3.5. On the other hand the Simpson diversity index is more robust to the detection of additional species with few individuals; values were greatest in 2000 (0.90, when 21 species detected) and lowest in 2002 (0.57, when 67 species, Table 9). The Shannon and Simpson indices are fairly intuitive in that the greater the number, the higher the diversity; however, they can yield different results. The diversity indices alone do not adequately describe the changes in the avian community as the restoration progresses, thus we examined changes in species composition by guild, year, tide, season, and behavior.

Table 9. Species diversity of birds detected during area bird surveys at Guadalcanal. Measures include Species Richness and Shannon, N1 (a transformation based on the # species detected).

	2000	2001	2002	2003	2004	2005	2006	2007
Species richness	21	17	67	54	58	64	63	58
Shannon Diversity Index	2.46	1.97	1.59	2.10	1.53	2.20	2.77	2.45
Shannon Diversity Index with N1 transformation	11.72	7.21	4.88	8.17	4.63	9.04	15.88	11.64
Simpson Diversity Index	0.90	0.81	0.57	0.76	0.57	0.83	0.87	0.85

Species numbers and composition varied by year, tide and season. Dabbling duck numbers have steadily increased between 2001 (17) to 2007 (123 ± 65) but piscivore and raptor numbers have remained relatively stable over the years (Figure 21).

a. Average number of birds per survey per year.



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

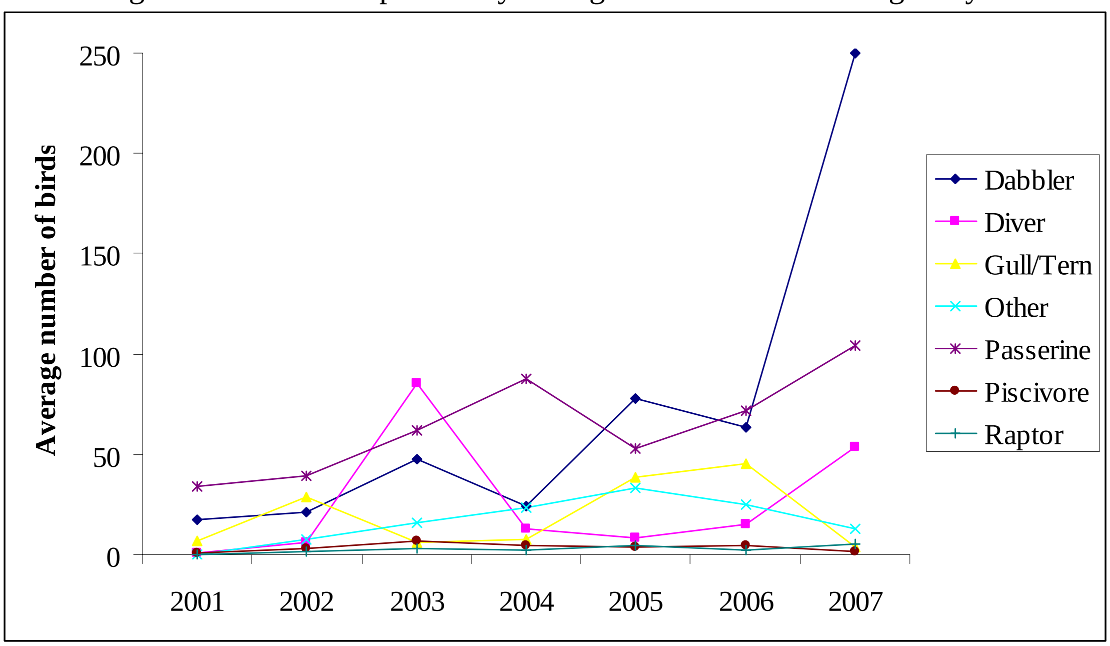


Figure 21. Average number of birds per survey (mean ± SE) detected (a) over all months and (b) during the migratory season (August-February).

The average number of shorebirds increased from a single low tide survey in 2001 (428) to their peak of abundance in 2004 (2,132 ± 1,319) but then decreased to 1,120 ± 344 in 2005, 598 ± 121 in 2006 and 725 ± 293 in 2007 (Figure 22). We also detected seasonal differences in bird abundance. In general, shorebird numbers peaked during fall through the spring (August - February) in all years with the exception of 2004 (Figure 22). Dabbling ducks and diving ducks also experienced slightly higher abundance during the fall through spring migratory seasons (Figure 21).

