Understanding Tidal Marsh Sedimentation in the Sacramento-San Joaquin Delta, California

Author: Reed, Denise J.

Source: Journal of Coastal Research, 36(sp1) : 605-611

Published By: Coastal Education and Research Foundation

URL: https://doi.org/10.2112/1551-5036-36.sp1.605

Journal of Coastal Research	SI 36	605-611	(ICS 2002 Proceedings)	Northern Ireland	ISSN 0749-0208

Understanding Tidal Marsh Sedimentation in the Sacramento-San Joaquin Delta, California

Denise J. Reed

Department of Geology and Geophysics
University of New Orleans
New Orleans LA70148 USA
djreed@uno.edu

ABSTRACT

Over 90% of the once vast tidal-freshwater wetlands of the Sacramento-San Joaquin Delta have been leveed and removed from tidal and floodwater inundation. Contemporary restoration efforts breach and/or remove the levees surrounding delta islands with the goal of regaining wetland habitat. However, experience so far with levee-breaches, both planned and unplanned, has shown that the transition from shallow open water to Tule marshes occurs slowly, if at all. Sedimentation rates in tidal marshes are an important control on this transition. This two-year study examined potential controlling factors on vertical accumulation including sediment type, and inorganic and organic soil components. Measured rates of surface accretion are in excess of 10 mm/yr. Gravimetric determinations show the main control on variations in soil accretion appears to be mineral sediment accumulation, with highest rates being close to inputs from the Sacramento River and lowest rates in interior marshes in the south-central delta. Rates of organic accumulation are remarkably similar among areas. However, measurements of marsh surface elevation change reflect the volumetric contributions of soil components and appear to be influenced by interannual changes in vegetation associated with minor variations in salinity. Marshes in breached-levee sites showed higher annual rates of marsh surface elevation change than reference marshes. This study demonstrates the importance of examining volumetric rather than gravimetric contributions to marsh soils in evaluating the factors controlling the vertical development of tidal marshes.

ADDITIONALINDEXWORDS: *Salt Marsh.*

INTRODUCTION

Over 90% of the once vast tidal–freshwater wetlands of the Sacramento–San Joaquin Delta have been leveed and removed from tidal and floodwater inundation. Drainage of tidal wetlands usually results in subsidence of the land surface through direct dewatering of the substrate and enhanced aerobic decomposition of organic material in marsh soils. Over time, the lower elevations caused by this subsidence are exacerbated by sea-level rise. In the Sacramento–San Joaquin Delta, the surface of many former tidal marsh areas is now more 5 m below the height of the mean tide level. Restoration of these drained areas to tidal marsh habitat requires surface elevations within the range of tidal water level fluctuations, and progressive increases in surface elevation to keep pace with regional sea-level rise. Currently the Delta includes several flooded islands where levee breaching has clearly not resulted in the restoration of former marsh habitats (e.g., Mildred Island and Franks Tract), and some areas where recovery of vegetated marsh has been almost complete (e.g., Lower Mandeville Tip). The goal of this study is to examine vertical marsh development in ‘restored’and natural marshes to determine the rate at which restored marsh, once established, will build in the tidal frame towards a mature ‘equilibrium’ elevation (PETHICK, 1981; ALLEN, 1990).

Breached-levee sites are former natural, freshwater tidal wetland areas that were leveed in the past and have now reverted to tidal action. This study examined sites that were accidentally or purposefully created by levee breaching, often with supplemental actions such as dredge material disposal. Using the same approach, the field effort compared the status of both these naturally and intentionally restored wetlands to the few natural "reference" wetland sites remaining in the delta. The objectives of this study are to evaluate rates of marsh surface sedimentation/accretion and elevation change in breached levee marshes within the delta, and to compare these rates to those in ‘natural’, unleveed marshes. In addition, the study will evaluate the relative roles of organic and inorganic components in vertical soil development.

