FINAL REPORT:

Salt Marsh Accretion Rates on the Upper Texas Coast:

Will Sea Level Rise Drown Our Marshes?

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Summary

For a *Spartina alterniflora* salt marsh to persist in the long-term, its accretion rate must at least match the rate of relative sea level rise. We found contrasting accretion rates for two different marshes located along the Upper Texas Coast. At Jumbile Cove in West Galveston Bay, experiments with Rod Sediment Elevation Tables (RSETs) indicated that there has been no sedimentary accretion on the marsh surface within the last year. Moreover, we found that there was an average of -8.02 cm/yr of vertical loss along a sloping marsh edge immediately behind the geo-textile tube at this site. The presence of *Spartina alterniflora* vegetation did not significantly affect the physical erosion of the soil surface at this site, but it appeared to affect the relative elevation through an expansion-compaction cycle that occurred in the root zone (although at a relatively small magnitude compared with the surface erosion). Radionuclide (^{137}Cs, ^{210}Pb) core data also suggests that decadal-centennial sedimentary accretion rates are much lower than the rate of relative sea level rise. At the Matagorda Bay Nature Park in East Matagorda Bay, accretion rates appear to be keeping up with relative sea level rise in *Spartina alterniflora* low marshes, but not in the salt flat zones that sit just above them in elevation. Moreover, on the down-thrown side of a growth fault at this site, historical subsidence has resulted in *Spartina alterniflora* low marsh submergence. Radionuclide core data from this submerging portion of the marsh indicates that a sharp drop in accretion began just before 1963. The subsidence of the fault block may have pushed *Spartina alterniflora* plants beyond their tolerance limit for higher water levels, resulting in a pronounced change in the rate of sedimentary accretion. This period was followed by surface erosion for the next several decades, as the plants became completely submerged and the marsh converted to open water. The next 100 years for Galveston-area *Spartina alterniflora* low marsh looks bleak with little accretion and lots of erosion, even when protected by geo-textile tubes, while the future for Matagorda-area *Spartina alterniflora* low marsh looks much better with accretion rates that appear to be keeping up with relative sea level rise. However, salt flats (important avian feeding habitats) will likely be converted into low marsh in the Matagorda-area, and low marshes that are subjected to growth faulting are likely to be lost.

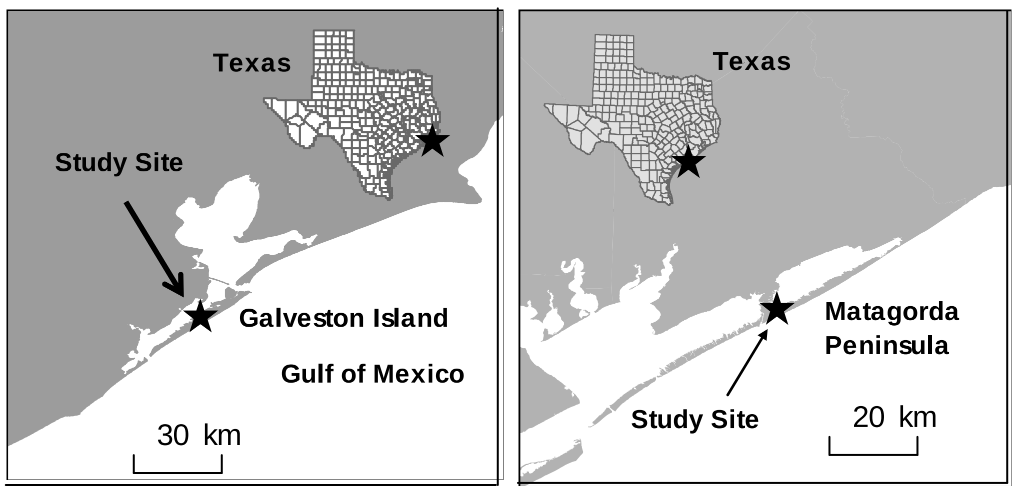
Introduction

Coastal salt marshes are among the world's most productive (BROOME *et al.,* 1988; MITSCH and GOSSELINK, 2000) and valuable ecosystems (COSTANZA *et al.,* 1997) having evolved in response to rising sea-levels (REDFIELD and RUBIN, 1962; PETHICK, 1981; DELAUNE *et al*., 1983). Marsh accretion is a natural process which changes the elevation of the marsh relative to sea-level. While the current rate of global sea-level rise is generally agreed to be around 0.20 – 0.30 cm/yr, some marshes are accreting fast enough to keep up with the rise (e.g. US Northeast, US Southwest), some are being uplifted by tectonic processes at a rate faster than the rise (e.g. US Northwest), and others are drowning due to local subsidence in combination with the global rise (e.g. US Southeast). In particular, salt marshes along the Upper Texas Coast are currently experiencing submergence and erosion in most locations (WHITE and MORTON, 1997).

Several components influence the accretion rate including the relative amount of organic and inorganic particles and their deposition rate (STEVENSON *et al*., 1986; CALLAWAY *et al*., 1997), the frequency and duration of extreme events such as hurricanes (MICHENER *et al*., 1997), the shape, roughness, and density of emergent plants (ROOTH and STEVENSON, 2000), and the ecosystem-level response of the marsh to rising sea-levels (WARREN and NIERING, 1993). Additional factors that affect marsh elevation include shallow and deep autocompaction (CAHOON *et al*., 1995) and accelerated local subsidence driven by growth faulting.

Our primary objective was to assess salt marsh accretion/erosion rates along the Upper Texas Coast. We were also interested in investigating the role of vegetation in promoting accretion and potentially reducing erosion in the short term, as well as the impact of growth faulting and subsidence upon long-term marsh accretion rates. We established two study sites to study these issues: one at Jumbile Cove on Galveston Island, Texas and the other at Matagorda Bay Nature Park on the Matagorda Peninsula, Texas (Fig. 1).

