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Sediment Elevation Dynamics in Tidal Marshes: Functional Assessment of Accretionary Biofilters

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Summary

In this report we discuss:

a)The role of coastal tidal marshes in functioning as biofilters for estuarine waters;

b)patterns of sediment elevation change at 11 marsh sites along the U.S. East Coast;

c)challenges and applications of a newly developed database to store and organize sediment elevation data as measured by the Sedimentation-Erosion Table;

d)guidelines for a standardized use of the Sedimentation-Erosion Table in different coastal habitats.

To investigate the role of coastal tidal marshes in functioning as biofilters for estuarine waters we monitored nutrient and total suspended solids at Jug Bay, Maryland, confirming our hypothesis that tidal marshes can improve the quality of estuarine waters providing a highly beneficial ecosystem service to humans.

To study patterns of sediment elevation change we monitored 11 tidal marsh sites subject to different levels of natural and anthropogenic influence by means of a Sedimentation-Erosion Table (SET) and marker horizons. The study included newly established sites, previously abandoned sites and a core of long-term monitoring sites within the National Estuarine Research Reserve system.

We constructed the Coastal Elevation Changes Database (CECD, accessible at: http://ecoinformatics.uvm.edu/SET) that provides an unprecedented potential to assess the proper temporal and spatial scales at which to observe sediment elevation change in relation to sea level rise, and the effect of restoration on marsh development. We also developed standardized guidelines on how to establish a SET monitoring site and on how to deploy this instrument.

Introduction

The National Estuarine Research Reserve system (NERR), a network of 25 protected areas, is committed to fulfill NOAA's stewardship of estuaries. The NERR sites were the focus of our study to address questions on the functioning of tidal marshes, their services to humans and their fate under pressure of rising sea levels.

Tidal marshes are self-sustaining ecosystems that, in the absence of human disturbance, have persisted for thousands of years. Adequate supplies of sediments from marine or riverine sources are critical for plant growth and peat formation to ensure equal rates in elevation gain towards sea level rise. Changes in estuarine hydrology and suspended sediment loads due to anthropogenic or other interventions can cause dramatic changes in salt marsh sediment supply, leading to changes in the rate of salt marsh formation and erosion (Figure 1). Already, human activities have increasingly led to destruction of a large proportion of coastal marsh habitat and have resulted in considerable ecological change in much of the salt marsh that remains.

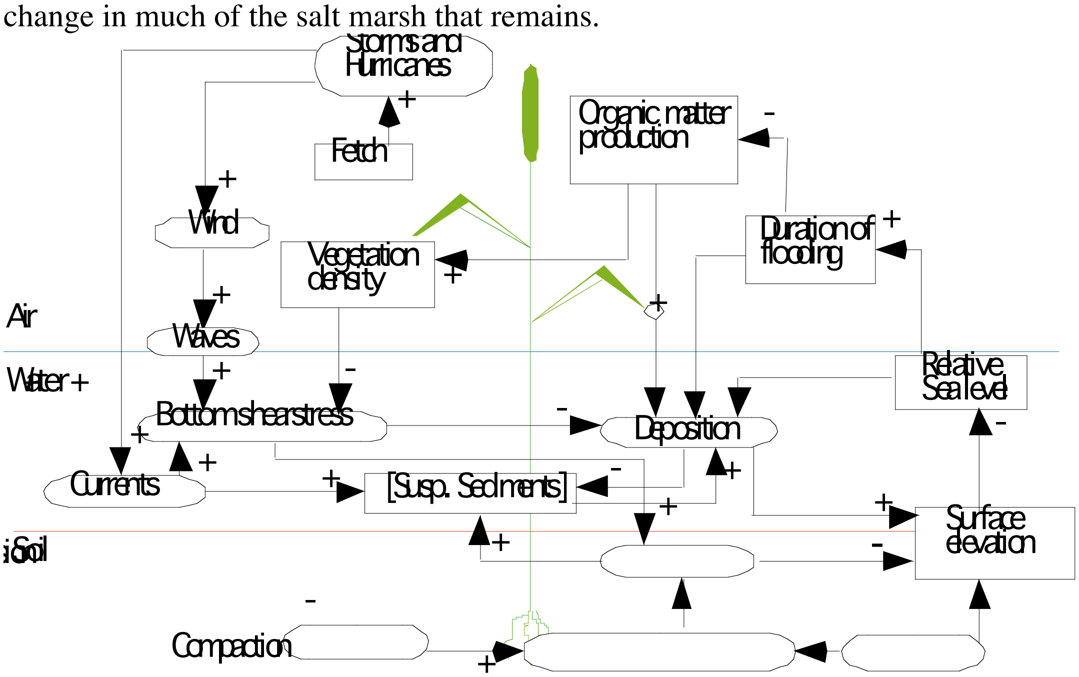


Figure 1 Conceptual model on the drivers, properties, and potential feedbacks within a salt marsh system.

Because tidal marshes are the interface between terrestrial and aquatic environments (Harvey and Odum 1990), they offer unique services in bio-filtering, that are performed during their daily exchanges of estuarine and riverine waters. The nature of these exchanges is not only critical for the persistence of marshes and its ecosystem services to humans, but also for the ecosystem health of estuaries and coastal waters. Sediment exchanges between marshes and tidal waters are determinant for peat formation and long term marsh persistence, even more so considering predictions of a global sea level rise. During sediment exchanges, tidal marshes can improve stream water quality as they trap the suspended sediments. Nutrient exchanges also improve stream water quality as tidal marshes transform and take nutrients and toxic chemicals up before they reach the estuary (Simpson et al. 1983, Carter 1986). The estimated economic contribution of tidal wetlands to water purification services exceeds $6500/ha/yr (Costanza et al. 1997). Of major importance in assessing the potential of these coastal wetlands to persist in the long term is monitoring the dynamics in Relative Sea Level (RSL).

RSL, or the average distance between the soil or sediment substrate elevation and the water elevation, can be seen as an indicator of marsh ecosystem health. RSL integrates a complex interplay of water level, plant growth and sediment accumulation, erosion and compaction dynamics in the system (Figure 1). Major factors that are changing RSL dynamics in coastal marshes are the rate of present sea level rise (Bijlsma 1996), and the reduction in suspended sediment loads from river alterations through damming and flood control projects**.** To preserve coastal marshes, the increased RSL requires their landward migration (Bijlsma 1996) so that future distribution and persistence depends largely on the availability of low-lying upland areas that allow marshe formation (Titus et al. 1991).

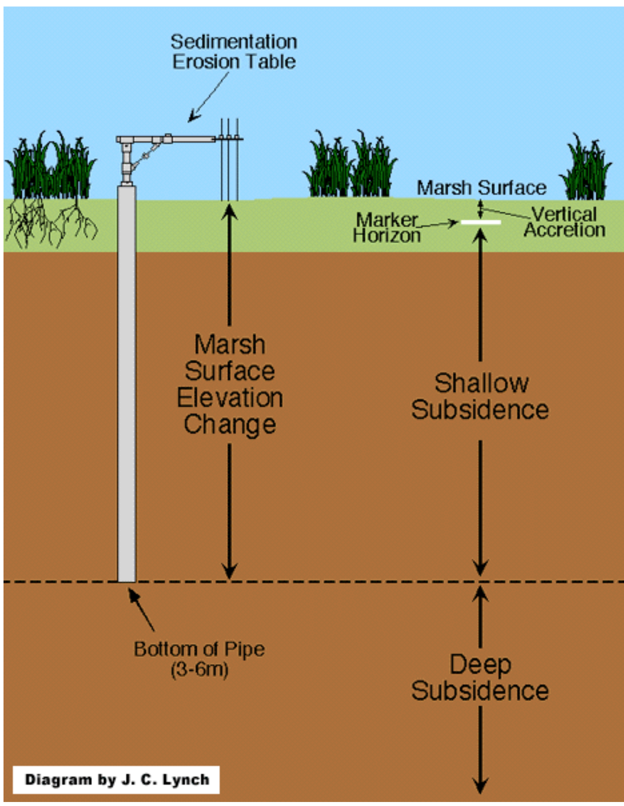


Figure 2. The Sedimentation Erosion Table (SET) measures vertical sediment elevation. Measurements reflect dynamics of surface (sediment deposition and erosion) and below-surface processes (organic matter decomposition and sediment compaction). Marker horizons capture only surface processes (deposition).

Tracking relative sea level rise, while measuring the sediment surface elevation relative to water level is the single most important factor for the assessment of coastal marsh vulnerability. Addressing the effects of current and future SLR involves studying the complex interplay of sediment accumulation, erosion, and compaction that eventually determines soil elevation (Figure 1).

In recent years, the Sedimentation Erosion Table (SET) has become an important technique in observing sediment elevation changes in coastal wetlands (Figure 2). SET monitoring provides time series of the integrated effect of surface and belowground processes on sediment elevation. This technique involves the installation of long aluminum pipes into the marsh by means of a vibra-corer to serve as permanent stations that sit the SET for measurements (Boumans and Day 1993). The concurrent use of the SET and traditional methods to assess accretion, such as marker horizons, has provided new insights on how surface and subsurface processes interact in determining marsh sediment elevation (Figure 2).

The analysis and interpretation of changes in vulnerability require an elaborate set of standards and methods of assessment and monitoring. The increased use of easily standardizable methodologies to study accretion and changes in sediment elevation, such as marker horizons and the SET, has generated large amounts of data that could be used to gain a better understanding of coastal processes in relation to sediment surface elevation, making it possible to compare different areas and develop simulation models. For these reasons we developed the Coastal Elevation Changes Database (CECD) designed to be a central repository and reference base for long-term monitoring of sediment elevation and accretion processes in coastal marshes. Building on the large amount of data that were contributed to the database, we present results in sediment elevation dynamics at 11 coastal sites, provide guidelines on standardized methodologies to deploy the SET, and describe the structure and application of the CECD.

Goals

The goals of our study were:

1. To establish a standardized protocol to obtain, analyze, and interpret substrate elevation change using the Sediment Elevation Table (SET).
2. To link marsh elevation changes and accretion processes to reductions in suspended sediments and nutrient concentrations of the estuarine waters.
3. To expand the network of SET monitoring sites, in order to gain a better understanding of coastal elevation changes at a larger spatial scale.
4. To develop a data depository on sediment elevation changes in estuarine habitat in cooperation with research coordinators of the National Estuarine Research Reserve (NERR) system and marsh ecologists. The purposes of this database were to establish baseline data of sediment elevation changes from a variety of estuaries, a standardized protocol for use and analysis of SET data, and criteria that can be used to assess success in created and restored critical habitats.

Methods

Measurement of Sediment Surface Elevation Changes

Measuring sediment elevation with a SET involves the installation of long aluminum pipes into the marsh by means of a vibracorer to serve as permanent stations that sit the SET for measurements. The actual measuring device is portable and has a leveling arm that, when attached to the permanent pipe, can provide measurements of the distance to the sediment surface. Repeated measurements of elevation are taken at four fixed different orientations at each station. Wooden boards are used to facilitate access to the stations and minimize damage and substrate disturbance. Marker horizons of feldspar are placed at each SET stations to measure solely accretion. Feldspar is a white material composed of silt and clay and has a bulk density similar to that of the marsh sediments. For this procedure it was spread out uniformly on the marsh to reach a thickness of 1 inch over a 1 m2 surface 50 cm away from the permanent SET pipe. Horizons are sampled after one year since their placement either by taking one ore more small cores or by inserting a sharp knife into the sediments and measuring the thickness of the dark layer of sediment deposits at three different points along the walls of the slit.