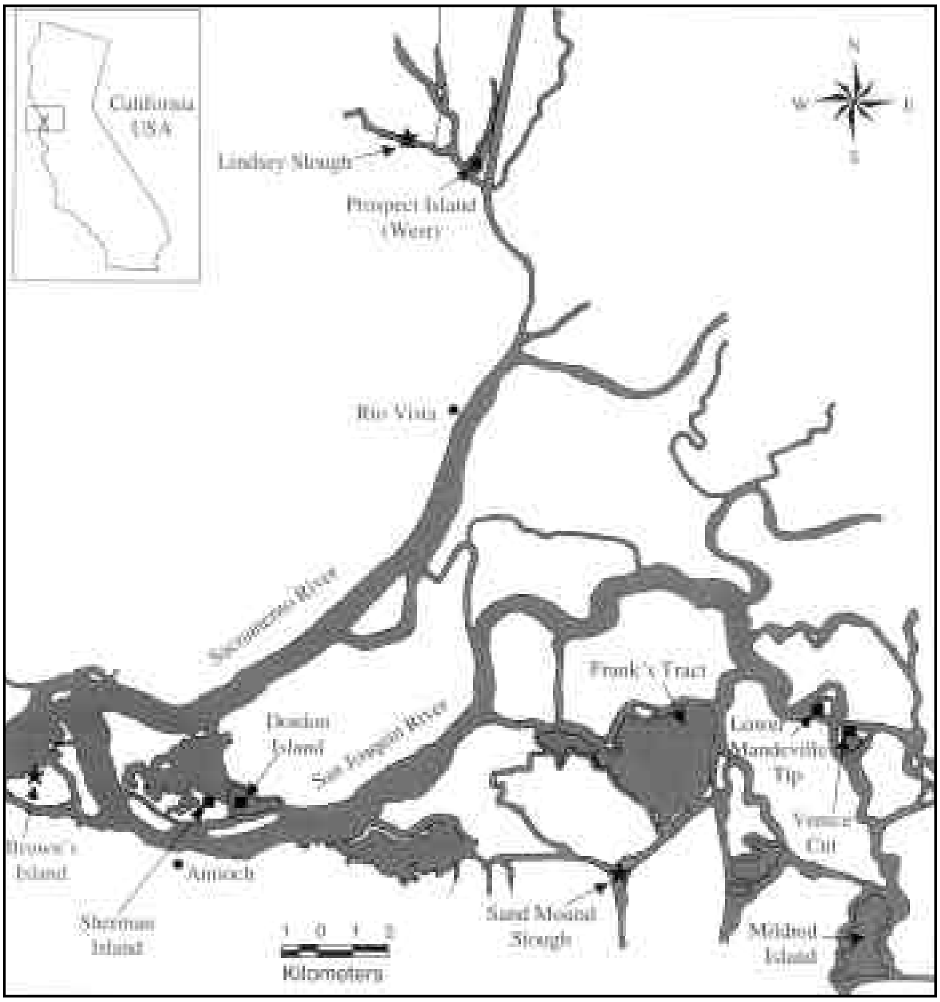

Figure 1. Location of study sites mentioned in text and Table 1.

Table 1.

Location in Delta	Site Name	Marsh Type	Dominant Vegetation
Western	Browns Interior	Reference	*Tule* with *Typha* spp.
	Browns Edge	Reference	*Scirpus americanus*
	Sherman Interior	Restored	*Tule*
	Sherman Edge	Restored	*Tule*
	Donlon	Restored with dredged material addition	*Tule*
Central	Mandeville Upst.	Restored	*Tule*
	Mandeville Downst.	Restored	*Tule*
	SMS Edge	Reference	*Scirpus americanus*
	SMS Interior	Reference	*Phragmites* spp.
	Venice Cut	Restored with dredged material addition	*Tule*
Northern	Lindsey	Reference	*Scirpus americanus*
	Prospect Interior	Restored	*Tule*
	Prospect Edge	Restored	*Tule*

Sampling Design

The study design encompasses three regions of the delta that are hypothetically characterized by different regimes of sediment supply and tidal energy both of which are potential controlling factors on vertical accumulation processes (Figure 1; Table 1). The northern delta area has relatively low tidal energy and high freshwater/sediment supply from the Sacramento-Yolo Bypass discharges. The western delta region is characterized by greater tidal energy, and both tidal and fluvial processes modulate sediment supply. The central delta area has low tidal energy and low freshwater/sediment supply. At the study areas with extensive tracts of marsh (i.e., Browns, Sherman, Prospect and Sand Mound), sites were established both adjacent to channels (edge) and approximately 25 m into the marsh (interior). At Lower Mandeville Tip, sites were established on the marsh edge at two locations on the creek network—downstream and upstream.