Figure 1 – Study sites



Methods

West Galveston Bay

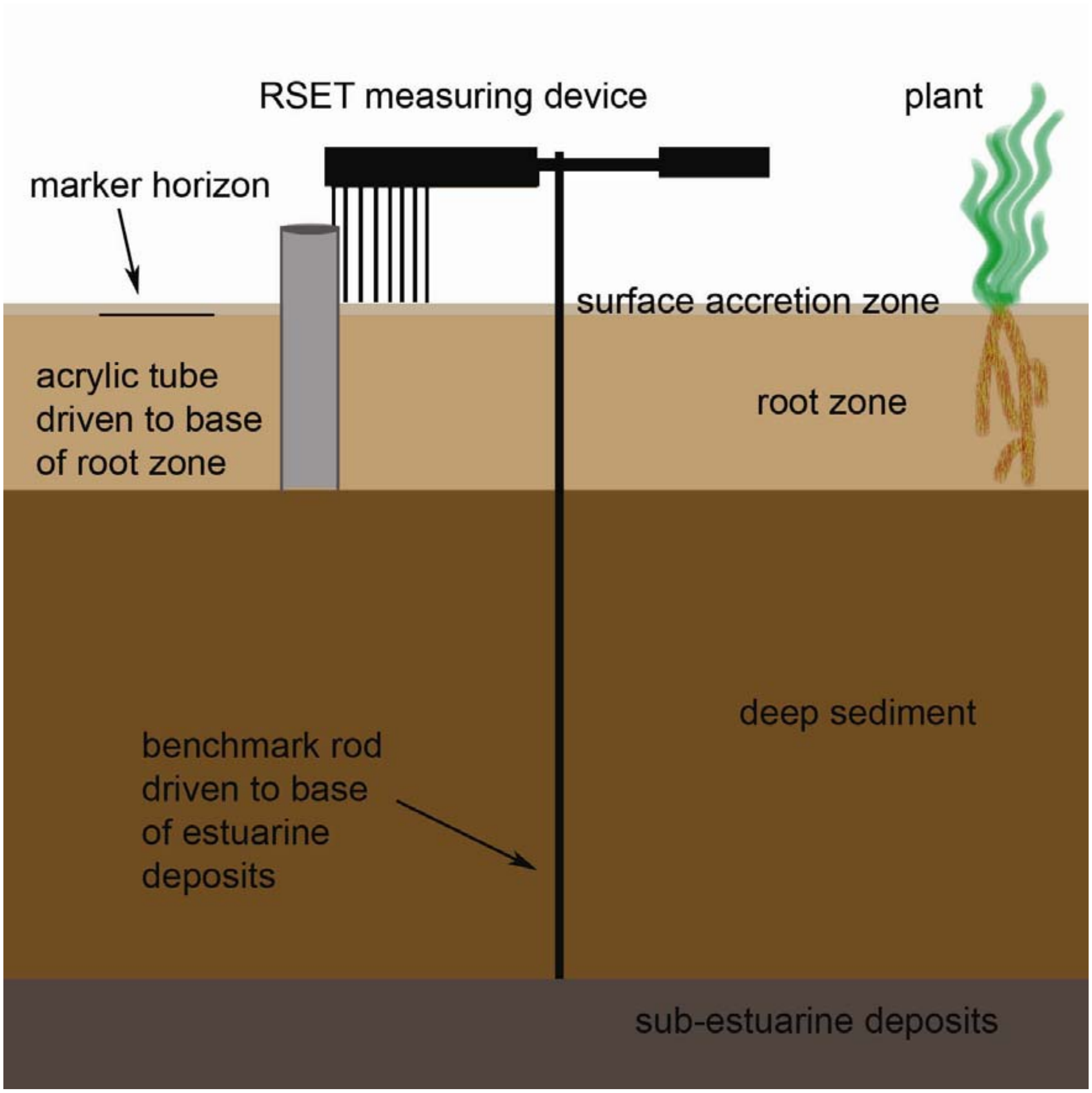
At Jumbile Cove, we set up four stations along a steeply-sloping *Spartina alterniflora* marsh edge. The marsh was restored at the interior portions of this site, although our experiment took place in a natural marsh that lies between the restored portions and a geo-textile tube that fronts West Galveston Bay (Fig. 2). The average wave conditions at this site are less than 0.1 m (RAVENS *et al.*, 2008).

Figure 2- *Spartina alterniflora* low marsh at Jumbile Cove, Galveston, TX (geo-textile tube is at back right, stations on back left)

At each station, we placed a Rod Sediment Elevation Table (RSET), essentially a permanent elevation benchmark upon which the surface of the marsh edge was recorded (Fig. 3, CAHOON *et al.,* 2002). To establish this benchmark, a 10.16 cm diameter hole was dug and a 50 cm long by 10.16 cm diameter PVC pipe was inserted into the hole. Coupled stainless steel rods (1.43 cm diameter) were then driven into the ground at the centroid of the PVC pipe, a connector rod was attached to the top rod, quick-drying concrete was poured into the PVC pipe, and a survey marker was set in the concrete, following USGS methods (CAHOON *et al.,* 2002).

To record compaction and expansion in the root zone near each RSET station, we inserted 40 cm long acrylic tubes into the surface, down to a depth of 30 cm. We also established G200 Feldspar clay marker horizons for the purpose of recording accretion, but all of these washed away due to the large amount of erosion at the site.

Figure 3 – RSET set-up (adapted from CAHOON *et al.* 2002)



To quantify the importance of vegetation in the erosion process, we established a 2 x 2 meter plot on each side of the four stations in the alongshore direction, eight plots in total. We randomly assigned one of two treatments to either side of a station, so that each station represented both treatments: unvegetated (removal) and vegetated (control). Removal plots were repeatedly inundated with 0.16% Imazapyr and 1.00% Glyphosate herbicide over the course of the experiment (Ortho GroundClear, Scotts Miracle-Gro, Marysville, Ohio, USA). Within 30 days, all vegetation appeared dead, but dead stalks remained and dead roots could be seen at the surface. After 60 days, the percent cover of all removal plots was reduced to 0% with very few roots remaining (dead material appeared to be removed by tidal and storm processes). The control plots were not manipulated and percent cover remained nearly 100%.