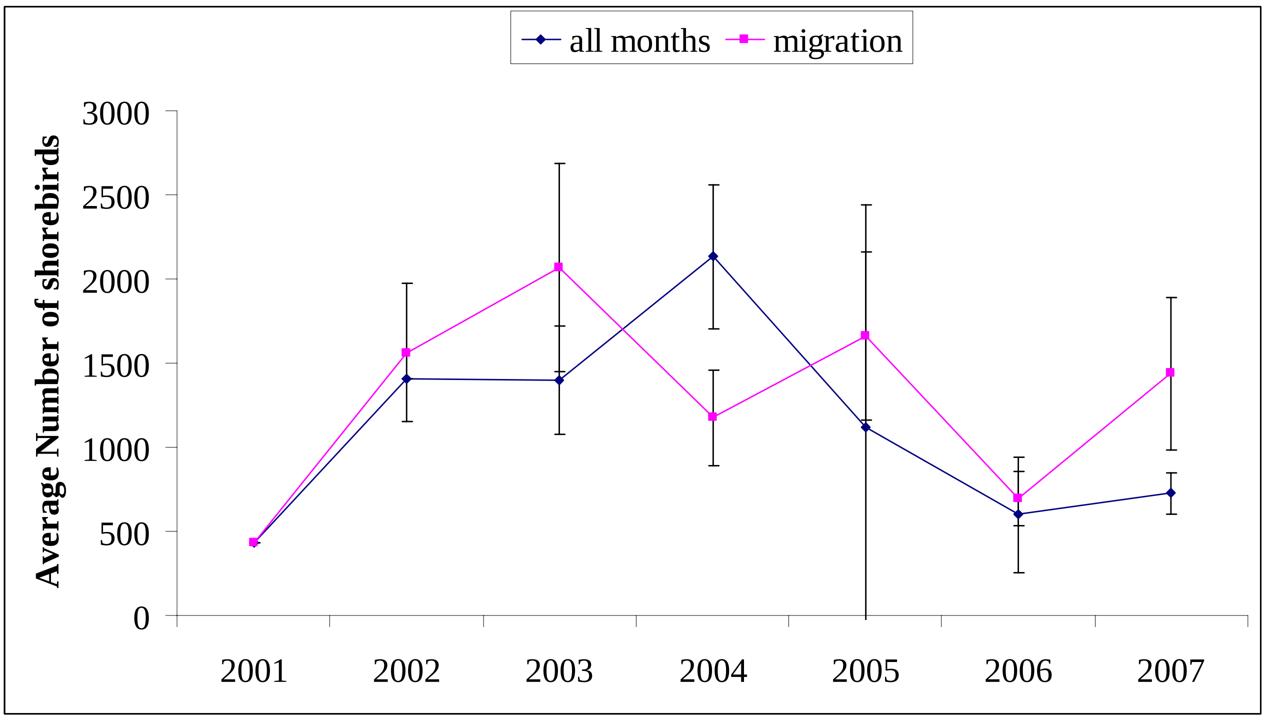
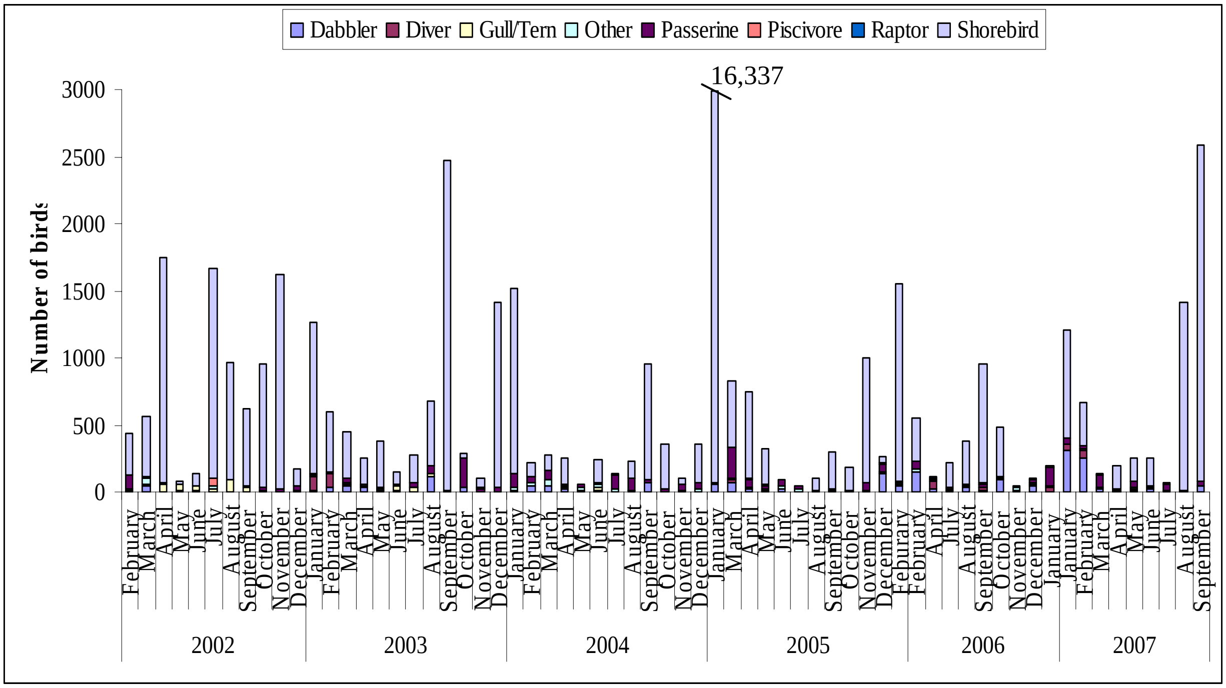