SET stations installed at sites across 7 US coastal areas were used in the exploration of processes that influence marsh elevation change. In 6 out of 7 areas SET stations were installed in or close to a NERRS site. Several SET monitoring sites were established before 1992 (Patuxent River, MD, Cumberland Island, GA, Atchafalaya and Terrebonne Basins, LA, Rookery Bay, FL and Tijuana Bay, CA); The sites in New Hampshire (Great Bay NERR) and Maine (Wells NERR) were established around 1995, while additional stations within the Patuxent River were established in 1998 at Jug Bay, MD. See elsewhere in the report for site descriptions.

In April 2000, we located, visited, and measured abandoned or scarcely visited SET stations along the Gulf and South Atlantic coasts. Newer SETs were calibrated against the older models originally used when the stations were established. These sites were: North Inlet NERR, SC, Cumberland Island, GA, and four locations along the Louisiana coast. At each location local researchers contributed historic data for their research sites. During the winters of 2000 and 2001 we located and visited stations along the Patuxent River, MD. Stations at Great Bay, Wells, Rookery Bay , Tijuana River and Jug Bay were measured at least twice yearly.

Total Suspended Solids

At the Jug Bay NERR site we investigated the tidal marsh ecosystem function of bio filtering and waste assimilation. Bio filtering of suspended sediments was investigated through the analysis of Total Suspended Solids (TSS) in waters entering and leaving the marsh. Two permanent sites for sampling water were established in the mid portion of two tidal creeks respectively located in the northern and southern marsh (see site descriptions). Total suspended solids were monitored during two 24 hours cycles at each site by collecting hourly water samples of 500ml under various weather conditions (Table 1).

Table 1 Sampling dates and weather conditions at the two Jug Bay marshes.

Date	Maximum Temperature (F)	Precipitation (Inches)	Wind conditions	Site
Sept 22-23 1999	67	0.48	breezy	North marsh
Mar 15 2000	63	0.00	breezy	North marsh
Oct 13-14 1999	68	0.01	calm	South marsh
Mar17 2000	72	0.56	windy	South marsh

A special floating device was built to ensure that sampling occurred at approximately mid water column. Water samples were collected with the automated sampler SIGMA 900 and then filtered at the Jug Bay laboratory through 1.7 micron, precombusted, preweighed, Pall glass fiber filters. The filters were dried overnight at 60 degrees Celsius and weighed to 0.1mg. Concentrations were calculated as mg/l by dividing the weight of the suspended solids by the volume of water filtered.

3.3. Nitrate and Ammonium Concentrations
Inorganic nutrient concentrations in the Patuxent River at Jug Bay have been measured from December 1987 to the present at three sites: in two shallow intertidal channels respectively located in the north and south marsh (see Figure 3), and in the main channel of the Patuxent River. Water samples for the measurement of NH4+ and NO3- were collected in pre cleaned propylene bottles and filtered immediately after collection using Whatman GF/F filters. Sub samples were placed into 3 ml plastic auto analyzer cups and promptly frozen. The samples were analyzed within three weeks of collection at the Nutrient Analytical Facility at the Chesapeake Biological Laboratory (University of Maryland, Solomons, MD) following standard methods (Parson et al. 1984, U.S. EPA 1992).

Research Results

Sediment Surface Elevation

Jug Bay, Maryland

Figure 3 Locations of SET stations within the Jug Bay, NERR site.

Jug Bay is a broad shallow embayment of the upper portion of the Patuxent River, a tributary of the Chesapeake Bay. Jug Bay habitat consists of a tidal freshwater wetland surrounded by upland forest and scattered farm fields (Figure 3). 722 ha of tidal wetlands make Jug Bay one of the largest tidal freshwater system on the U.S. East coast. Salinity, normally lower than 0.5 ppt, can reach levels of about 2 ppt under low flow conditions.

In 1895 a railroad bed was laid across the marsh, dividing it into two parts, the North Glebe and the South Glebe marshes (we will use south and north marsh for brevity throughout the report). The railroad tract was dismissed in 1935 and the Jug Bay area was abandoned until in 1985 it became a wildlife sanctuary for scientific research as part of the Chesapeake Bay-Maryland National Estuarine Research Reserve.

Highly unconsolidated sediments with *Nuphar advena* (spatterdock) as the dominant species characterizes the low marshes at Jug Bay. *Peltandra virginica* (arrow-arum) and *Zizania aquatica* (wild rice) co-occur in this marsh where vegetated mounds interspersed within a relatively flat surface drained by small creeks characterize the substrate. Low marsh floods range between 30 cm and 65 cm for 8-9 hour periods during a tidal cycle (Khan and Brush 1994).

Typha angustifolia and *T. latifolia* dominate the mid marshes. At intermediate elevations the mid marshes at Jug Bay feature a higher number of plant species than any of the other habitats. Species compositions of a mid marsh include *Sagittaria latifolia* (arrowhead) and *Bidens leavis* (bur marigold). The substrate is covered with an intricate root-mat, which during the summer becomes almost impenetrable. *Typha* stalks stay upright through most of the winter. This marsh is inundated to an average depth of 5cm on higher areas and 20 cm on lower areas for a period of time of 2-4h during each tidal cycle (Khan and Brush 1994).

High marshes at Jug Bay are typically inundated for shorter periods of time during the tidal cycles. Short trees and bushes, mostly *Alnus serrulata* (elder) dominate the high marsh vegetation, commonly referred to as scrub-shrub wetland. Elder roots form hummocks or small islands within an otherwise lower elevated substrate high in decomposed organic matter (muck). The areas between the hummocks range within a few square meters surface area and are flooded by tidal waters. SET elevation measurements are taken at this lower elevated substrate.

Low marshes at Jug Bay are reported to have low carbon content and high decomposition rates, while mid marshes are characterized by higher organic and nutrient content (Kahn and Brush 1994). The North marsh is expected to receive a higher load of nutrients and sediments, due to the proximity of the Western Branch estuary into the Patuxent River. On the Western Branch a wastewater treatment plant is active during the summer.

Khan and Brush (1994) reconstructed the marsh changes at Jug Bay over the last 200 years through pollen coring and sediment and nutrient concentration profiles. Their findings show that high sedimentation rates following early settlement deforestation and the subsequent construction of the railroad bed have caused Jug Bay waters to become more shallow. As a consequence, a big portion of the open water area became vegetated and shifted to low marsh while similarly, the previous low marsh turned into mid marsh. The construction of the railroad bed affected sediment deposition directly, due to the movement and accumulation of debris from construction material and indirectly by altering the water flow in the main channel. Sediment supply at this site doesn't seem to be limiting, due to the sediment discharge from the nearby creeks. Also, major sources of bioturbation are muskrats.

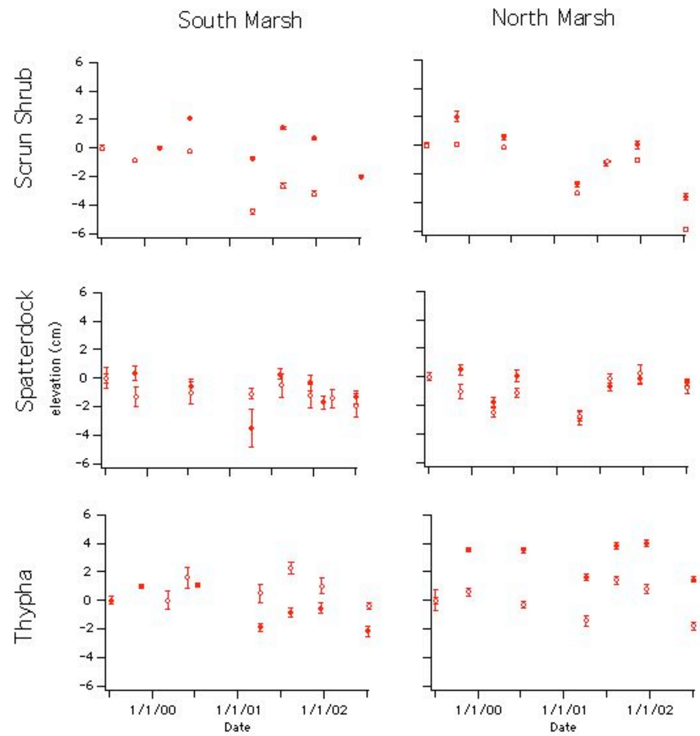


Figure 4. Sediment elevations over time (as the mean +- SE of the 36 measurements at each station) at the north and south marsh relative to the initial zero value

In February 1999 twelve SET permanent aluminum pipes were installed at the Jug Bay Wetlands Sanctuary by means of a vibracorer following the methodology developed by Boumans and Day (1993) and described in more detail in the Appendix of this report.

The experimental design was meant to partition variability of processes in relation to geographic orientation (north marsh versus south marsh), habitat type and elevation profile from low, spatterdock dominated marsh, to mid-cattail marsh, to the high scrub shrub marsh. Six stations were placed in the northern and the remaining six in the southern marsh. Within each side of the railroad bed two stations were established at the low, mid and high marsh. Placing two SET stations at a short distance from each other assessed variations within habitat. Measurements of elevation were taken at four fixed different orientations at each station twice a year, usually in summer (or late spring) and winter (or early spring). Wooden boards were used to facilitate access to the stations and minimize damage and substrate disturbance. We did not record a measurement if a pin fell on a vegetation stem, branch or large piece of debris.

Marker horizons were laid in Summer 2000 and sampled in July 2002 at each station. Only three marker horizons out of four could be recovered at the spatterdock stations. Although horizons were potentially lost to erosion the more likely cause was the unconsolidated state of the substrate that made it impossible to find the feldspar layer.

Stations within each habitat showed similar, well replicated dynamics. This was most profound for the north scrub shrub and spatterdock habitat sites, where relative changes in elevation for the two replicates are almost coincident (Figure 4). The variability of surface elevation measures within station doesn't show any clear seasonal trend, indicating that the substrate keeps relatively homogeneous throughout the seasons. The lowest within-station variability is found at the scrub shrub sites that are known to be flat sparsely vegetated surfaces, where the sediment is an organic unconsolidated soup that prevents the establishment of root masses.