During each sampling visit, we recorded the erosion of the marsh surface at eight sub-sampled points within each plot. Records were taken at day 0, day 57, day 90, day 196, and day 277.

A single factor randomized block ANOVA was conducted with the treatments as vegetated marsh edge versus unvegetated marsh edge, with each station as a block. The eight recorded points within a plot at a given sampling date were treated as subsamples; the plots were the replicates. Root zone compaction and expansion data is presented as a single value with no statistical analysis, as only one acrylic tube from one of the vegetated plots survived the large amount of erosion at the site.

East Matagorda Bay

We also established four stations in the interior portion of a salt marsh in the Matagorda Bay Nature Park on Matagorda Peninsula, Texas. There is an active growth fault that runs through this site, which drives differential rates of subsidence resulting in up-thrown and down-dropped sides (Fig. 4). Marsh loss appears greatest on the down-dropped side due to subsidence of the fault block. We established two stations on either side of the fault, for a total of four. Of the two stations on a single side of the fault, one was placed in *Spartina alterniflora* low marsh (Fig. 5) and the second on a salt flat (Fig. 6). RSETs were also established at these stations.

Figure 4 – Growth fault line at Matagorda Bay Nature Park

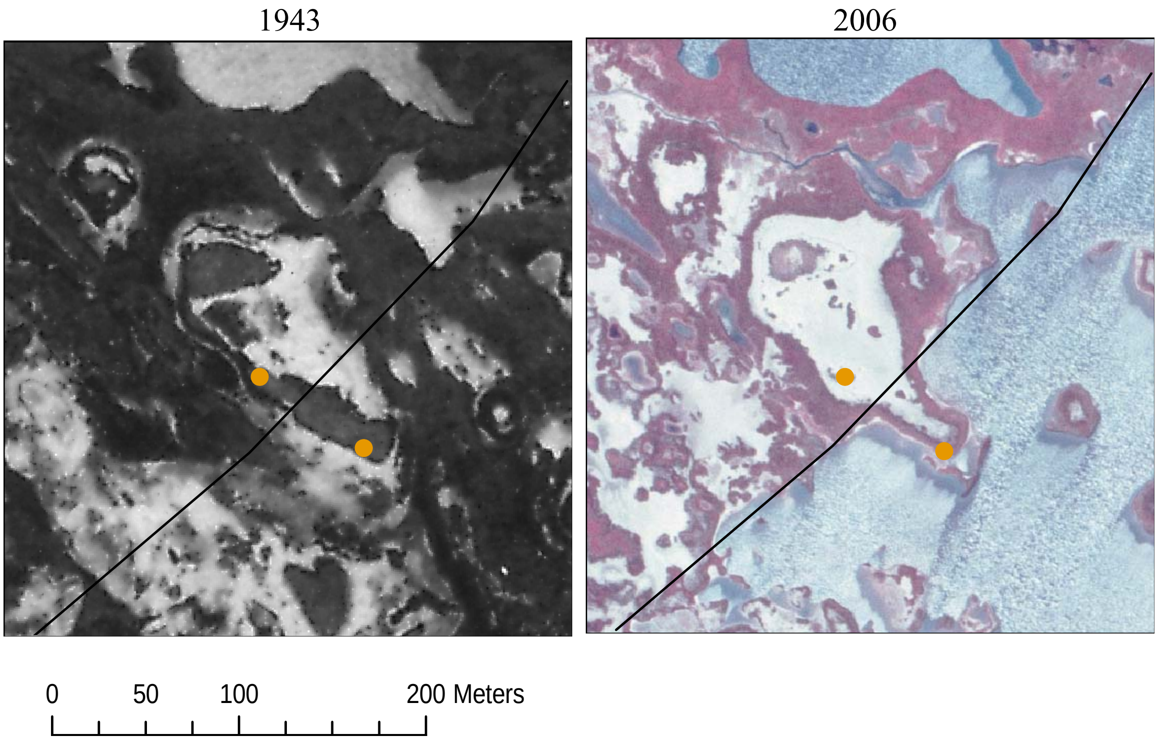


Figure 5- ***Spartina alterniflora*** **low marsh at Matagorda, TX**

Figure 6- Salt flat at Matagorda, TX

The methods were the same as for the Jumbile Cove site, except at Matagorda: (a) marker horizons did not erode away, (b) acrylic tubes were not used to measure root zone compaction/expansion, (c) nine recorded points within a plot at a given sampling date were treated as subsamples as opposed to eight points, and (d) only two dates were sampled, day 0 and day 398.

At Matagorda, we also quantified historical accretion rates over a decadal-centennial time scale in the *Spartina alterniflora* low marsh and the salt flat. Sediment cores were extracted (~2 m depth) in the same general area as the RSET stations (within 10 m distance). They were then transported to the laboratory for immediate processing. Cores were sectioned at 1 cm intervals, and aliquots of each interval were divided to allow for: (1) gamma counting (^{7}Be and ^{137}Cs), and (2) determination of ^{210}Pb activity concentrations by alpha counting its granddaughter, ^{210}Po.

A suite of fallout radionuclides (^{7}Be, ^{137}Cs and ^{210}Pb) were used to determine depths of sediment mixing, rates of sediment accumulation, and sediment geochronology at these sites across a range of time scales, (years, decades, century), with a maximum temporal resolution of approximately 100 years. These fallout radionuclides have been used to measure sediment mixing and accumulation and to determine sediment geochronology in a wide range of coastal settings (e.g., YEAGER *et al*., 2005, 2006, 2007; HUNTLEY *et al*., 1995).