Figure 22. Average number of shorebirds per survey (mean +SE) detected over all months and during the migratory season (August-February).

a. High Tide



b. Low Tide

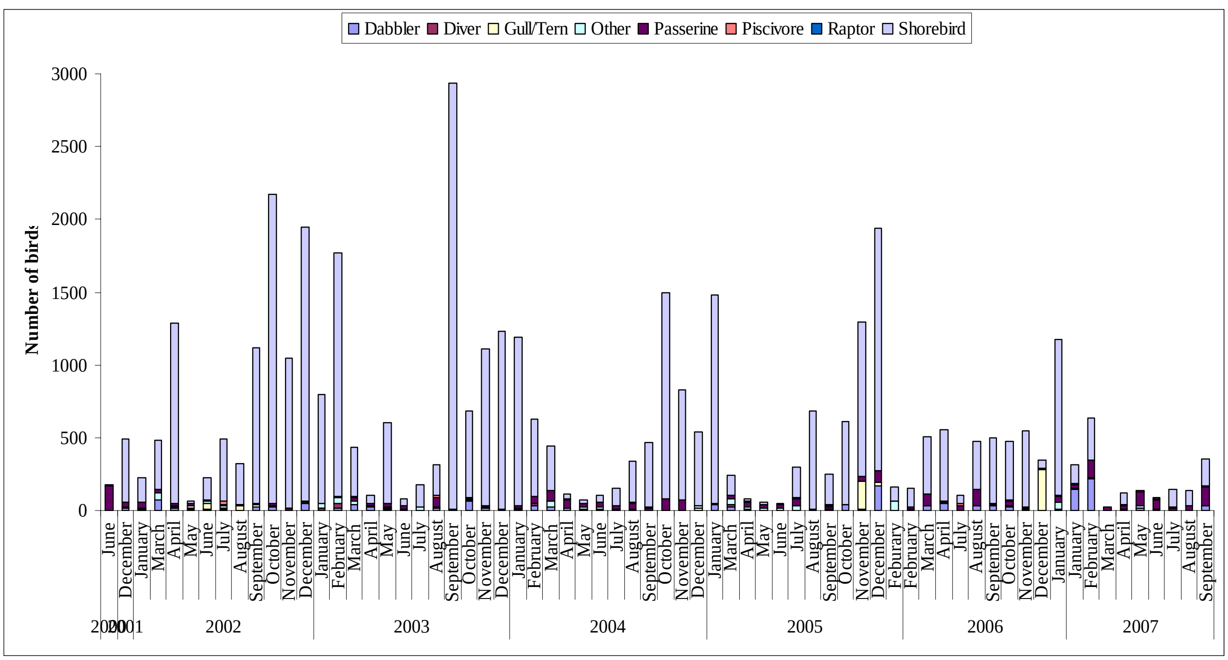


Figure 23. Monthly bird abundances by guild during (a) high tide and (b) low tide at the Guadalcanal Restoration Project.