METHODS

Sedimentation on the marsh surface was measured as vertical accretion of material over an artificial marker horizon placed on the surface when the study was begun (REED and CAHOON, 1993). White feldspar was laid on the marsh surface at each site in three 0.5- x 0.5-m plots. Approximately 0.5 cm of feldspar was applied in each case . On subsequent sampling visits, cryogenic coring (KNAUS and CAHOON, 1990) was used to extract a small frozen core from the marker plot, enabling direct measurements of accretion above the white feldspar layer. Feldspar was laid at all sites at the beginning of the study in March 1998, except Lower Mandeville Tip Upstream where sampling did not commence until June 1998. The relatively high energy conditions at Venice Cut, immediately adjacent to the Stockton Ship Channel and affected by hull displacement waves from large ships, prevented recovery of feldspar during the first sampling, it was likely washed out soon after placement, and the markers were not re-established.

Processes other than those operating directly at the surface can affect marsh surface elevation. Thus, a sediment-erosion table (SET) was used to integrate the effects of processes over the upper 3–5 m of the substrate. The SET (BOUMANS and DAY 1993) consists of an arm temporarily inserted into a deep basepipe. Pins are then inserted through a plate on the arm and successive measurements track changes in marsh surface elevation relative to the base of the pipe. In this study, basepipes were inserted to refusal with a vibracore system. Pipes were approximately 9 m in length and penetrated over 8.75 m at the interior site on Browns Island.

Additional cryogenic cores, 5 cm in diameter and 2 cm in length, were taken in spring 1999 to determine the bulk density and organic/inorganic composition of the material accumulating on the marsh surface. Cores were kept on ice for return to the laboratory where they were dried and weighed. Samples were then incinerated in a muffle furnace (450°C for 16 hours) to determine organic matter content by loss-on-ignition.

At each site, temporary boardwalks were installed during each site visit to prevent disturbance of the surface where measurements were made. For both methods, baseline measurements were taken in March 1998 (except Lower Mandeville Tip –Upstream where the baseline was taken in August 1998) and data for seasonal intervals through June 1999 are reported here for both marsh surface elevation change and accretion, with a subsequent measurement of marsh surface elevation one year later in August 2000.