Non-destructive, high-resolution gamma spectrometry was used to resolve ^{7}Be ($t_{1/2}$ = 53.5 d, E = 477 keV) and ^{137}Cs ($t_{1/2}$ = 30 y, E = 661 keV) using Canberra HPGe well detectors and digital spectrum analyzer (DSA), model 1000. Samples of ~10 g were stored in plastic test tubes prior to analysis. Standards (^{137}Cs: NIST, SRM #4357, and ^{7}Be: Isotope Products Laboratories CN #6007) were prepared and run on each detector to determine representative efficiencies for each nuclide. Counting and efficiency 1-sigma errors based on standards were typically less than ~ 2% and all samples, on average, were counted for 3 - 4 days to reach a standard deviation for both isotopes on the order of ~3 - 5%.

Alpha spectrometry was used to resolve ^{210}Pb ($t_{1/2}$ = 22.4 years), using a Canberra alpha spectrometer, model 7200. Lead-210 samples (~4 g) were spiked with a certified ^{209}Po tracer (Isotope Products Laboratory, #6209-100N) and leached using a method described in detail in Yeager *et al.* (2007). Ascorbic acid was added to the leachate to bind free Fe(III) and a Ag disk was then added to the solution over low heat to provide a substrate for the spontaneous deposition of polonium isotopes (SANTSCHI *et al*., 1980; YEAGER *et al.*, 2004).

The rate of sediment accumulation over the last four decades was determined using ^{137}Cs by: S = (D_{pk}/T) where S = sediment accumulation (g cm^{-2} yr^{-1}), D_{pk} = mass depth (g cm^{-2}) at which the ^{137}Cs maximum occurs (1963) and T = time (yr). The rate of sediment accumulation over the last century was determined using $^{210}Pb_{xs}$ via the constant flux-constant sedimentation (CF-CS) model, where accumulation rates are calculated assuming steady-state conditions, little sediment mixing, and a relatively constant porosity, using: $[I(z)] = [I(0)]\exp(-\alpha z)]$, or $\alpha = (\lambda/S)$ where [I(z)] and [I(0)] represents the $^{210}Pb_{xs}$ concentration at depth z and at the sediment-water interface, respectively, S = sediment accumulation (g cm^{-2} yr^{-1}) and λ = ^{210}Pb decay constant (0.031 yr^{-1}). This model was applied to the asymptotic portion of the $^{210}Pb_{xs}$ profile, excluding the uppermost sections that appears mixed based on ^{7}Be data.

All radionuclide data was graphically plotted versus sediment cumulative mass depth (g cm^{-2}) to eliminate the influence of variable sediment compaction due to coring artifacts (core shortening), as well as auto-compaction over time. We also present accretion rates in the form of cm yr^{-1}, for comparison to relative sea level rise and for ease of use by coastal managers. In these cases, radionuclide data was re-plotted versus depth in cm. There was no observed core shortening in the low marsh core, so this process was straight-forward for this core. For the salt flat core, we assumed linear core shortening and adjusted the data by 1.22 cm for each 1 cm in depth, as there was 13.4 cm of total shortening over the 60 cm length of this core, from the original hole depth of 73.4 cm (1.22 = (60+13.4)/60). This linear adjustment is reasonable, considering bulk density was strongly and linearly related with depth in this core ($p = 0.0005$).

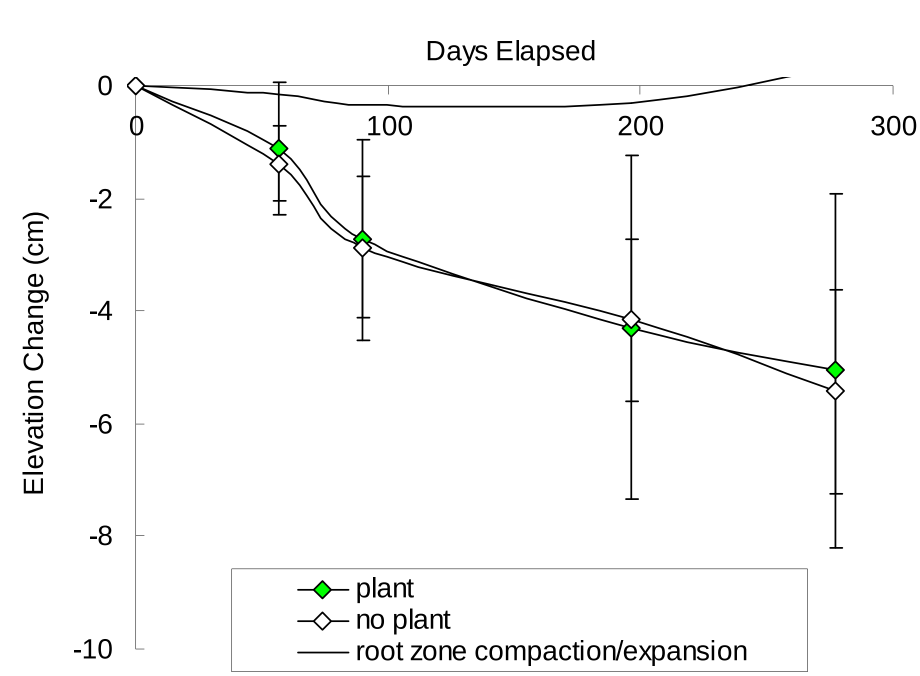
Results

West Galveston Bay

Results show that there has been no accretion at this site within the sampling year. All marker horizons disappeared within one month, denoting erosion. Nearly all elevation change was accounted for by this surface erosion of the sloping marsh edge; there was little contribution from marsh compaction/expansion processes in the root zone, and no sedimentary accretion.

After 277 days, which included the passing of Hurricane Humberto within 50 km of the study site and several winter storm events, we found no significant difference in the amount of elevation change between vegetated and unvegetated locations ($p = 0.4344$) (Fig. 7). Rather, erosion appeared to be related to a spatial gradient along the shoreline, as the east-to-west grouping of experimental blocks showed significant differences ($p < 0.0001$). This erosion gradient was likely due to the interaction of the wave energy with the topography/bathymetry at the site, and subsequent wave refraction/ attenuation before striking the marsh. For all plots and converting to cm yr^{-1}, there was an average of -8.02 cm yr^{-1} of vertical loss.