Since bird composition and abundance vary with tide (Takakawa et al. 2002), we conducted avian surveys at both high and low tide in 2002. We observed a greater abundance of birds during high tide in 2004 (high tide=1,753 birds/survey; low tide=531 birds/survey), 2005 (high tide=703 birds/survey; low tide=650 birds/survey) and 2007 (high tide=753 birds/survey; low tide=218 birds/survey; Figure 23). We detected a decline in the number of birds observed at low tide since 2002, which coincides with the breach of Pond 3 to the north of Guadalcanal. Shorebirds were the most abundant guild recorded at both high and low tide, comprising over 80% of the relative abundance from 2001-2006 and declined to 48% in 2007. Passerines relative abundance has increased from 7% in 2006 to 27% in 2007 (Figure 24). The greatest number of birds recorded at a single high tide survey on 8 July 2004, was 16,624 individuals (14,080 of which were western sandpipers), with shorebirds comprising 99% of all birds (Figure 25).

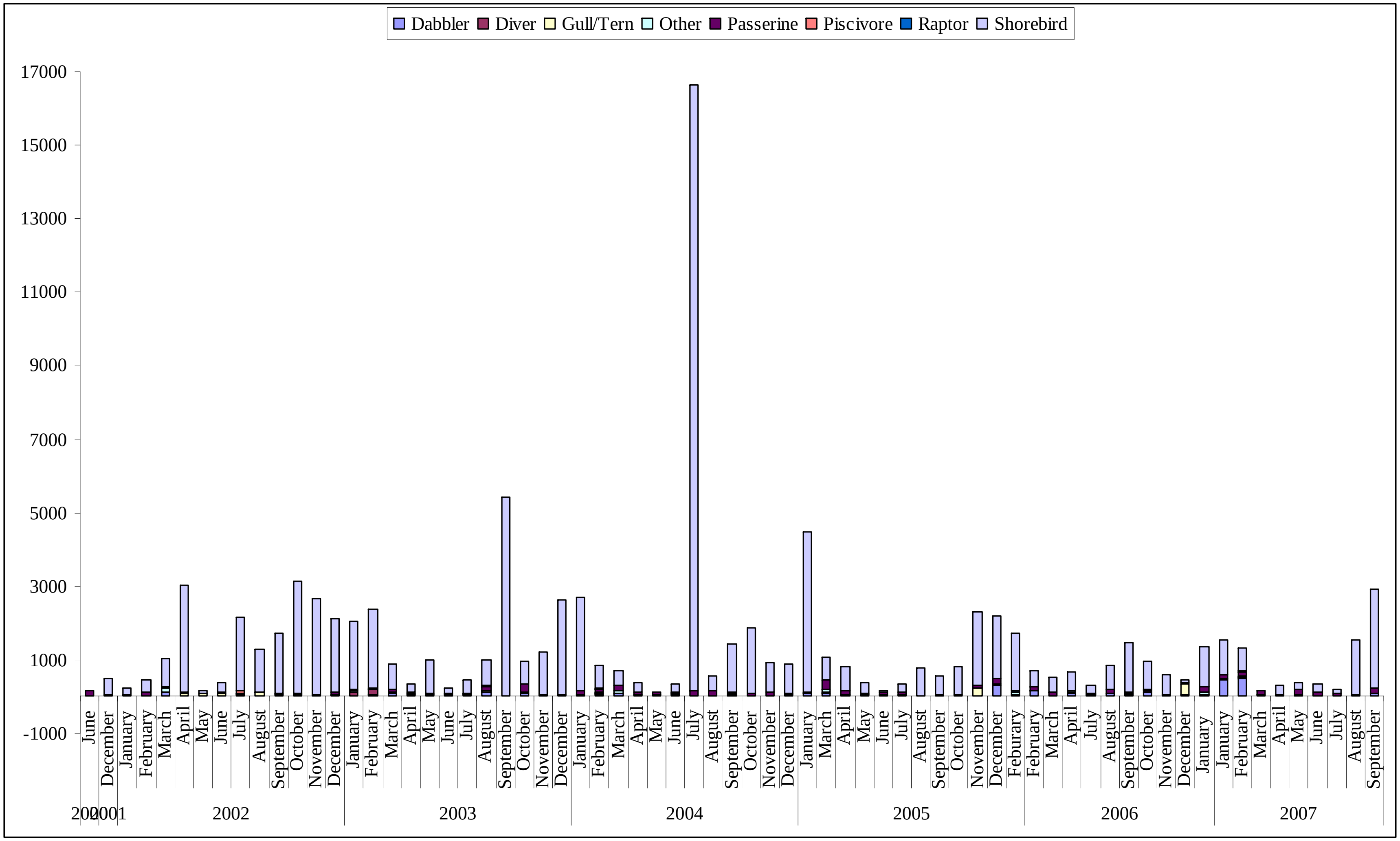
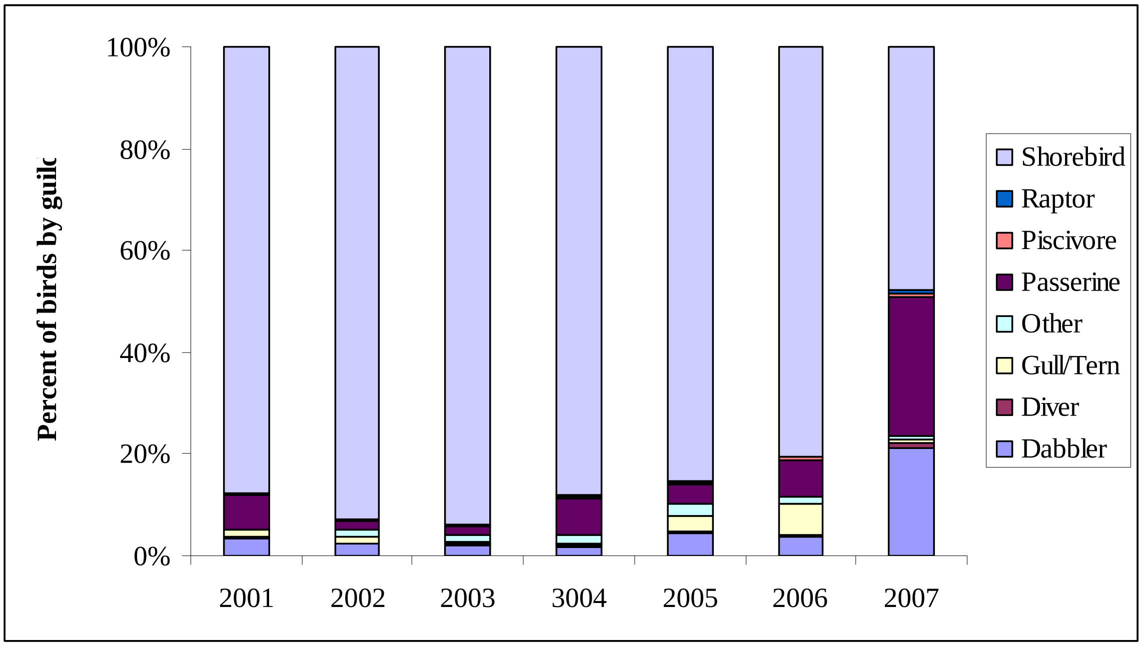


Figure 24. The total number of birds observed at Guadalcanal presented by guild and month.