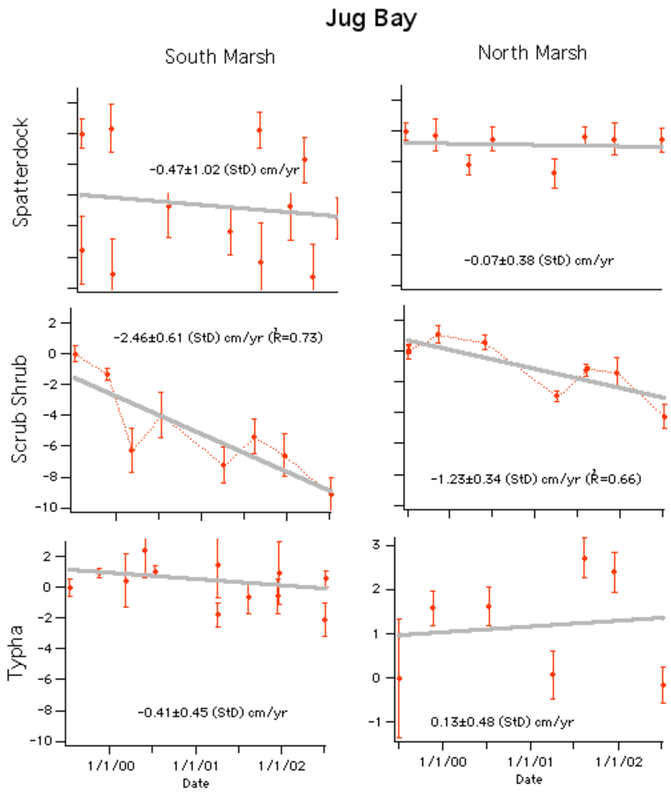


Figure 5. Trends in Sediment Elevation Change between July 1999 and July 2002. Plotted are average corner means and standard errors pooled from the two replicate stations at each habitat by marsh location

Only shrub scrub sites showed significant trends in sediment elevation change with a loss in elevation of 2.46 ±0.61cm/yr for the south marsh and 1.23 ±0.34 cm/yr for the North marsh. Marker horizon data suggest that sediment elevation loss at the scrub shrub sites is rather a result from subsurface processes such as consolidation of mineral sediments and decomposition of organic matter, than from erosional process as we recorded sediment deposition. The formation of a small tidal channel in the south cattail marsh and a vegetation shift from spatterdock to cattail in the south spatterdock marsh created the highest within-station variability among all stations.

No hurricane impacts on marsh elevations were observed after hurricane Floyd passed through the region on September 16, 1999, with some areas receiving 11 inches of rain. Elevation dynamics were more defined and better replicated within north marsh habitats than in south marsh habitats. These dynamics, after an initial gain in elevation, were followed by a loss, a subsequent gain and another loss (Figure 4). The early spring 2001 measurements marked steep declines in elevations due to the effect of ice covering the marsh for a prolonged period of time within the exceptional cold winter from 2000-2001. The patterns in elevation changes were rather independent of habitat, suggesting that vegetation is not a driving factor in sediment surface dynamics.

Although, sediment dynamics did not follow a marked seasonal variation, indicating that other factors might be predominant in influencing sediment surface changes than biomass accumulation and decomposition, the overall vegetation cover had a strong influence on sediment accretion. Marker horizons data for the period July 2000 - July 2002 (Table 1) show that *Typha* sites are able to trap the highest amount of sediments (30.57± 2.25 mm SE) followed by scrub shrub sites (27±1.80 mm SE) and spatterdock sites (20.17 ±3.45 mm SE). No significant differences were detectable between sediment deposition at the north and south marsh.

GreatBay, New Hampshire and Wells, Maine

SET stations at New England sites were established to observe sediment elevation processes in salt marshes following restoration. Each study site paired a marsh impounded by roads or invaded by *Phragmites australis* (common reed) with a reference site (Burdick et al. 1997). Stations impacted by tidal restriction were Drakes Island Marsh within the Wells National Estuarine Research Reserve in Maine (43.33 N, 70.63 W), Mill Brook Marsh at Stuart Farm in New Hampshire (43.08 N, 70.94 W) (Figure 6), and Oak Knoll at the Rough Meadows Sanctuary of the Massachusetts Audubon Society in Massachusetts (42.81 N, 70.89 W). Stations invaded by common reed were Sandy Point, within the Great Bay NERR (Figure 6), and Awcomin marsh close to Rye Harbor, NH. Figure 8 shows the trends in sediment elevation from the five sites that underwent restoration.

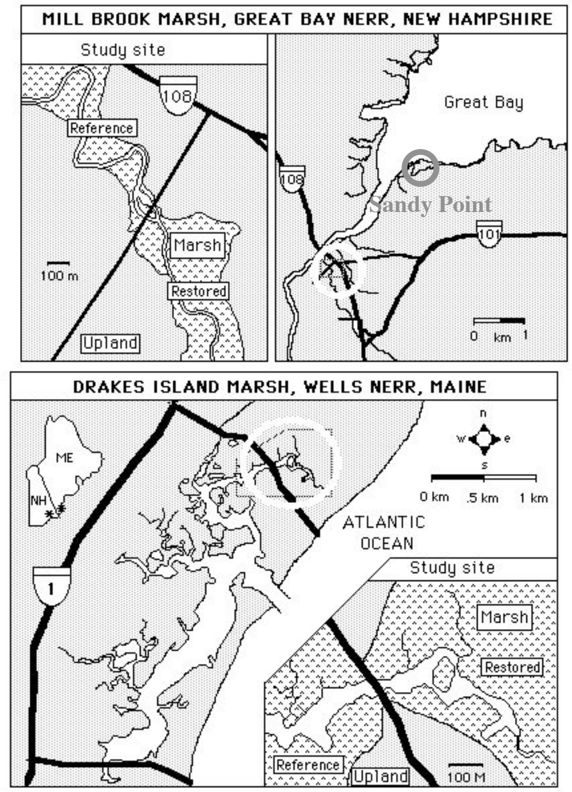


Figure 6 SET stations at GreatBay, NH and Wells, ME NERR sites.

Drakes Island marsh formed landward of a barrier beach system in a lagoon estuary approximately 4,000 years old (Kelley et al. 1995). The marsh was first impounded around 1848 for pasture. Early in the 20th century, a road replaced the original low dike and water control structures were installed to control water flow out of the marsh while preventing water inflow. Tidal flow to this marsh was re-established in 1988 when accidentally a culvert flap gate fell off the water control structure.

Mill Brook marsh at Stuart Farm formed in a minor fluvial valley near the mouth of the Squamscott River, a major tributary to Great Bay in New Hampshire (Figure 6). When an access road was upgraded in the mid-1960s, a pipe culvert with a flap gate replaced a bridge over the tidal creek that connected the marsh to the Squamscott River and larger estuary. Subsequently the area became a wet meadow, flooded by snowmelt each spring and by salt water from occasional flap gate failures or storm tides over the road. In October 1993, a new arched culvert 2.1 m in diameter was installed and the flap gate on the existing culvert was removed to restored the tidal flow and salt marsh habitat upstream of the road at Mill Creek.

Oak Knoll marsh is part of the Great Marsh complex in Massachusetts north of Cape Ann and south of the Merrimack River. This tidally restricted site is part of a back barrier salt marsh that formed landward of Plum Island about 6,000 years old. Most of the marsh occurs as high marsh and is surrounded by low relief islands vegetated by oak trees. A small section of marsh was divided from the larger marsh by the Route 1 causeway that was built in the middle of last century at the border of Rowley and Newbury, with the present culvert configuration established ca. 1930. Two undersized culverts (south culvert 1.03-m diameter, north culvert 0.69-m diameter) conduct tidal waters to several hectares of marsh.

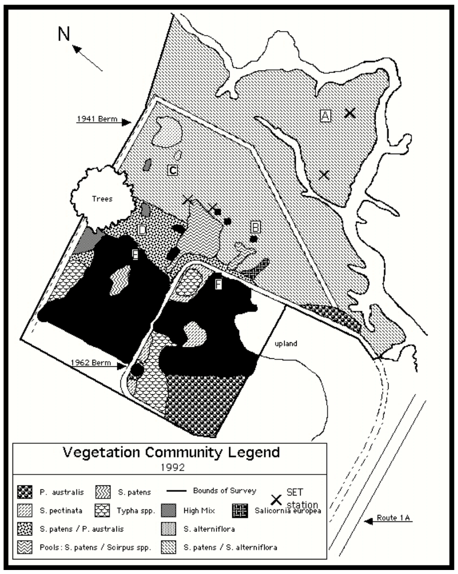


Figure 7. Awcomin marsh, NH. Vegetation cover, areas of spoil operation and SET sites

Awcomin marsh is a 120 acre back barrier salt marsh in Rye, New Hampshire, that contains 35 acres of impacted marsh directly west of Rye Harbor. In 1941, and again in 1962, dredge spoils from the maintenance of Rye Harbor were placed directly on approximately 35 acres of salt marsh to the west of Rye Harbor. The 1941 spoils operations were allowed to cover the entire 35 area with between 12 and 20 inches of material contained by low dikes. The 1962 operations were placed directly over the 1941 filling, but were contained to an area about 15 acres in size. This has resulted in marsh elevations of varying heights, from 3 to 5 feet above the original marsh surface, with an average of 3.5 feet. Between the 1960s dike and the 1940s dike, what appears as salt marsh surface is actually marsh reformed on top of spoil. Unfortunately, while these areas received enough tidal flow (at least during extreme tides) to re-vegetate with marsh vegetation, the new surfaces were high enough to allow the subsequent invasion of *Phragmites*. At the present time, most of the Awcomin marsh has been invaded by dense stands of *Phragmites* except for the highest elevations toward Route 1A which are wooded. In 1991 and 1992, restoration efforts were undertaken to restore about 5 acres of the impacted marsh to a mixture of low and high marsh. During these efforts,

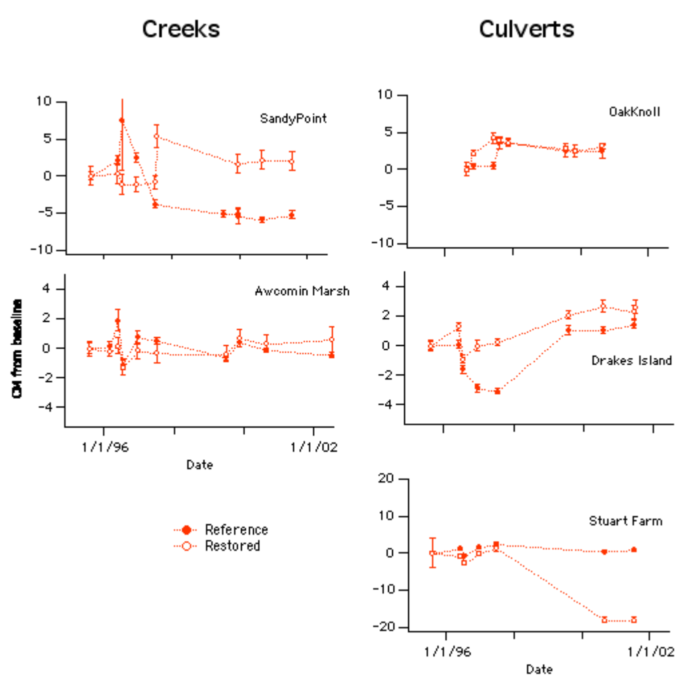


Figure 8. Sediment elevation trends at restored and control sites. Elevation monitoring started after restoration at all sites.

spoil was removed from several small areas that reseeded themselves and re-vegetated with marsh grasses within 4 years with indications that pannes are forming. SET stations were placed in restored areas and areas that had been impacted by only the 1940s dredging.

Sandy Point marsh is located on the southern shore of the Great Bay NERR, New Hampshire (Figure 6). This area features salt marshes, woodlands, a sandy shoreline and tidal water. In 1994, volunteers cleaned sediment and debris from a tidal creek and side ditches to restore tidal flow further into the marsh. The restoration was intended to control *Phragmites australis*, considered an invasive species in New England salt marsh habitat. Sandy Point experiences the sloughing of marsh sediments at the lake site. In 1995 SET stations were established in the sloughing sediments vegetated with *Spartina alterniflora* (low marsh) and in the *Spartina patens* vegetation (high marsh) to monitor the effect of the restoration on the sediment surface dynamics.