Figure 7- Erosion at Jumbile Cove



East Matagorda Bay

Results show that at the Matagorda Bay Nature Park, there have been very different accretion rates in the *Spartina alterniflora* low marsh (+3.27 cm yr^{-1} average) versus the salt flat (+0.27 cm yr^{-1}) within the last year. There have also been very different surface elevation change rates (+3.52 cm yr^{-1} average versus +0.24 cm yr^{-1} average, respectively). Typically, we would expect *Spartina alternflora* low marsh to accrete more quickly than an unvegetated salt flat, but our recorded low marsh accretion rate was unusually high. Perhaps, this large amount of accretion was due to the unusually high level of precipitation that occurred at this site during the growing season.

There have been slightly different accretion rates on either side of the fault within the sampling year. For example, in the salt flat, the average rate of accretion on the up-thrown side was +0.22 cm yr^{-1}, while on the down-dropped side the rate was +0.33 cm yr^{-1}. The up-thrown average rate of surface elevation change was +0.19 cm yr^{-1}, while the down-dropped rate was +0.29 cm yr^{-1} (these values do not include fault block movement). The difference between the accretion rate and surface elevation change rate is assumed to be below-ground compaction of the substrate. It appears from this data set that compaction is relatively minor in the salt flat, ~10% of the accretion rate, likely due to the sandy and inorganic nature of the soil here. In the low marsh, deviations from the mean amount of accretion for both sides of the fault were significantly large, obscuring any differences between the two sides of the fault. There appeared to be no compaction of the substrate in the low marsh, but rather an expansion, perhaps due to plant root growth.

Long-term accretion rates at Matagorda were different in the *Spartina alterniflora* low marsh versus the salt flat. For the low marsh, there appears to be erosion, and physical and/or biological mixing at the near surface as shown by the ^{7}Be profile (Fig. 8). The ^{137}Cs peak coinciding with the international moratorium on above-ground nuclear weapons testing in 1963 is clearly identifiable (Fig. 9). The rate of sediment accumulation over the last four decades was determined to be 0.20 ± 0.02 cm yr^{-1} using ^{137}Cs. The profile for $^{210}Pb_{xs}$ also indicated that erosion, and physical and/or biological mixing has occurred in the near surface. The ^{7}Be and $^{210}Pb_{xs}$ data profiles are in congruence with the interpretation of surface erosion at this site. Beneath the mixed/eroded layer, there are two distinct groups of $^{210}Pb_{xs}$ data with much different slopes, indicative of a sharp change in the rate of sedimentation (Fig. 10). The rate of sediment accumulation was determined to be 0.78 ± 0.12 cm yr^{-1} for the older portion of the core using $^{210}Pb_{xs}$. The near-surface, or "younger" portion of the core has a rate of 0.05 ± 0.01 cm yr^{-1}. The timing of the break between the two sediment accumulation regimes appears to occur just before the ^{137}Cs peak, or just prior to 1963. This timing is congruent with the time period during which fault movement began at this site.