a. High Tide



b. Low Tide

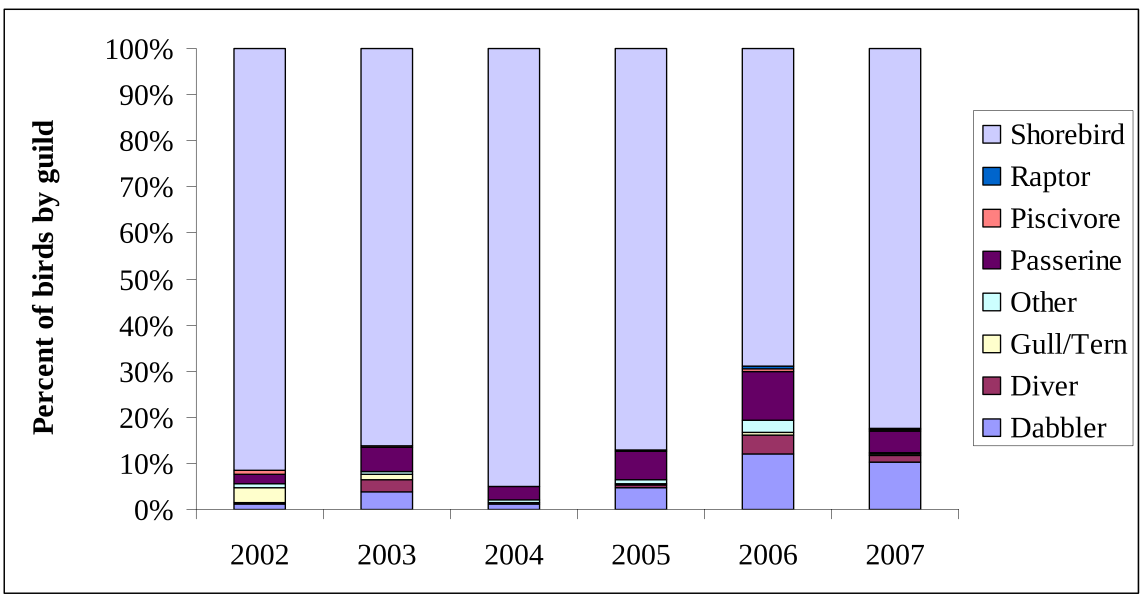
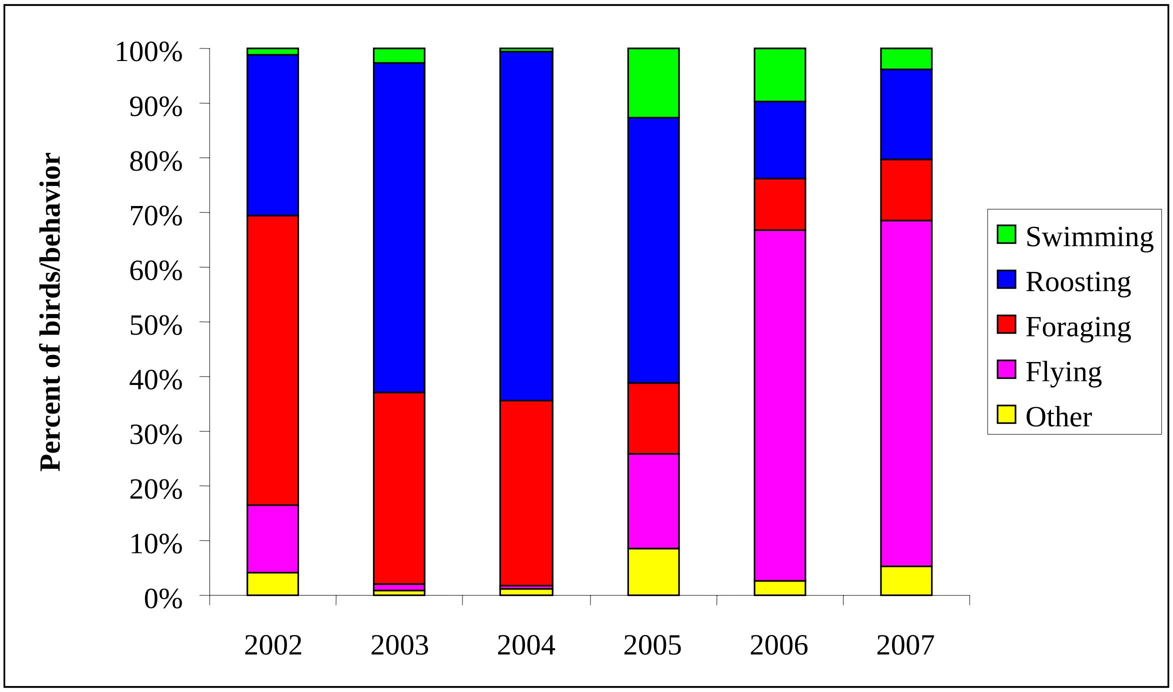


Figure 25. Annual percentage of birds detected per survey at (a) high tide and (b) low tide.