Table 2. Sediment accretion ; New England marker horizons were placed on 8/23/95 and sampled on 12/16/98 (cm ± Standard Error)

Location	Reference	Restored
Awcomin	14.1±4.7	4.4±0.3
Drakes Island	7.4±1.1	7.8±1.2
Sandy Point	Not available	4.7±0.1
Mill Brook	10.6±0.8	61.1±10.5

Rookery Bay, Florida

Surface elevation tables (SET) were established in the mangrove forests at Rookery Bay National Estuarine Research Reserve to investigate sediment elevation patterns in relation to mangrove morphology. Sea-level rise at Rookery Bay, located in southwestern Florida adjacent to the Gulf of Mexico (Figure 9), ranges from 2 to 4 mm/yr, which is typical for this region of the Gulf of Mexico (Cahoon and Lynch 1997).

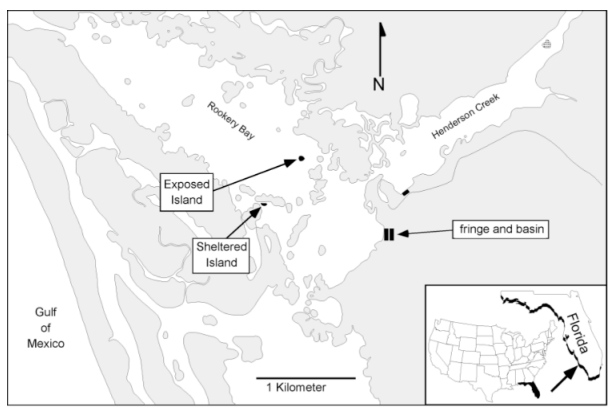


Figure 9. Location of the Rookery Bay SET stations

Figure 9. Site map of Rookery Bay National Estuarine Research Reserve.

In 1993, field plots were established in fringe and basin forests to study the effect of wave exposure on mangrove sediment elevations. In 1994, additional stations were established in two over-wash island forests, one with an exposed shoreline and one with a sheltered shoreline (Fig 9).

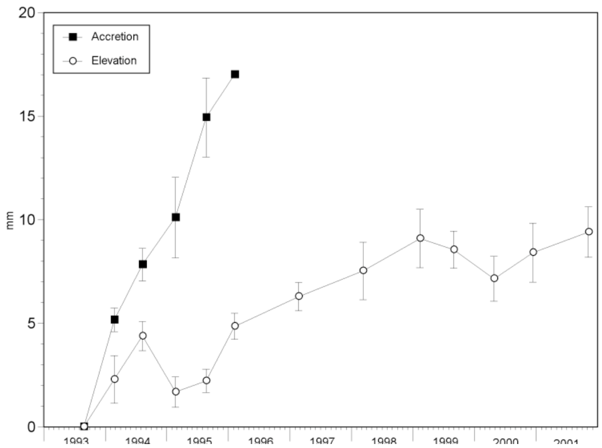


Figure 10. Soil surface elevation change and vertical accretion at the fringe mangrove forest site at Rookery bay NERR.

The four forests are typical of the forest types around Rookery Bay and represent a range of hydrodynamic settings. The fringe and exposed island forests are dominated by red mangrove (*Rhizophora mangle* L) and have sloping shorelines with a 0.6 m berm created by wave action at the high tide line. Surficial sediments are a combination of mineral and root matter. Erosion is prevalent at the fringe forest with sediment accretion occurring primarily where sediments are bound in place by turf algae. The basin and sheltered island forests are relatively flat with very low micro-topographic relief due to low hydrodynamic energy. The basin forest is a mixture of red mangrove and black mangrove (*Avicennia germinans* L), with occasional white mangroves (*Laguncularia racemosa* (L.) Gaertn.) present. The sheltered island forest is a pure stand of red mangrove. The basin forest is hydrologically isolated and surface sediments are composed primarily of organic matter. A complete description of these forest settings is provided in Cahoon and Lynch (1997).

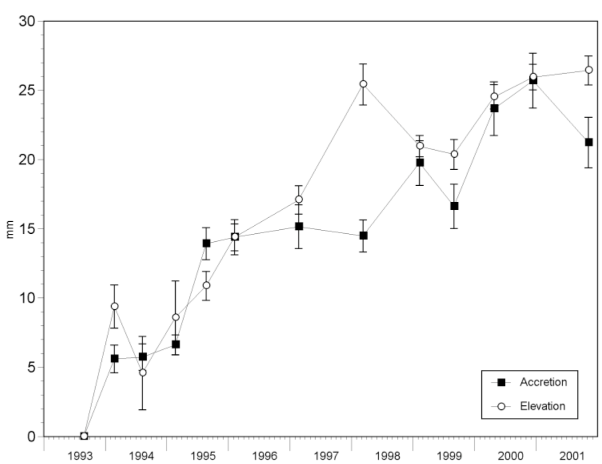


Figure 11. Soil surface elevation change and vertical accretion at the basin mangrove forest site at Rookery bay NERR.

Collecting the Sediment elevation and vertical accretion data at Rookery Bay started three to five years prior to 1999 the start our project. From 1999 on, we conducted additional samplings five in the fringe and basin forests, and four in the two over-wash island forests (Figures 10, 11, 12, and 13). Cahoon and Lynch (1997), who compared sediment elevation change with vertical accretion, showed that elevation dynamics in all sites are dominated by mineral sediment deposition. Fringe forest experienced surface erosion, Basin forest had large amounts of organic sediment deposition and subsurface water storage, and overwash islands showed a combination of mineral sediment deposition (bound by surface roots) and shallow subsidence.

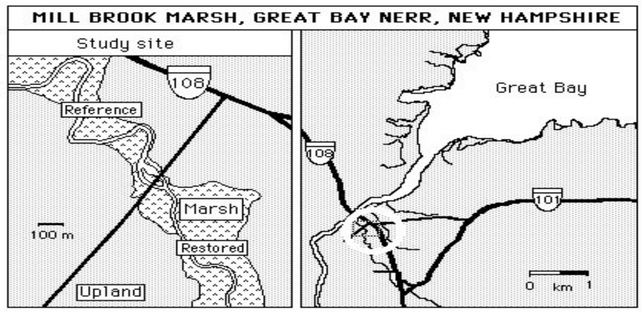
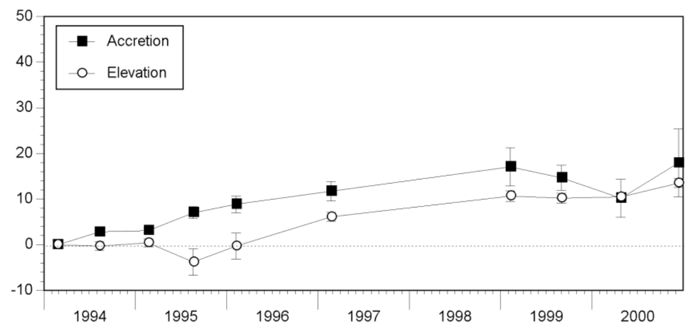


Figure 12. Soil surface elevation change and vertical accretion at the exposed mangrove forest site at Rookery bay NERR

Figure 13. Soil surface elevation change and vertical accretion at the protected mangrove forest site at Rookery bay NERR



Since 1999, the trends in elevation change have continued. During the 8-year period between 1993 to 2001, elevation in the fringe forest increased at a rate of 1 mm/yr (± 0.1, R^2=0.78, p<0.00+; Figure 10) and in the basin forest with a rate of 3 mm/yr (± 0.3, R^2=0.88, p<0.00+;Figure 11). Between 1994 to 2000, the sediment elevation in the exposed island forest increased with 4.1 mm/yr (± 0.3, R^2=0.98, p<0.00+;Figure 12), while the sheltered island forest increased with 1.8 mm/yr (± 0.2, R^2=0.88, p<0.00+; Figure 13). In the near term, all four sites are keeping pace with sea-level rise, although the fringe forest is lagging somewhat behind. Over the past 3 years, the rate of sediment elevation increase on the exposed island accelerated (p=0.07) from 10.6 mm/yr ± 1.2 between 1994 to 1997, to 12.5 mm/yr ± 3.2 between 1999 to 2000. Although the driver to this increase is not known, a potential cause could be a heron rookery that developed during the gap in sampling from 1997 to 1999. Nutrients provided in the bird guano could have stimulated root production to lead to an increase in root volume and to sediment elevation. It would be useful to test this hypothesis through continued sampling of sediment elevation and sediment deposition.

Tijuana River, California

In 1992, low and high salt marsh SET stations were established in the northern arm of Tijuana River, central within the Tijuana River National Estuarine Research Reserve (Figure 14). The 160 ha regularly flooded low marsh, dominated by salt marsh cordgrass *Spartina foliosa* is on sediment substrate that is primarily composed of silts and clays. The low marsh surface is flooded once a day for an average of 4h to a depth of 13-17 cm (Cahoon et al. 1996). The high marsh, dominated by the glasswort (*Salicornia subterminalis)* on sediments composed primarily of fine sands, flood only 5-6 days per month for 2h per event to a depth of less than 10cm.

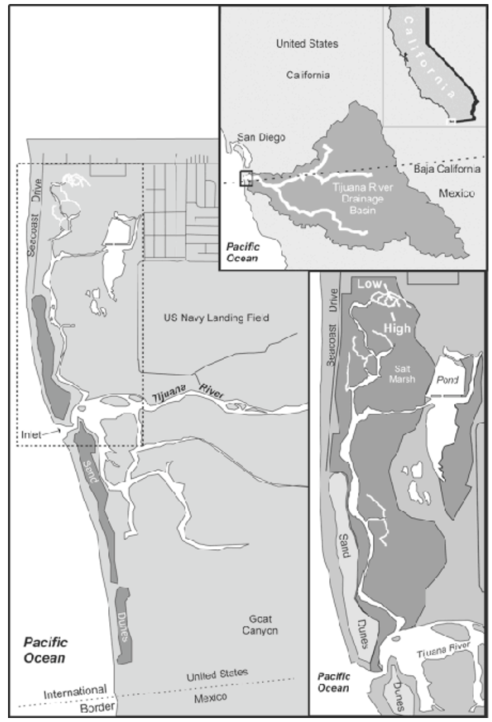


Figure 14. Tijuana River watershed and estuary; Inter-tidal salt marsh is indicated by shading.

In the arid climate of southern California, rainfall and streamflow in coastal drainage basins are highly seasonal and may not occur during multiple year periods of extended drought. Winter storms, related to El Nino-Southern Oscillations, occasionally do mobilize large quantities of water and suspended sediments from the desiccated watershed and cause acute sedimentation events throughout the basin, often with catastrophic consequences (i.e.> 1m thick deposits).

Salt marsh habitat is prevalent within the northern arm of the Tijuana River estuary, which is sheltered from these catastrophic sedimentation events. However, winter storms do increase the flooding in these marshes, and cause sediment deposition to far exceeds the deposition provided by years of daily tidal flooding (Cahoon et al. 1996).

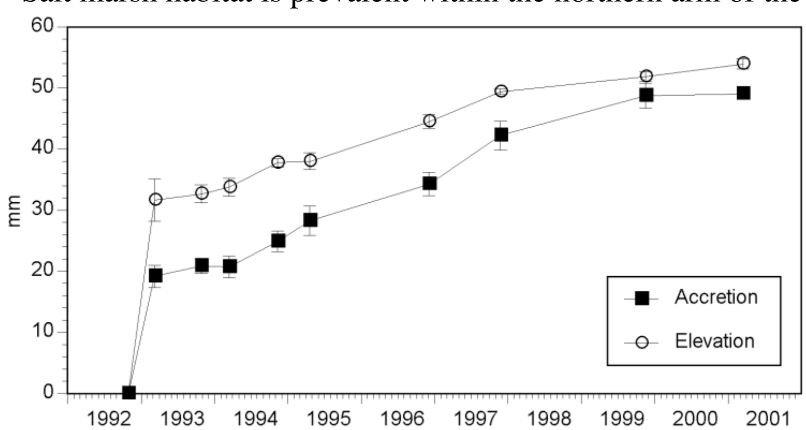


Figure 15. Surface elevation change and vertical accretion at the Tijuana River NERR low marsh sites. Results show the complete data set, including those measurements that were affected by prolonged inundations caused by an El Nino storm. Compare results to Figure 17 where these El Nino storm effects were not included.