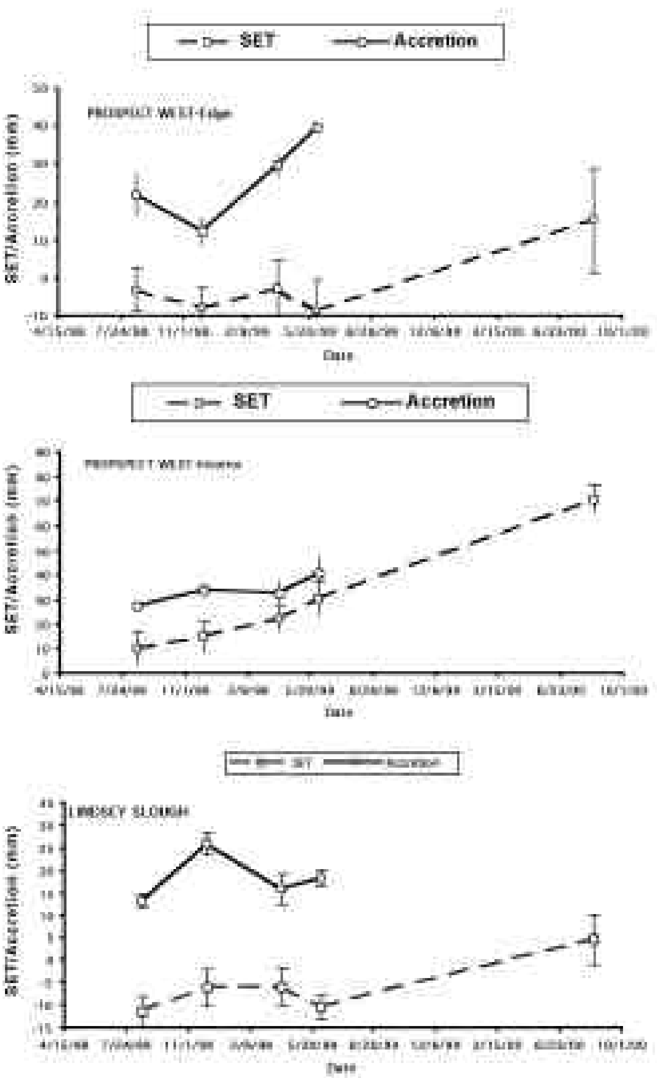

Figure 2. Results of marsh surface accretion and elevation change (SET) measurements at the northern delta study sites (Northern delta sites were not measured in June 1998 because of logistical difficulties).

RESULTS

Accretion and Marsh Surface Elevation Change

At all sites in the northern delta, accretion exceeds elevation change (Fig. 2). At the edge of the marsh in Old Prospect West, almost 40 mm of material accumulated over the marker horizon while elevation change was effectively zero. This means that while material was being deposited on the marsh surface, subsurface processes such as decomposition and compaction compensated for the new material and there was no net increase in marsh surface elevation. This phenomenon has been termed shallow subsidence by CAHOON *et al*. (1995). In contrast, the interior site at Old Prospect West shows a similar amount of accretion and a net increase in marsh surface elevation of almost 30 mm. The reference site in the northern delta is Lindsey Slough on the marsh edge. The pattern here is similar to the Old Prospect West edge site with accretion on the surface and no net increase in marsh surface elevation. Between summer 1999 and summer 2000 all sites in the north Delta show an increase in marsh surface elevation.

In the western Delta the natural site at Browns shows great differences between edge and interior sites (Fig. 3). The interior site shows low rates of both accretion and elevation change with the two following the same pattern. In contrast, the edge site shows slightly higher accretion rates than the interior but a large increase in surface elevation. Over the period of sampling, the elevation of the marsh surface rose by approximately 80 mm at the Browns Edge site with most of the increase during the first 6 months of measurement. Observation of this site between November 1997 and December 1998 suggests an increase in *Typha* spp. at the site relative to *Scirpus* spp. This may have caused an increase in belowground biomass, which could result in the elevation increase recorded by the SET.

At the breached levee site at Sherman Island, there is less difference between the edge and interior sites. For example, similar amounts of accretion occur over the year. Elevation change for the first year is lower than accretion but not dramatically so. The extended period of marsh surface elevation monitoring shows very little net change in elevation at either edge or interior at Sherman. With the exception of the dramatic increase in elevation at the Browns Island Edge site, both Sherman and Browns Islands show similar low rates of elevation change with accretion of approximately 10 mm at Browns at 20 mm at Sherman.

The marsh site at Donlon Island, on dredged material introduced for marsh creation, shows essentially no elevation change over the period of record through summer 2000 while there was over 30 mm of accretion at the surface during the initial year of monitoring. This indicates that while material is accumulating, there are processes below the surface counterbalancing the accretion and maintaining a constant elevation.