Observation of bird behavior was conducted during surveys and we examined the percent occurrence of roosting, swimming, foraging, and other behaviors at high and low tide and between survey years (Figure 26). During high tide surveys, there was a decrease in roosting and foraging behaviors in the past 3 years and a significant increase birds recorded flying (from 1% in 2003 and 2004 to 18% in 2005 to approximately 64% in 2006 and 2007; Figure 26a). Field observations have noted large numbers of shorebirds flying from the north (Pond 3, Dutchman Slough) across the project to the south (Triangle ponds, San Pablo Bay). This may be due to physical changes in the adjacent Pond 3 where five new breaches were constructed in the spring of 2006. The breaches in Pond 3 have increased sedimentation, providing a large area of mudflat habitat for foraging shorebirds in Pond 3. In a single low tide survey in 2001, there were equal numbers of birds recorded roosting and foraging; however, in subsequent years the prominent behavior at low tide has been foraging due to the exposed mudflat (Figure 26). In the past 6 years we have also recorded a steady increase in birds flying over Guadalcanal at low tide as well (from <6% in 2001-2004, to 13% in 2005 to approximately 25% in 2006 and 2007. Direction of bird flight was not recorded during low tide surveys. The relative percent of birds observed foraging also declined during high tide (from 53% in 2002 to approximately 33% in 2003 and 2004 to 13% in 2005 and approximately 10% in 2006 and 2007) and low tide (from 48% in 2001 to >75% in 2002-2005 to 60% in 2006 and 51% in 2007.

a) High Tide



b. Low Tide

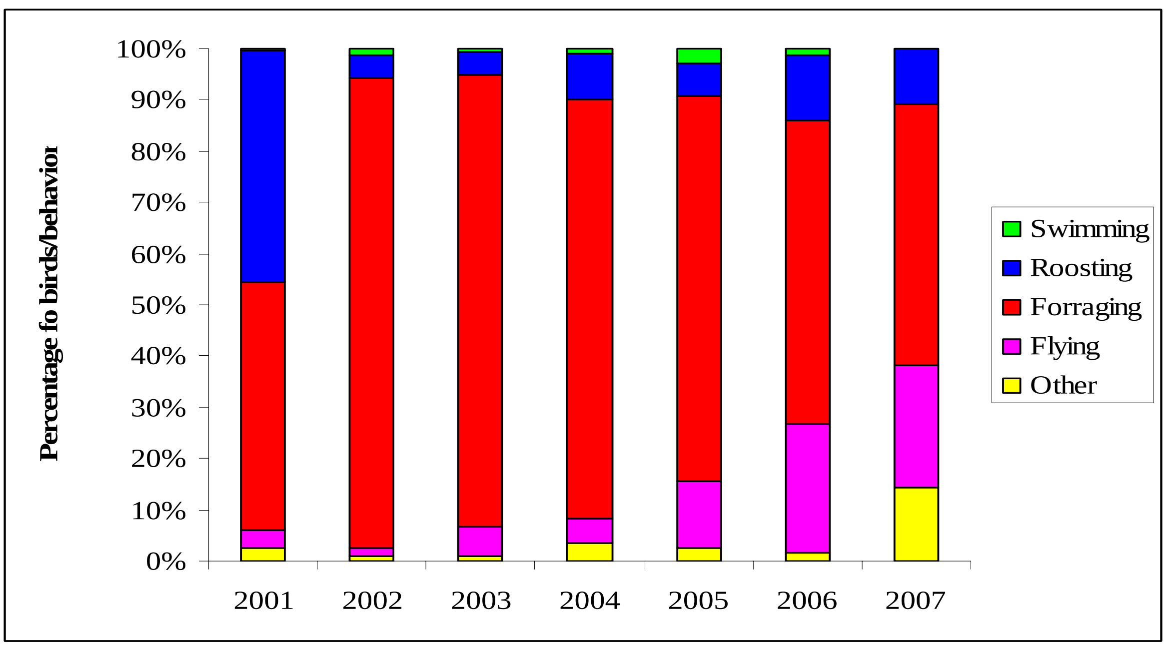


Figure 26. Percentage of behaviors observed by birds at (a) high tide and (b) low tide. "Other" behavior includes: aggression, alert, calling, courtship display, carrying food, carrying nest material, preening, and unknown.