Data on high and low marsh sediment elevations and vertical accretion at Tijuana River NERR were collected from 1992 to 2001. The 1993 El Nino storm caused prolonged flooding of the northern arm, inundating both the low and the high marsh for several days (Cahoon et al. 1996). While the low marsh trapped approximately 2 cm of sediment (Figure 15), the SET recorded a larger than 3 cm increase in elevation. This elevation increase in excess of sediment deposition was most likely the result of settling of the pipe, which would be read as an increase in elevation by the SET, and not an effect of the storm on subsurface processes. Apparently there were logistical difficulties in establishing the low marsh benchmarks and pipes were compacted by the weight of the overlying floodwaters. However, the SET benchmarks remained stable after the storm, as determined by direct surveys in relation to Corps of Engineer benchmarks (Cahoon et al. 1996). The rate of elevation change was 3 ± 0.2 mm/yr (R^2=0.96, p=0.00+) excluding the SET reading immediately after the storm (Figure 17), and 4.3 ± 1.1 mm/yr (R^2 =0.65, p=0.005) including the SET reading immediately after the storm (Figure 15). The SET readings in 1999 and 2001 fall along the trend of the 1992-1997 data. At least in the short term, the low marsh is keeping pace with the local rate of relative sea-level rise of 1-3 mm/yr (Cahoon et al. 1996).

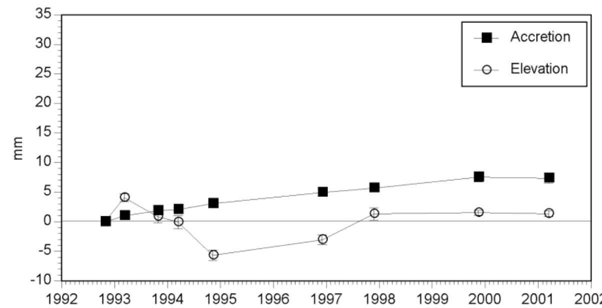


Figure 16. Surface elevation change and vertical accretion at the high marsh at Tijuana River NERR.

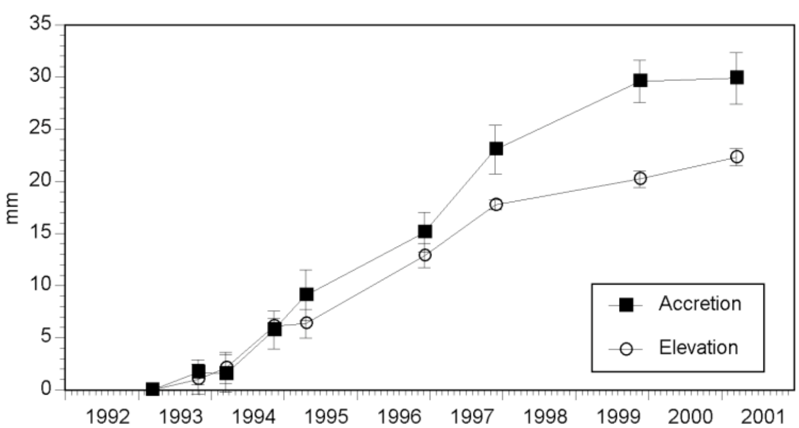


Figure 17. Low marsh surface elevation change and vertical accretion at the at Tijuana River NERR. Measurements affected by an El Nino storm were removed (compare with Figure 15 where the effects of a prolonged inundation are evident).

The high marsh did not trap a significant quantity (only about 1 mm) of sediment. Yet, sediment elevation increased nearly 5 mm, indicating a strong subsurface influence on sediment elevation (Figure 16). Cahoon et al. (1996) hypothesized that the flushing of the high marsh sediments with a large pulse of freshwater improved soil conditions for plant growth, which led to increased root growth and an increase in sediment elevation. After hyper-saline soil conditions returned to the high marsh, the sediment elevation dropped apparently as a result of decomposition and reduced plant growth. The SET readings in 1999 and 2001 indicated that sediment elevation gradually recovered to about 1 mm/yr. The overall 9-year trend in sediment elevation in the high marsh was not significantly different from zero (0.08 ± 0.4 mm/yr, R^2=0.007, p=0.857). Despite the low rate of elevation change, the high marsh is not in any immediate danger of submerging from sea-level rise because it is perched high within the tidal range. The response of the high marsh underscores the importance of belowground processes (e.g., root growth, compaction) to sediment elevation dynamics. It would be useful to continue to monitor the marshes at Tijuana River NERR to evaluate the impact of future major winter storms on sediment elevation dynamics in this arid coastal environment.

North Inlet, South Carolina

The North Inlet salt marsh is part of the North Inlet-Winyah Bay NERR site in Georgetown County, South Carolina (Figure 18). The estuary is bordered to the west by maritime coastal forest and to the south it adjoins Winyah Bay, the Pee Dee/Yadkin drainage basin estuary. Winyah Bay and the Pee Dee River are important sources of sediments in the North Inlet system. Sediment elevation measurements started in spring of 1990 and stopped after the autumn of 1992. Additional measurements were conducted by Jim Morris in 1997 and in 2000. A detailed description of the results and the experimental design can be found in Childers et al. (1993). Six sites were selected to monitor sediment elevation changes in marshes that were receiving freshwater inflows (Oyster Landing and Town Creek), in marshes located near the ends of tidal creeks and were receiving little or no freshwater input (Debidue Creek and Bly Creek), and in mature

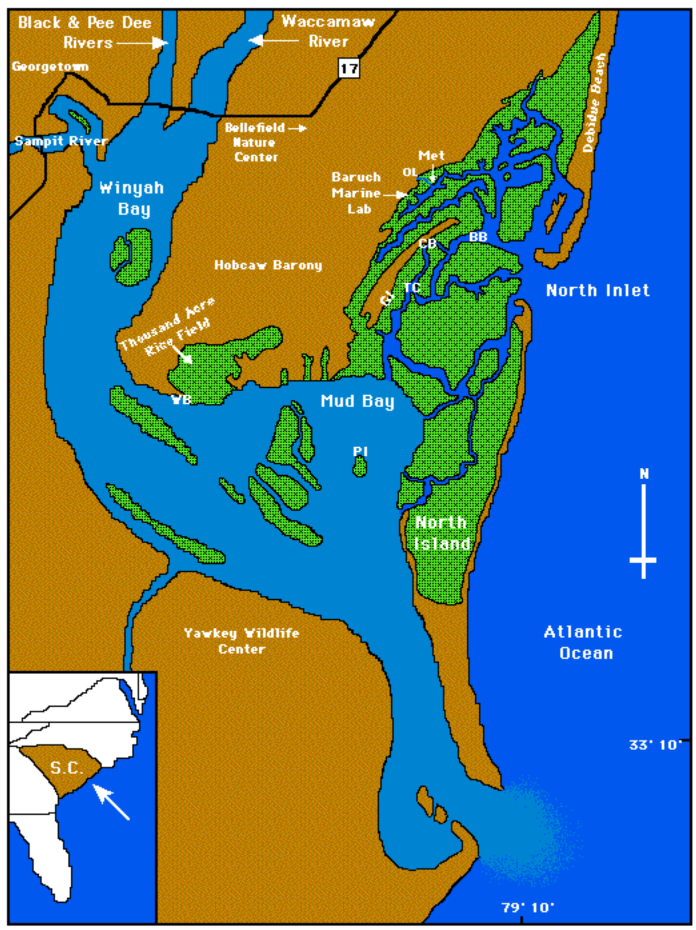
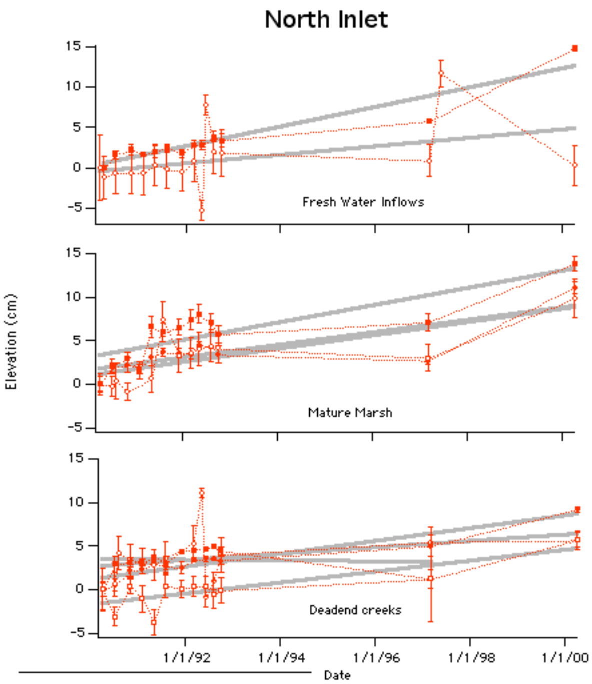


Figure 18. Map of the North Inlet marsh system; SET stations are established at Oyster Landing (OL) Town Creek (TC), Debidue Creek, Bly Creek, Old Man Creek and Sixty-Bass Creek



Geology	Slope	StD	R^2
Fresh water inflows			
Low Marsh	0.51	0.32	0.15
Mid Marsh	1.21	0.13	0.89
Mature marshes			
High Marsh	0.72	0.16	0.64
Low Marsh	0.76	0.23	0.49
Mid Marsh	1.00	0.22	0.64
Deadend creeks			
High Marsh	0.73	0.08	0.88
Low Marsh	0.37	0.29	0.12
Mid Marsh	-0.04	0.26	0.00
Mud Flat	0.62	0.14	0.63

marshes (Old Man Creek and Sixty-Bass Creek).

Sediment elevations showed little variation five years after the end of the original project. Recent measurements in May 2000 showed a general increase in elevation at all sites (Figure 19). The Sixty-Bass Creek site showed very variable patterns throughout the three initial years and was the only one that revealed a marked decline in elevation.

Figure 19. Sediment elevation trends at different marsh sites at North Inlet NERR.

Patuxent River, Maryland

Between the summer of1990 and the winter of 1992 a study was carried out along the Patuxent River, MD to assess rates of sediment elevation change in comparison to the rates of locale sea level rise.