Figure 8 – Low marsh ^{7}Be profile at Matagorda

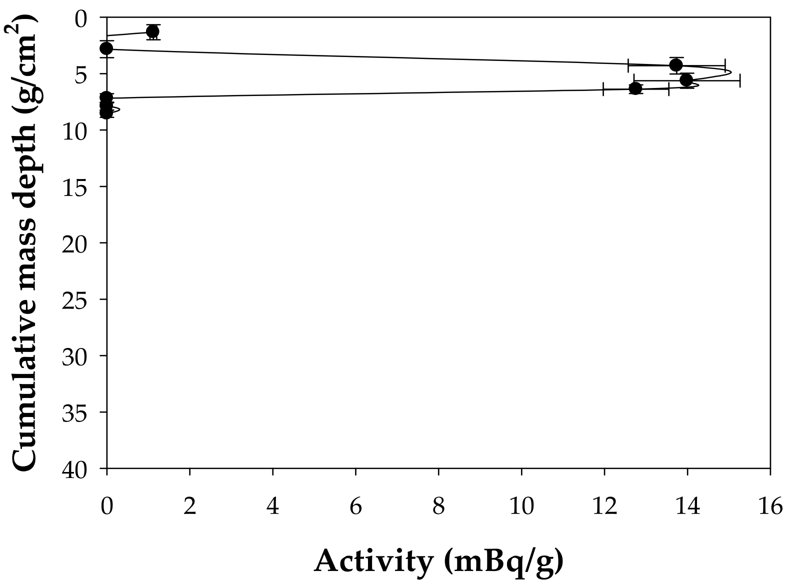


Figure 9 – Low marsh ^{137}Cs profile at Matagorda

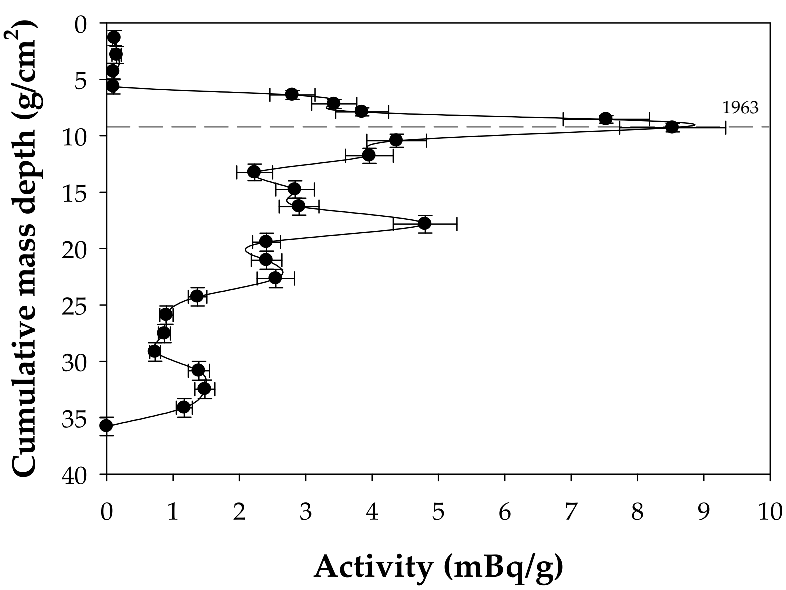
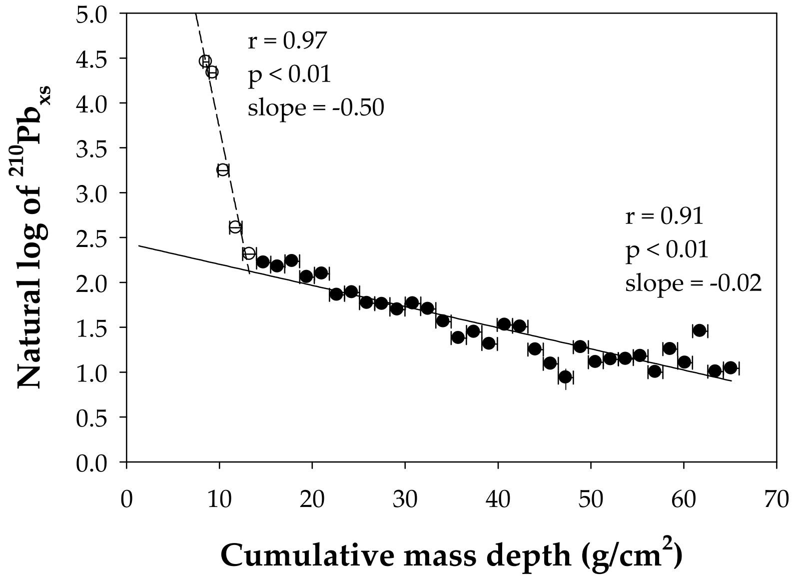


Figure 10 – Low marsh $^{210}Pb_{xs}$ profile at Matagorda



For the salt flat, radionuclide profiles show nearly ideal distributions with depth, indicating that this environment has remained undisturbed over a significant time frame (on the order of 100 yr). Over the short term, (~ 1 yr), the ^{7}Be profile (Fig. 11) indicates that physical and/or biological mixing has been restricted to only the very near surface here. The ^{137}Cs peak, coinciding with the international moratorium on above-ground nuclear weapons testing in 1963, is clearly identifiable (Fig. 12). The rate of sediment accumulation over the last four decades was determined to be 0.21 $\pm$ 0.03 cm yr^{-1} using ^{137}Cs. The profile for $^{210}Pb_{xs}$ (Fig. 13) is supportive of a stable setting here over the centennial time scale. The rate of sediment accumulation was determined to be 0.45 $\pm$ 0.05 cm yr^{-1} using $^{210}Pb_{xs}$. There is no evidence of significant erosion at this station based on any of the radionuclide profiles.