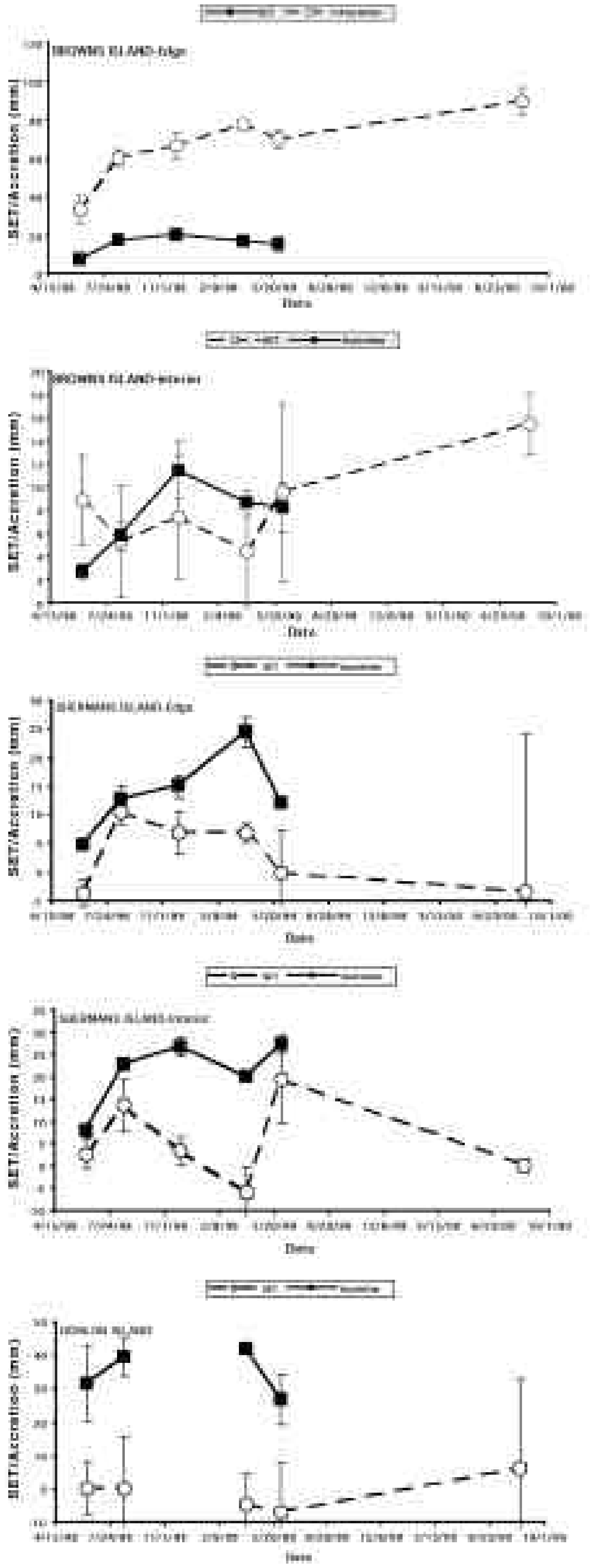

Figure 3. Results of marsh surface accretion and elevation change (SET) measurements at the western delta study sites.

Among the central delta sites, Lower Mandeville Tip data indicate a difference in pattern between upstream and downstream sites from August 1998 to March 1999 (data collection at Lower Mandeville Tip upstream sites did not commence until August 1998). Downstream elevation change and accretion track each other closely over time (Fig. 3). Both show rapid increases between March 1999 and August 1999 with little change thereafter. The upstream site shows almost 40 mm of accretion between August and March with no effective change in elevation—suggesting substantial influence of subsurface processes.

Venice Cut, located on the opposite side of the Stockton Ship Channel in a marsh created with dredged material, shows a pattern of elevation change similar to that of the Lower Mandeville Tip sites. Elevation increases between March 1998 and August 1998 and there is little change through June 1999. This site, however, was subjected to substantial changes during this period as a large mat of wrack was deposited over much of the site between March and June 1998, and its subsequent removal has exposed a surface with only sparse vegetation in some areas. The subsequent increase in elevation through August 2000 likely reflects the recovery of the vegetation and a renewed contribution of below ground plant biomass to marsh soil volume.

The reference site for the central delta is Sand Mound Slough. Both edge and interior sites here show shallow subsidence with elevation change lower than accretion. Indeed the interior site shows over 20 mm of elevation decrease over the first year of sampling, and was not recovered in 2000 so no additional information is available. The site was relocated during fall 2001 and subsequent reporting of data for this study may provide some additional insights on the longer term elevation response of the interior marsh at Sand Mound Slough. Accretion at the marsh edge over the entire period of accretion measurement is approximately twice that of the interior site.