Replicate SET monitoring sites were established in tributary marsh creeks (Hall Creek and St Leonard Creek), in main channels marshes (Lunch Gut

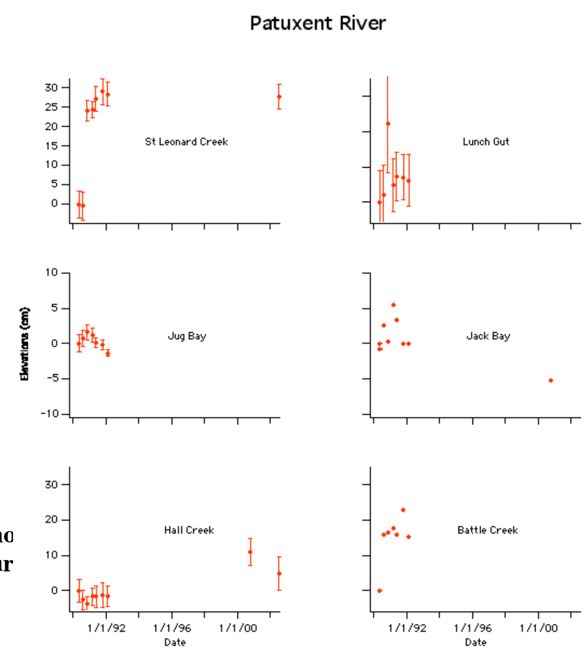


Figure 20. Sediment elevation at six different marsh sites along the Patuxent River, MD; Isolated points in the year 2000 and 2002 are tho abandoned sites that could be found and measur

and Battle Creek), and on main channel mudflats (Jack Bay and Jug Bay) to a total of six

(Table 3).

Out of 6 original stations we were able to find four and measure three. Measurements of these three stations provided insights of the most recent sediment elevation changes in relation to SLR.

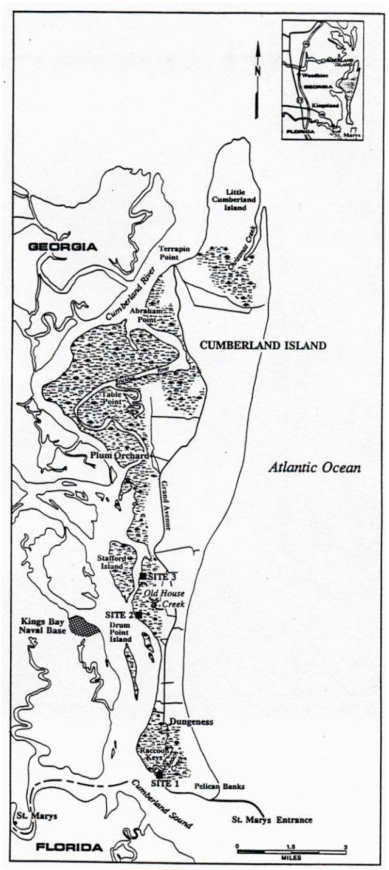
Table 3. Short description of SET sites along the Patuxent River (Childers 1993); Sites are ordered by distance, the first one being the closest to the mouth of the River.

Site	***Environment***	***Vegetation type***	***Portion of river***
St Leonard creek	Tributary marsh	*Spartina patens*	lower
Jack Bay	Main channel marsh	*Phragmites australis*	lower
Battle Creek	Tributary marsh	*Spartina patens*	lower
Lunch Gut	Tributary marsh	*Typha angustifolia*	upper
Hall Creek	Tributary marsh	*Typha/ Nuphar*	upper
Jug Bay	Main channel marsh	*Nuphar advena*	upper

Revisiting the sites after eight years showed considerable erosion at Jack Bay, sediment elevation increase at Hall Creek and no change at the St Leonard Creek site (Figure 20). Lateral erosion of the marsh at the Jack Bay station caused a more than 5 cm loss at this very geo-morphologically active marsh. Hall Creek, where sediment elevation increased more than 10 cm in the last ten years, is in a cattail marsh bordered by a large patch of spatterdock. Findings at Hall Creek agree with the findings from the Jug Bay study, where the cattail sites showed the highest rate of sediment deposition.

It is still unclear from this study if the Patuxent marshes are keeping up with sea level. The large between-site differences among the revisited stations seem to be more a consequence of site-specific processes rather than reflecting an area-wide trend. A higher number of stations would be needed in order to get a more conclusive understanding of the sediment elevation patterns at the regional scale.

Cumberland Island, Georgia



The Cumberland Island SET stations were established as part of a study to assess the impact of dredging activity on the delivery and supply of sediments to the neighboring marshes and mudflats. The dredging was carried out to facilitate the access of triton submarines to the King's Bay Naval Base

In December 1989 three sites were chosen within the boundaries of the Cumberland Island National Seashore. Each site differed in distances from the area subject to the dredging. Sites 1 and 2 were adjacent to the dredged canal while site 3 was the least exposed, being protected by Stafford Island. Site 2, right in front of the King's Bay Naval Base, was closest to the dredging. At each site SET stations were installed in the marsh and on a mudflat in the proximity of a tidal creek, for a total of six stations.

Figure 21. Map of Cumberland Island National Seashore; three monitoring sites are shown.

The original study was conducted between December 1989 and April 1993 and regular measurements were taken at least twice a year. Employed were four alternative methods, along with SET and marker horizons, to monitor changes in sediment dynamics: field surveys, sedimentation pins, rare element tracers, and cesium dating. In 1992 the mudflat station at site 3 was replaced after a sediment failure had bent the previous station and broken the pipe at about 1 m under the sediment surface. After being interrupted for three years, monitoring resumed in 1997 at marsh 1 and 2 sites.

All marsh sites showed long term elevation gains. The sites 2 and 3 mudflat stations could not be found while the site 1 station had experienced severe decline in

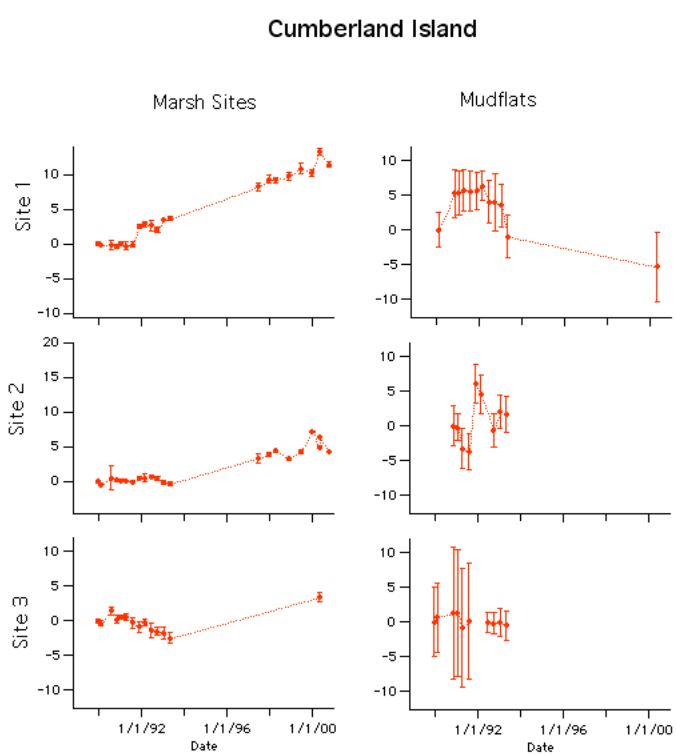
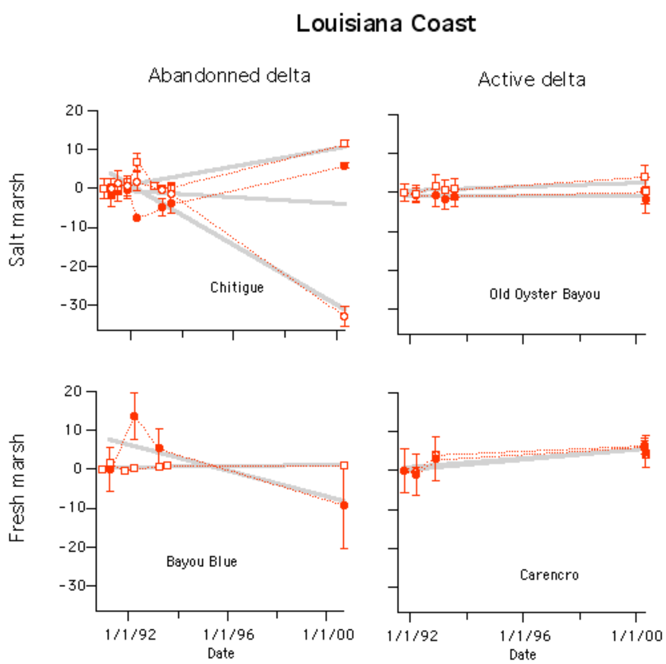


Figure 22. Sediment elevation at six sites at Cumberland Island, GA

elevation (Figure 22). Dredging activity or other causes had affected the mudflat sites through lateral erosion, causing elevations in the marsh sites to increase from importing the eroded materials. Visual signs of lateral erosion are common along the marshes bordering Cumberland Sound.

Terrebonne and Atchafalaya Basins, Louisiana

In December 1991 a total of nine SET stations were established in the Atchafalaya and Terrebonne basins in Louisiana (Figure 23). The goal of the study was to investigate the formation and evolution of shallow bodies of water (ponds) in relation to processes of sediment elevation change. The study contrasted transgressive marshes (Terrebonne basin) against progressive marshes (Atchafalaya basin) and salt marsh against fresh marsh. Each site was characterized by the presence of a pond separated by a strip of marsh from a bayou that provided the boat access to the study site. SET stations were installed on the edge of the pond, in the marsh or in the pond.



Location	Site	Slope (cm/yr)	StD	R^2
Chitigue				
	Edge	-0.40	0.34	0.31
	Pond	-3.88	0.40	0.95
	Marsh	1.15	0.32	0.65
Bayou Blue				
	Edge	-1.67	1.04	0.56
	Marsh	0.06	0.09	0.07
Old Oyster Bayou				
	Edge	-0.02	0.09	0.01
	Marsh	0.24	0.14	0.36
Carencro				
	Edge	0.63	0.17	0.82
	Pond	0.53	0.23	0.63

Figure 23. Sediment elevation at Terrebonne and Atchafalaya Basins, Louisiana. Solid circles indicate measurements taken on the edge of a pond, while open circles indicate measurements taken in the pond. The station on the edge of the pond was able to provide measurements of sediment elevation in open water and of the edging marsh.

A fresh marsh and a salt marsh site were selected within each basin: Old Oyster Bayou (saline, OOB) and Carencro Bayou (fresh, CB) in the Atchafalaya basin, and Bayou Chitigue (saline, BC) and Bayou Blue (fresh, BB) in the Terrebonne basin. The Atchafalaya Basin features high levels of Total Suspended Solids (TSS), while Terrebonne Basin is typically very low in TSS.

The experiment at these sites was designed to assess variability: 1) between basins, 2) between marsh types (freshwater or salt marsh) within basins, 3) between marsh and pond stations within each marsh type, and 4) between the four orientations within each station.

The monitoring that had started in December 1991 stopped after the end of the original funding in 1993 and stations were not revisited till we visited Louisiana in April 2000. Denise Reed and colleagues adopted the Louisiana stations that are now again measured twice a year.

Old Oyster Bayou measurements taken seasonally throughout the period between 1990 and 1993 showed little change in sediment elevation. Even after measurements resumed in 2000, sediment elevation remained stable at both stations. Carencro Bayou gained 3.5 cm at the edge and 4.3 cm at pond site before the winter of 1992 measurements. These gains followed a 1990 to 1992 period of no change. Similar gains before the 1992 winter were recorded for the Terrebonne basin sites and in particular at Bayou Chitigue where the marsh site gained 5.2 cm (Figure 23). These episodic increases in elevation could be related to sediment deposition after Hurricane Andrew hit the western edge of the Mississippi delta plain on August 26, 1992, with maximum sustained winds of 54 m/s (120 mph) and a storm surge of 1-2m (see also Cahoon et al. 1995).