Figure 11 – Salt flat ^{7}Be profile at Matagorda

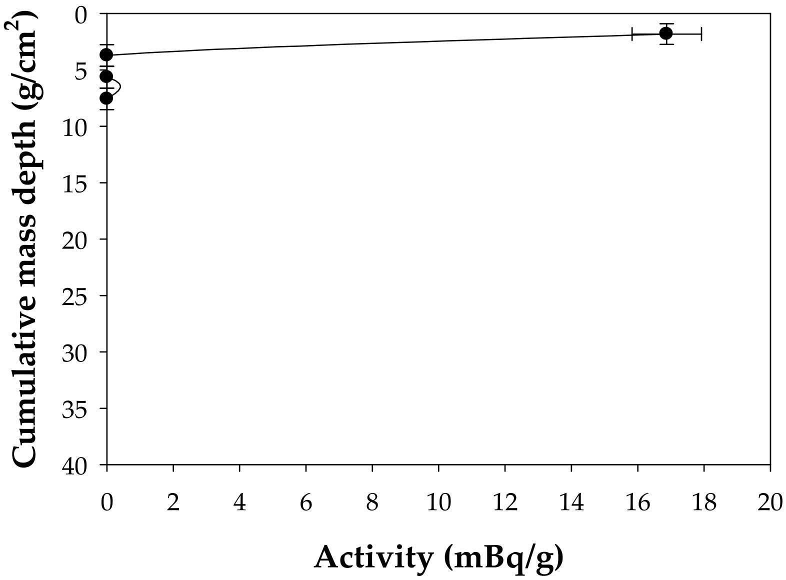


Figure 12 – Salt flat ^{137}Cs profile at Matagorda

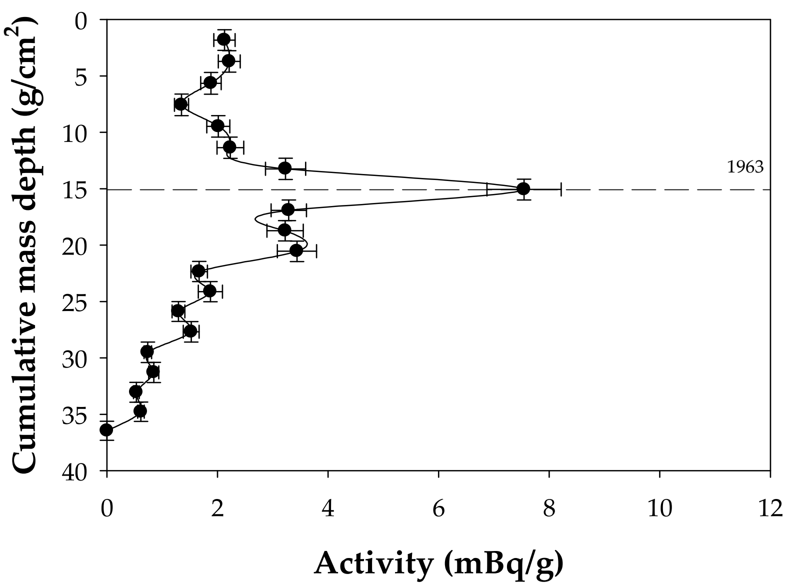
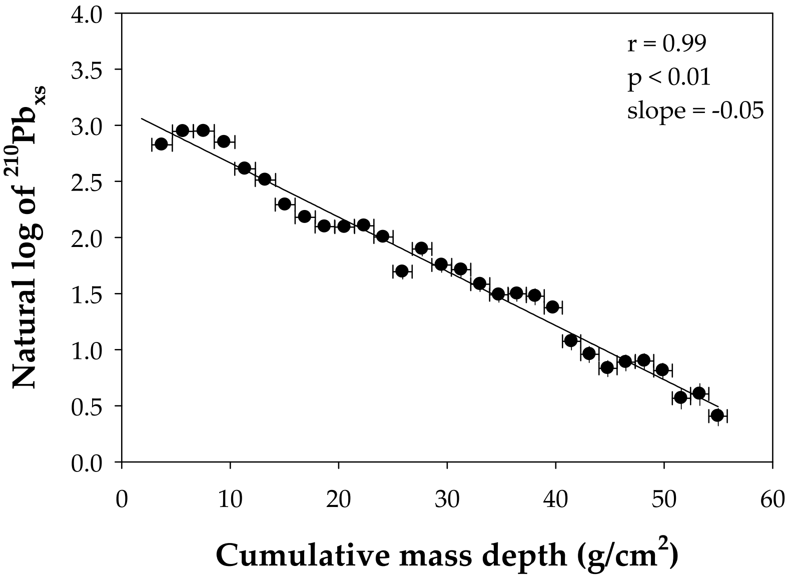


Figure 13 – Salt flat $^{210}Pb_{xs}$ profile at Matagorda



Discussion

Accretion rates in West Galveston Bay are quite low when compared to the rate of relative sea level (RSL) rise. The rate of RSL rise in this general area over the last 100 years (1908-2008) has been 0.60 cm yr^{-1}, as recorded by the Galveston Pier 21 tidal station (NOAA Station ID 8771450). We recorded 0 cm yr^{-1} of accretion within the sampling year. We found only surface erosion, and a slight compaction and/or expansion component to elevation change in the root zone, depending upon the season. In winter, compaction was predominant, while in the summer expansion was predominant. This pattern is somewhat typical and has been related to seasonal growth patterns of *Spartina alterniflora* by other researchers (MORRIS *et al.*, 2002). However, erosion is the dominant process in West Galveston Bay, as shown by both this study and those of other researchers (GIBEAUT *et al.*, 2003a). The magnitude of erosion behind geo-textile tubes, an average of -8.02 cm yr^{-1}, is surprising and should be especially worrisome for coastal managers.

Accretion rates in East Matagorda Bay are varied, depending upon plant community zone and specific location along the fault, but appear to be keeping pace with RSL rise in general. The rate of RSL rise in this general area over the last 54 years (1954-2008) has been 0.84 cm yr^{-1}, as recorded by the Freeport tidal station (NOAA Station ID: 8772440). The true rate may be slightly lower, as the Matagorda site is further south and the rate decreases as one moves towards the south. However, estimating RSL rise at a specific point in a specific marsh is a complex endeavor. For example, growth faulting in particular can affect the rate at a specific point in a marsh.

Our short-term monitoring over the sampling year points to only slight differences in accretion rates on either side of the Matagorda fault, although there was higher accretion on the down-dropped side, as one would expect. Still, the temporal range of our sampling is insufficient to fully define the effects of the fault; other processes likely override the effect of growth faulting upon marsh accretion within a single year, for example the effect of precipitation upon plant productivity and subsequent marsh accretion may explain the large amount of accretion in the low marsh, 3.27 cm yr^{-1}. The salt flat rates, regardless of which side of the fault they were representative of, were much lower and may point to potential future losses in this habitat zone.

Decadal and centennial accretion rates in the *Spartina alterniflora* low marsh were moderate, and in the absence of faulting appear capable of keeping pace with RSL rise. In the low marsh, the accretion rate was nearly the same as the RSL rise rate, or 0.78 cm yr^{-1} prior to faulting. However, when fault displacement likely began just prior to 1963, this rate fell precipitously to 0.05 cm yr^{-1} as recorded by the $^{210}Pb_{xs}$ data profile. The ^{137}Cs profile shows a more moderate rate since faulting, 0.20 cm yr^{-1}. Thus in this area of the down-dropped fault block, there is a long-term accretion deficit on the order of -0.64 to -0.79 cm yr^{-1}, in the low marsh. The upper 5 cm of this surface continues to be eroded and mixed today.

In the salt flat, the decadal-centennial accretion rates are lower than in the low marsh, and there is a greater deficit relative to the sea level rise rate. This deficit is fairly large, -0.39 to -63 cm yr^{-1}, and may explain the findings of White *et al.* (2002) that show salt flats were lost in the Matagorda area over the 1950-2000 time period, having been converted into low marsh as the sea rose.