Marsh Soil Composition

Table 2 shows the variation in marsh soil composition for all delta sites except Venice Cut where it was not possible to measure accretion. The actual rates of accumulation are dependent upon the rates of accretion at the sites, but the soil matter % data shows the composition of the material accumulating independent of the amount. The lowest contributions of organic matter are found at the restored sites in the west Delta (Donlon, and the Sherman sites) and at Lindsay and Prospect in the north Delta. The maximum contribution of organic matter is at Sand Mound Slough in the central Delta. The high contribution of inorganic matter to soils in the northern Delta is also reflected in the highest absolute accumulation of inorganic material at the Prospect sites. Donlon also shows high accumulation of inorganic material relative to other sites.

Table 2.

	Organic Accum. ($g/cm^2/yr$)	**Inorganic Accum. ($g/cm^2/yr$)**	**Soil Organic Matter %**	**Soil Inorganic Matter %**
Browns Interior	0.70	1.80	28.00	72.00
Browns Edge	1.10	3.10	26.19	73.81
Sherman Interior	1.20	8.70	12.15	87.85
Sherman Edge	1.22	6.77	15.21	84.79
Donlon	2.16	14.71	12.81	87.19
Mandeville Upst.	2.32	10.78	17.70	82.30
Mandeville Downst.	0.65	2.44	21.00	79.00
SMS Edge	2.83	6.25	31.21	68.79
SMS Interior	1.45	2.23	39.38	60.62
Lindsey	0.86	4.70	15.42	84.58
Prospect Interior	2.08	22.55	8.45	91.55
Prospect Edge	1.61	19.05	7.80	92.20