The most evident changes after revisiting the station in 2000 took place at the Terrebonne sites: Bayou Chitigue and Bayou Blue. With the exception of the edge station at Bayou Blue, which had experienced significant changes in sediment elevation through the original measuring period 1990-1993, all stations had been rather stable. Seven years later though, sediment elevation at the marsh station in Bayou Chitigue was considerably higher than the average seasonal measurements done in 1993 while the pond station showed a dramatic loss in elevation. Also at the Bayou Blue site the edge station lost elevation, and the marsh station gained.

Total Suspended Solids at Jug Bay, Maryland

The processes around the bio filtration function performed by tidal marshes are the workings on how and when suspended materials are moved from the estuarine water column and deposited on the marsh sediment surface. These processes not only remove sediments and other substances from the water column (bio filtration), but also provide nutrients and new soil substrate to tidal marsh vegetation to offset relative sea level rises. To investigate biofiltration and marsh depositional processes, we carried out 4 comprehensive field experiments that monitored total suspended sediments (TSS) at hourly intervals and water levels (WL) at 5 minute intervals (Figure 24). Two sampling intervals took place at the Jug Bay north marsh and 2 at the south marsh. Marsh levels at both sides were at 40 cm above datum. Weather conditions varied for each of the experiments and ranged from calm with only a trace of rain (October 1999 South side, S1) to windy and 1.42 cm of total rain (September 1999 North side, N1; Table 1).

Sediments that are suspended during the incoming tides are likely to be transported towards the interior of the marsh while those suspended during the outgoing tides are transported away from the marsh. Suspension of sediments due to tidal scour is most likely to occur between high and low water when currents are at their highest velocities, while suspension from waves is most likely to occur at low water levels (i.e. at low tide in creeks and at high tide on the surface of the marsh).

The large variation in flood patterns and TSS loads between monitoring periods prevented the detection of differences between sites. Variations were largely associated with weather conditions, when high winds and rains showed high TSS loads and low TSS loads were during calm winds and no rain. TSS concentration ranged from 0.01 to 14.6 g/l at the north marsh and from 0.0 to 0.9 g/l at the south marsh. Most often the tidal currents caused TSS loads to increase or decrease, with sediment deposition and suspension alternating between deceleration and acceleration of tidal waters. Tidal currents only caused marsh deposition when, at the onset of the deceleration, water levels were above marsh elevation. Additional energies from wind/waves or raindrops extended this period of sediment deposition potential by adding water turbulence which allowed TSS loads to stay in suspension after the moment of deceleration.

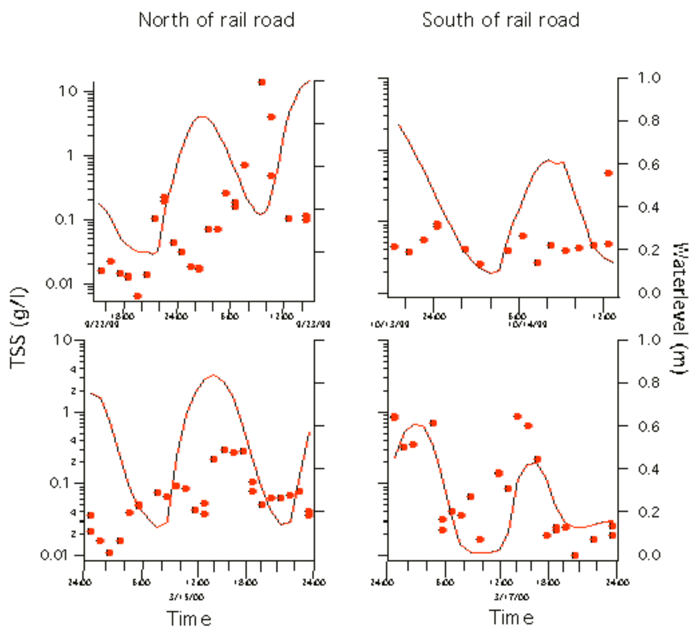


Figure 24. Total suspended solid concentrations and water levels in small tidal creeks. Data were collected at four different dates at two site in Jug Bay MD.

Dependent on the wind direction, tides at Jug Bay can either be increased or reduced by wind velocity, which is apparent when the two episodes with windy conditions are contrasted against each other. Tides during the September 1999 sampling (N1) were elevated, while those on the 17th of march 2000 (S2) were subdued. The N1 first incoming tide, following the general concept of current induced deposition and suspension, did not deposit sediments in the marsh as sediments were already deposited before water levels reached the marsh. During the second N1 tide, sediments did not drop from suspension after deceleration of the outgoing tide, but kept increasing to extreme high loads due to a combination of strong winds and shallow water depths in the flooded marshes. During this tide water levels stayed above or at marsh level and the tidal currents were able to transport the high TSS loads further into the interior of the marsh.

During the S2 sampling, tides with reduced water levels experienced a strong effect of wind energy and rain on the TSS loads during brief moment of high tide when the marsh was flooded. When the marsh was not flooded, dynamics in TSS load followed a wind distorted current induced deposition and suspension pattern. Elevated high tide TSS loads were not further transported towards the interior of the marsh.

Sediment Loads during the October 1999 sampling south of the railroad (S1) were very low and followed the current induced deposition and suspension pattern. Marsh deposition did not take place as sediments had already dropped out of suspension before water levels reached marsh level. Weather conditions were calm winds with a trace of rain.

The current induced deposition and suspension pattern was also observed for the second tide during the March 15 sampling at the North side of the railroad (N1). Breezy winds did elevate the TSS loads above what was observed for S1, but were not sufficient to distort the current induced pattern. Breezy winds did alter the pattern during the decelerating phase of the first tide. Higher TSS loads during the accelerating phase of the second tide, when water levels were above marsh level, were most likely suspended from the marsh surface and transported away from the marsh surface towards the tidal creeks causing marsh erosion.

The waste assimilation function performed by tidal marshes involves the dynamics that cause suspended sediments to be imported from the estuarine water column and deposited between the marsh vegetation. While sediments are transported on a daily basis between the estuary and the tidal creeks, favorable severe weather conditions are needed to transport sediments from the tidal creeks onto the marsh. There is the potential for unfavorable weather conditions to transport sediments from the marsh, back to the tidal creeks, which is a process that can be prevented by a dense cover in marsh vegetation.

Water Quality at Jug Bay, Maryland

Overall, water at high tide had higher Nitrate + Nitrite ($NO^{2/3-}$) concentrations than water at low tide, but not during spring and summer months when all $NO^{2/3-}$ concentrations were low. The seasonal trends, particularly pronounced for high tide values of $NO^{2/3-}$ during winter months might be related to the West Branch wastewater treatment plant which is only active during the summer months. No such trends are found in concentrations of $NO^{2/3-}$ at low tide waters.

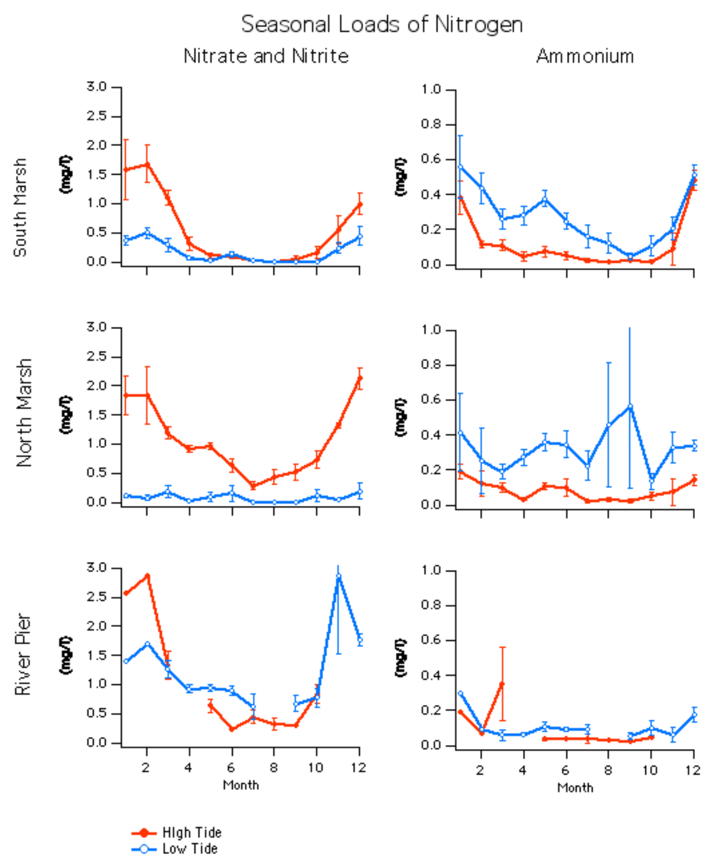


Figure 25. Monthly averages of NO^{3-} and NH^{4+} concentrations from a three year period of sampling at three sites in Jug Bay, Maryland. Samples were taken bimonthly at the marsh sites and more intermittently at the main river channel. Standard errors reflect monthly variations. Values at high tide are indicated in red while values at low tide are shown in blue.

Higher concentrations of Ammonium (NH^{4+}) were found in waters leaving the marsh, i.e. at low tide. Similarly to $NO^{2/3-}$, NH^{4+} reached the highest concentrations in winter both at low and high tide, although several peaks during spring and summer were also observed.

These results show how the marshes at Jug Bay work as sinks and transformers of nutrients, as flooding waters rich in $NO^{2/3-}$ leave the marshes with lowered $NO^{2/3-}$ concentrations. Potential mechanisms for loss of nitrates from flooding waters are denitrification and plant uptake, two biological processes that are temperature dependent and are inhibited during cold weather. What is surprising in our results is that the marshes are efficient in $NO^{2/3-}$ removal also during the winter months, when the vegetation is known to be inactive. An alternative explanation for the observed $NO^{2/3-}$ subtraction could be bacterial activity in the surface sediments of the marsh. In fact the higher concentrations of NH^{4+} found in ebbing waters can result from nitrite reduction in anaerobic marsh soils. Previous studies at Jug Bay reported similar patterns in $NO^{2/3-}$ and NH^{4+} concentrations in the water column and show high temporal and microspatial variation of $NO^{2/3-}$ and NH^{4+} fluxes (Ziegler et al. 1999). The data shown in this report confirm the hypothesis that Jug Bay marshes act as a net sink for nitrogen, importing nitrogen from $NO^{2/3-}$, and releasing reduced amounts of nitrogen in the form of NH^{4+}.

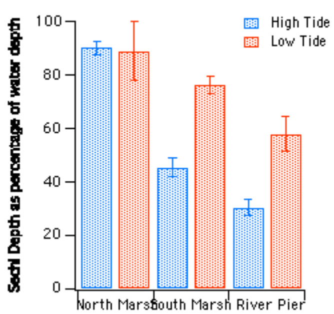


Figure 26. Average Secchi depths ± Standard Error in larger than 30 cm water depths sampled twice a month for three years at three different sites in Jug Bay.

In our study, Secchi disk measurements estimate water clarity as the percentage of water column depth at which a Secchi disk can be observed (Figure 26). Although Secchi disk measurements are poor estimators of suspended sediments or nutrient loads, reduced nutrients and sediments increase the water clarity and therefore Secchi depths. The presented results in Figure 26 only include those Secchi depth readings that were taken in 30cm or deeper water. No significant differences were found between the high and low tide waters in the North marsh where the water clarity was always close to 90% of the water column. The South marsh and the River Pier had significantly largerSecchi depths at low tide than at high tide, which confirms the importance of biofiltration of the marsh.