Small Mammals

We detected 3 small mammal species in the Guadalcanal Restoration Project. Analyses included a 0.5 trap night correction for sprung traps (Nelson and Clark 1973). Species abundance of house mouse (new captures per 100 trap nights) ranged from 6.82 in 2003 to 30.6 in 2007 (Table 10). All *Mus musculus* trapped on the last morning of captures in 2007 (n=49) were donated to the UC Davis Museum of Wildlife and Fish Biology at the request of the Caltrans Biologist, (Scientific Collecting Permit # 005749). *R. raviventris* numbers decreased from 4.31 new captures per 100 trap nights (11 individuals) in 2005 to 0.45 new captures per 100 trap nights (1 individual) in both 2006 and 2007. It may be necessary to add additional grids in the interior of the project where the pickleweed is developing to capture more *R. raviventris* and *Microtus* species. Current transect locations are primarily upland habitat and there is now sufficient vegetation in the lower marsh to provide safe and dry placement for traps. One possible reason for *R. raviventris* decline is the extreme high tide and flooding event that occurred on Jan 1 2006, the winter prior to trapping. Similarly, a 98% decline in small mammal captures was observed at Tolay Creek in the summer of 2006.

Table 10. List of small mammal species and abundance index (new captures per 100 trap nights) for each trapping year at Guadalcanal.

Common Name	Scientific Name	2003	2005	2006	2007
House Mouse	*Mus musculus*	6.82	2.90	8.11	30.60
California Vole	*Microtus californicus*	0.45	-	-	-
Salt marsh harvest mouse	*Reithrodontomys raviventris*	-	5.31	0.45	0.45
Grand Total		7.27	8.21	8.56	31.05

CONCLUSION

The Guadalcanal restoration site has changed appreciatively since the breach in October 2001. The site progressed from a paint ball facility (prior to restoration) to marsh that exhibits wildlife value. Guadalcanal is an engineered marsh where oversized channels have increasingly filled in with sediment. Elevations were also engineered for rapid colonization of the marsh plain and indeed, *Spartina foliosa* was detected within the first year. Genetic tests of *Spartina* plants that exhibited physical attributes associated with invasive *Spartina* hybrids were negative and confirmed the species was native. Between 2003 and 2005, non-native plants had greater percent cover than native species. In 2006 and 2007 native species percent cover increased from 14% in 2005 to 28% in 2006 and to 27% in 2007. At the same time, percent cover of non-natives declined from 19% in 2006 to 7% in 2007 such that native species now have almost four times more cover than non-natives. Invasive species such as purple starthistle, fennel, and Russian thistle occur on site; however are predominately associated with levee tops and the high marsh transition zone. Shorebirds were the most abundant bird guild recorded at both high and low tide comprising over 80% of the relative abundance from 2001-2006. Shorebird relative abundance declined to 48% in 2007, reflecting greater detection of passerines. Passerines relative abundance increased from 7% in 2006 to 27% in 2007. The greatest number of birds was recorded at a single high tide survey in Jul 2004 with >16,000 birds, of which 99% were shorebirds. The endangered salt marsh harvest mouse were detected, though in low abundances (0.45 new captures/trapnight) in both 2006 and 2007, while house mouse detection increased from 8.1 new captures/trapnight in 2006 to 30.6 new captures/trapnight in 2007.

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Point No. 1: Facing south central

Point No. 2: Facing southeast

Point No. 3: Facing east

Point No. 4: Facing southwest

Appendix A. Panoramic view at photopoints taken throughout Guadalcanal Restoration Project in June 2000.

Point No.5: Facing northwest

Point No. 6: Facing north

Point No. 7. Facing northeast

Appendix A. Continued.

Point No. 1

Point No. 2

Point No. 3

Point No. 4

Point No. 5

Point No. 6

Point No. 7

Appendix B. Panoramic views at photopoints throughout the Guadalcanal Restoration Project in August 2007.