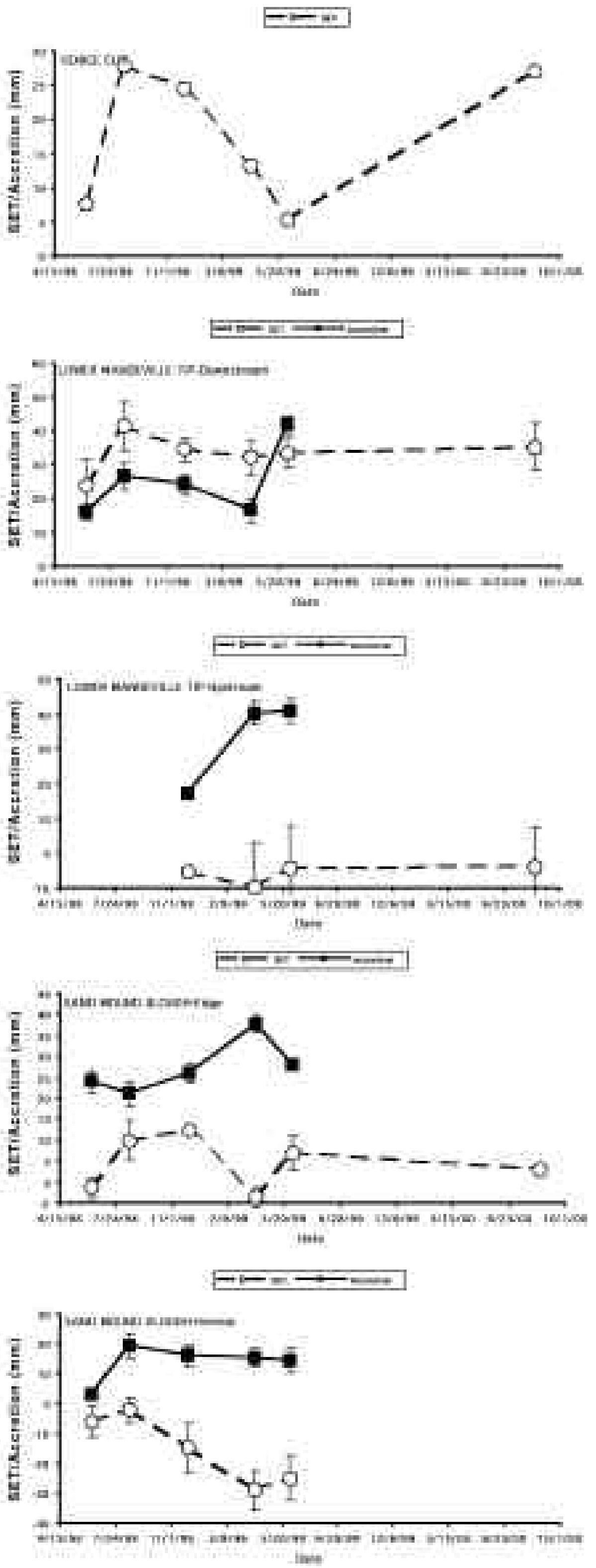

Figure 4. Results of marsh surface accretion and elevation change (SET) measurements at the central delta study sites. Note that it was not possible to measure accretion at Venice Cut.

DISCUSSION

The data presented here provide insight into the potential variation in marsh surface accretion and elevation change across the delta. Measured rates of surface accretion are in excess of 10 mm/yr. for the period of the accretion study. At most sites, more accretion occurs between March and August than between August and December. This is likely attributed to higher Sacramento River flows during this period and the consequent increase in flooding duration and availability of suspended sediments. All sites in the central and western deltas show an increase in elevation, whether or not there is an increase in accretion, between June and August (the slight apparent decrease at Browns Interior is not statistically significant), which may be attributed to seasonal accumulation of belowground plant biomass.

In general, sites with high rates of accretion rarely show similarly high rates of elevation change. This dissociation between surface processes that add soil at the top of the profile and subsurface processes that can affect the actual elevation of the marsh surface relative to a datum (in this case the base of the SET pipe) is an important aspect of understanding the response of marshes to rising sea-levels and their vertical development towards mature marsh equilibrium elevations. 'Shallow subsidence' has been used to describe the condition where material is accumulating at the marsh surface at a rate greater than the actual elevation is changing (CAHOON *et al*., 1995). This is the case at almost all the sites in this study for the period when accretion was being measured. This illustrates the importance of evaluating the actual change in marsh elevation as well as the process influencing the marsh surface in determining the vertical response of marshes in a formerly subsided breached-levee site.

Gravimetric determinations show the main control on variations in surface soil accretion appears to be mineral sediment accumulation, with highest rates being close to inputs from the Sacramento River and lowest rates in interior marshes in the south-central Delta. The rates of organic accumulation are remarkably similar among areas, perhaps reflecting the magnitude of the contribution that plants can make to surface soil composition. Observations of the sites during sampling suggest the growth in all areas is vigorous and healthy despite the slight variations in species composition between areas and reference and restored sites. However, measurements of marsh surface elevation change reflect the volumetric contributions of soil components. The western part of the Delta is close to the low-salinity zone of the San Francisco estuary (JASSBY *et al*., 1995) and is influenced by interannual variations in salinity associated with river flow. Such changes may result in slight changes in vegetation at these sites, such as the observed increase in Typha spp. at the Browns edge site during the period when marsh surface elevation increased dramatically. Ongoing studies of the potential of both Typha and Scirpus spp. to develop organic soils suggest a difference in the character of the belowground components of these plants and confirm the possibility that a change in species could affect soil volume (DREXLER *et al*., 2001).

Comparison among all sites suggests that sediment accretion shows a decreasing trend in rate as a function of marsh age, with reference sites having lower rates of accretion. However, there is considerable variability among the three different regions of the delta and between edge and interior areas of the marshes. Marsh surface elevation change shows no trend among reference and restored sites during the two years of data shown here. With the exception of Sand Mound Slough-Interior, most marshes are maintaining a constant surface elevation or gained elevation over the entire period of study (e.g., Prospect West-Interior, Lower Mandeville Tip-Downstream, and Browns Island-Edge). However, the studies of marsh surface elevation change are ongoing at the sites and as longer term data sets become available trends that do not reflect seasonal or interannual factors may provide more insight into the differences or similarities between reference and breached-levee restored marshes.