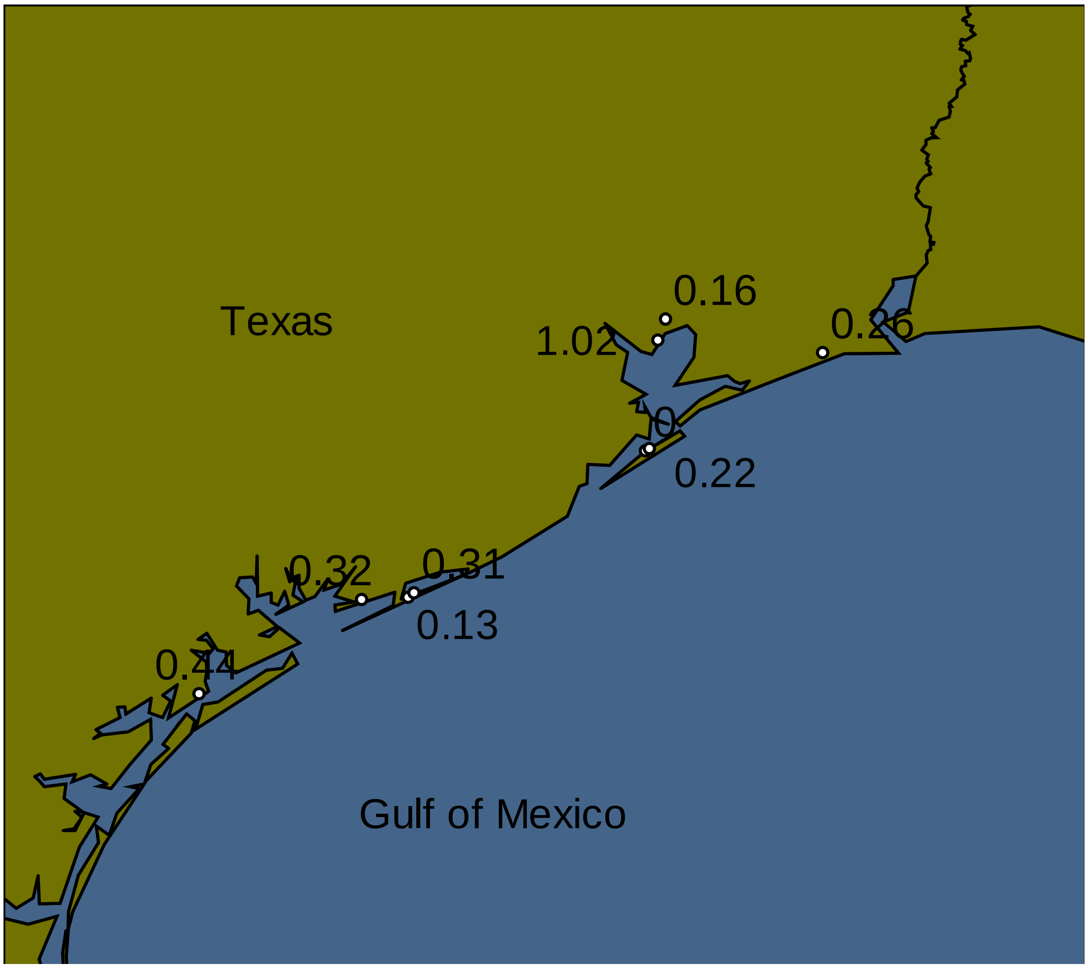
An accretion map for the Upper Texas Coast

Table 1 details a compilation of accretion-related studies along the Upper Texas Coast. We then mapped these rates spatially, excluding the pre-diversion studies (Figure 14). This depiction should be viewed as a generalized representation only, as there are different hydrodynamics, different plant communities, and different anthropogenic modifications at specific locations lowering sediment flow in one location while raising it in another (STEVENSON *et al*., 1988; REED *et al*., 1997; HARTIG *et al*., 2002), thus differentially affecting the potential marsh loss/gain in a single estuary or marsh (WILLIAMS 2003). Much of the variation among accretion rates along the Upper Texas Coast can be related to the proximity of major river inputs, for example WILLIAMS (2003) and WHITE & CALNAN (1990) found high accretion rates near the Trinity River, while YEAGER *et al.* (2007) found low rates. Away from these sources of riverine sediment, accretion is likely to be less variable.

Table 1 – Compilation of accretion rate studies along the Upper Texas Coast

Study	**Location and Description**	**Accretion Rate (cm yr^{-1})**
White & Calnan 1990	Colorado River Delta (prior to diversion, after log-jam removed)	6.40 average
White & Calnan 1990	Trinity River Delta (prior to diversion)	7.00-9.00 average
Williams 1995	Mad Island Slough, Matagorda Island, Cs-137	0.32 average
Callaway *et al.* 1997	low marsh, Aransas National Wildlife Refuge, Pb-210	0.44 average
Brian Perez, USGS unpublished data	McFaddin National Wildlife Refuge, RSETs	0.26 average
Williams 2003	Trinity River Estuary, Cs-137	1.02 average
Yeager *et al.* 2007	Trinity River floodplain marsh, Cs-137 and Pb-210	0.16 average
Ravens *et al.* 2008	Galveston Island State Park and Starvation Cove area, Cs-137 and Pb-210	0.22 average
Feagin & Yeager 2008 (present study)	Jumbile Cove, Galveston, RSETs	0.00 average
Feagin & Yeager 2008 (present study)	Matagorda Bay Nature Park, Cs-137 and Pb-210	0.78 / 0.13 average in low marsh before / after faulting 0.33 average in salt flat

Figure 14 – Accretion rates along the Upper Texas Coast in cm yr^{-1} (see Table 1). NB: This map is generalized representation only. Accretion rates vary spatially according to many parameters (see text).



Conclusion

Most Upper Texas Coast marshes are at risk for submergence. This risk appears to be highest for marshes along the north-easterly reaches of the coast, Galveston Island in particular, due to the low accretion rates. The problem in this sector has surpassed being a simple accretion problem; the most likely future is that the marshes that are left will be eroded over time. Erosion rates are quite high, even in areas that are protected by geo-textile tubes.

In the south-westerly reaches of this coast, for example along the Matagorda Peninsula, the risk of losing *Spartina alterniflora* marshes is less worrisome as accretion rates are close to the rate of RSL rise. However, a pressing concern for the future is that salt flats (important avian habitats) will be lost as they convert to low marshes. Moreover, continued growth fault activity may also result in further *Spartina alterniflora* marsh losses, although on a more localized basis.

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