CONCLUSIONS AND IMPLICATIONS FOR DELTA RESTORATION

The call for wetland restoration in the Sacramento-San Joaquin Delta arises not only from the recognition that a vast acreage has been lost but also that shallow-water habitat, and particularly emergent marshes, have value both for at-risk species and society as a whole. Planning, designing and implementing restoration of emergent marshes in the delta requires an appreciation for the complex interactions among physical, sedimentological and biotic processes. While one of the major challenges in restoration of tidal wetlands in the San Francisco estuary is the availability of sediments to build back substrate in highly subsided areas, the role of vegetation must also be considered. The delta has traditionally been viewed as a peat-dominated landscape, and high rates of subsidence in drained areas reflect the thickness of the former peats (CDWR, 1995). However, this study has shown that contemporary processes forming marsh soils in the Delta are by no means dominated by peat accumulation processes. At least on a percent weight basis, inorganic material is a major contributor to marsh surface soils and there are clear gradients across the Delta in the amount, timing and delivery of suspended sediments associated with riverine inputs. Such insight should provide an opportunity for resource managers and those interested in increasing the extent and elevation of restored marshes, to strategically plan future restoration projects in areas where the rate of marsh development can be maximized.

ACKNOWLEDGEMENTS

This study was funded as part of Breached Levee Wetland Study by the Water Resources Management Group of the Metropolitan Water District of Southern California. Charles Simenstad was Principal Investigator and he and the other members of the BREACH team are thanked for their support and help with this work. Nina de Luca and and Wendy Morrison of LUMCON provided data analysis and field work support respectively. Jason Toft drafted Figure 1. Boat support was proved by the California Department of Water Resources as part of the BREACH study and Rob Miller and Lenny Grimaldo are acknowledged for their help in the field.

LITERATURE CITED

ALLEN, J. R. L. 1990. The formation of coastal peat marshes under an upward tendency of relative sea-level. *Journal of the Geological Society, London*, 147, 743-745.

BOUMANS, R. M. J. and J. W. DAY 1993. High precision measurements of sediment elevation in shallow coastal areas using a sedimentation-erosion table. *Estuaries*, 16(2), 375-380.

CAHOON, D. R., D. J. REED, and J.W. DAY. 1995. Estimating shallow subsidence in microtidal salt marshes of the southeastern United States: Kaye and Barghoorn revisited. *Marine Geology*, 128,1-9.

CALIFORNIADEPARTMENT OF WATER RESOURCES (CDWR). 1995. *Sacramento San Joaquin Delta Atlas*. (http://rubicon.water.ca.gov/delta_atlas.fdr/datp.html)

DREXLER, J.Z., R.L. MILLER, G. WHEELER and R. FUJII. 2001. Reversing subsidence through wetland restoration on Twitchell Island, Sacramento-San Joaquin Delta. *Abstract presented at State of the Estuary Conference*, October 9-11, 2001, Palace of Fine Arts, San Francisco.

JASSBY, A.D., W.J. KIMMERER, S.G. MONISMITH, C. ARMOR, J.E. CLOERN, T.M. POWELL, J.R. SCHUBEL, and T.J. VENDLINSKI. 1995. Isohaline position as a habitat indicator of estuarine populations. *Ecological Applications*, 5, 272-289.

KNAUS, R. M. and D. R. CAHOON 1990. Improved cryogenic coring device for measuring soil accretion and bulk density. *Journal of Sedimentary Petrology*, 60(4), 622-623.

PETHICK, J. S. 1981. Long-term accretion rates on tidal salt marshes. *Journal of Sedimentary Petrology*, 51(2),571-577.

REED, D. J. and D. R. CAHOON 1993. Marsh submergence vs. marsh accretion: interpreting accretion deficit data in coastal Louisiana. Coastal Zone '93, *Proceedings, 8th Symposium on coastal and ocean management*, American Shore and Beach Preservation Association/ASCE. pp. 243-257.