The Coastal Elevation Changes Database at: http://www.ecoinformatics.uvm.edu/SET

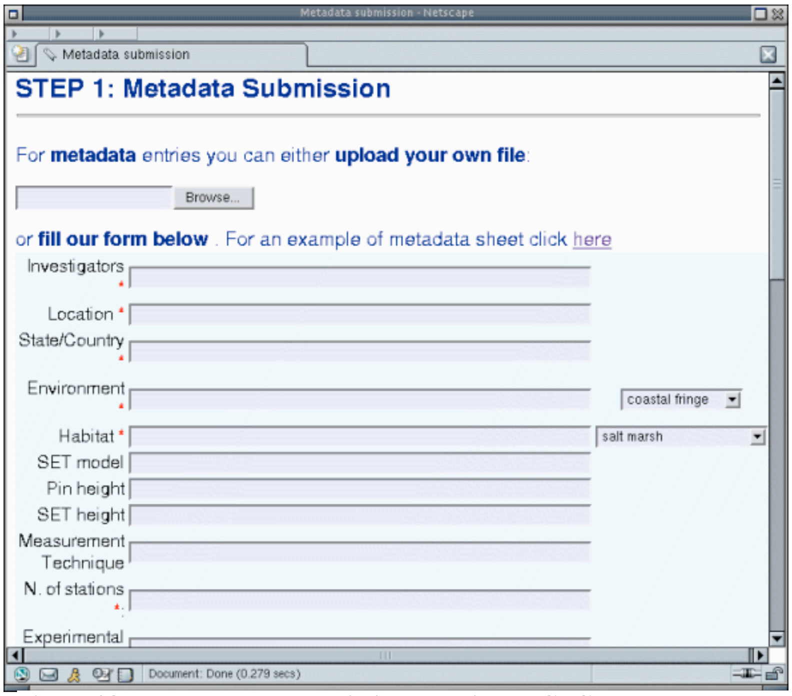


Figure 28. The metadata submission page in the CECD

The goal of the web accessible Coastal Elevation Changes Database (CECD) is to make available baseline data on coastal sediment surface changes to forward the estuarine sciences in understanding elevation dynamics nationwide. The CECD is a reference information site on the Sedimentation Erosion Table and the standard ways to deploy it. It provides important contact information on research sites, allows for downloading (Figure 31) and uploading specific datasets and metadata (Figure 28), and can also be conveniently searched (Figure 30). The interactive search database is based on a relational model, with relations between objects described in the entity-relationship diagram in Figure 29. Each "table" (or box) in the figure represents an object (entity) that stores information. For example the object "site" stores information about the name of a site and GPS coordinates. At each station more than one measurement is taken, which in the diagram is expressed as a "one-to-many" relationship through means of the triple ending of the connecting line between the "site" and the "site_measure" object. The database was built using SQL, an open-source software, with PostgreSQL as the database management system (http://www.us.postgresql.org). A CGI user interface was developed to allow for interactive retrieval of information (Figure 30).

The design of the database reflects the different ways to collect SET data in different habitats and was based on close feedback from researchers in the field. The first opportunity to meet with marsh ecologists interested in monitoring sediment elevation was within the Estuarine Research Federation Conference in

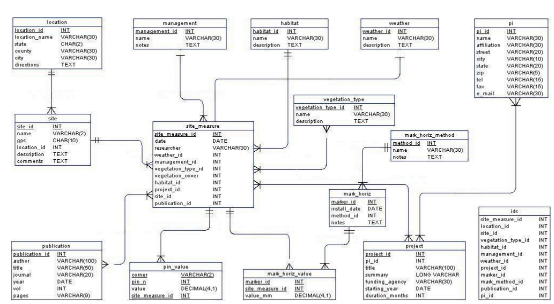


Figure 29. The CECD object-relationship diagram

New Orleans, 1999. A one-day workshop was held just after the conference to discuss methodologies and standardizations for the SET. Before populating the database we conducted a survey among SET researchers to identify a policy for data sharing. Participants in the survey voiced the need for access control through password and login protection. It was suggested that users apply for passwords and login names through a registration form.

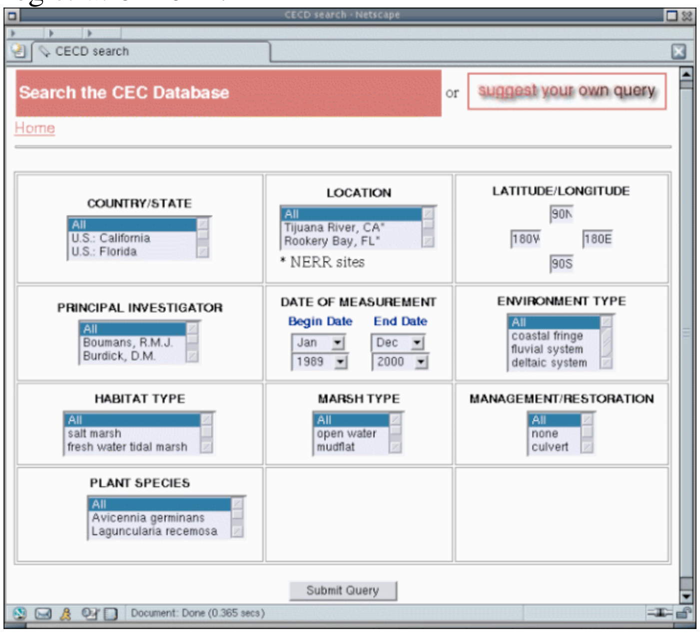


Figure 30. The interactive search page of the CECD

Although this viewpoint can be easily understood, it is established knowledge that password-protected web sites normally attract less users, due to the registration process and the requirement to remember the user's password. Based on this observed pattern we decided to start populating the database with data that had been already published or for which the contributors had agreed on their public release. As part of the survey, we received many interesting comments and suggestions. There was a shared concern about the way to make sure that data contributors were properly credited (especially for unpublished data) and on how to ensure a proper use and understanding of what the data represent. It was suggested that co-authorship with data contributors could be a good way to address these causes of concern.

Figure 31. The download page for individual datasets. Metadata are available for several sites and hyperlinks point to publications, maps and site descriptions.

The database has been populated with data from the following sites: Rookery Bay, FL, Tijuana River, CA, North Inlet, SC, Jug Bay, MD, GreatBay, NH, Wells, ME and sites that are not part of the NERR system such as Cumberland Island, GA, and sites in the Terrebonne and Atchafalaya Basins, Louisiana. We received several requests for authorizing the use of data made available on the CECD, and were contacted by a research group from England to make our data available for modeling purposes. An active link to the CECD database on the Jug Bay Wetlands Sanctuary web site (www.jugbay.org) directs interested people to the pages showing results of monitoring at this NERR site.

Defining the SET Standard Operating Procedures

Standard ways to install and deploy the SET were initially discussed at the SET workshop held in New Orleans as part of the Estuarine Research Federation conference in 1999. The final SOPs manual is included in Appendix 1 of this report and is available on-line at http://www.ecoinformatics.uvm.edu/SET.

Related Projects

As part of two one-year contracts with the Maryland Department of Natural Resources we monitored basic parameters of water quality at the Jug Bay and Patuxent River Park sites through the year 2001 and 2002. Data are currently being analyzed and will be an important complement to the nutrient study at Jug Bay.

This study benefited from the synergy with CICEET research project "Spatial Modeling and Visualization of Salt Marsh Habitat Change due to Restoration in Great Bay and Wells NERR", by Burdick, Konisky, Short and Boumans, in which SET stations were measured at Wells, ME and Stuart Farm, NH.

Difficulties Encountered

Besides difficulties with the weather conditions, the greatest challenges were related to the development of the web-accessible database, where we encountered reluctance in contributing data to the database. We believe this obstacle can be easily overcome by developing a system of incentives through increasing the services that the database can provide. As a last remark, as a consequence of the recent move of the Institute for Ecological Economics to the University of Vermont, the main server that stores the CEC database has not been accessible for six weeks. This initial problem is been taken care of and the database at present is accessible at: http://www.ecoinformatics.uvm.edu/SET

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Appendixes

Appendix 1. Standard Operating Procedures for Installation and Measurements of Dynamic Coastal Habitats Using the Surface Elevation Table

Preface

The critical importance of establishing standard operating procedures (SOPs) for environmental sampling is recognized worldwide. Standard operating procedures allow environmental data that has been generated by various programs and separated by large scales of space and time to be compared and combined to answer important questions regarding changes in coastal habitats. This document presents SOPs developed for measuring elevation changes in coastal habitats. The two SOPs cover installation and measurement protocols with the Surface Elevation Table and were developed from earlier work (Boumans and Day 1993, Cahoon et al. 1995, Cahoon and Lynch 1997). The project is important to a new initiative to develop a national and potential international database on coastal elevation dynamics. The database will facilitate the ability to share data over internet and will be especially useful in building the larger context on relationships between human activities, coastal resources and its management.

The procedures in this appendix are preceded by a generic SOP format. The format of the SOPs is self explanatory, and was adopted from an earlier publication of the Environmental Research Laboratory, Narragansett, U.S.EPA (Mueller et al. 1992). The generic SOP presented here was written with salt marshes in mind, but consideration was given to other coastal habitats. Procedures were designed to minimize direct impacts to research sites and also to minimize effects on processes associated with sediment dynamics that might lead to elevation change. Once established, these procedures are intended to be adapted to local conditions and improved. However, such adjustments must be documented. An updated record of procedures associated with the database provides a foundation for improvement, and provides a clear record of the procedures used in sampling. Only through careful comparison of procedures can data be pooled for larger scale interpretations. Discussions at the SET workshop, held in New Orleans, November 1999, clearly indicated that protocols needed to be adapted for each habitat type, so that studies in mangrove swamps and seagrass beds needed significant modifications. The contact person(s) for each of these SOPs is the person who was responsible for developing or applying the method to a particular project, and is available to answer specific questions regarding the SOPs.

The value of environmental sampling data is not assured unless standard laboratory practices are coupled with an appropriate quality assurance and quality control (QA/QC) program. The QA/QC program is a system of internal checks on all the aspects of sample collection and analysis that could compromise results. Since every scientific investigation has different project goals and data collection requirements, these SOPs do not include specific QA/QC requirements, but some suggestions are made so such requirements could be built into procedures for specifics projects and laboratories.

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SET STATION INSTALLATION Revision 2

UNH, JEL STANDARD OPERATING PROCEDURE JEL SOP 1.25

December 2002

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I. OBJECTIVE

Install SET stations for the measurement of sediment elevation in coastal habitats, such as salt marshes. Short (2-3 years) and long-term (5-20 years) measurements will help assess negative and positive impacts from human and natural processes or events as well as guide management of salt marshes. The rationale for the approach is to measure changes in surface elevation at points established where the device rests on the basement of the soft, surficial sediments, (e.g., especially peat).

II. SAFETY

Access to sites may require use of small boats to transport equipment and crew, though use of land vehicles is recommended. All safety regulations and precautions should be observed while in boats. The minimum number of personnel needed for install is recommended at four. In the event of an accident, individuals can follow the necessary accident assessment, first aid and reporting procedures. Radio or cellular phone (vessels) and first aid kit should be available. Protective clothing should be worn that is appropriate for the tasks undertaken. Participating individuals should be instructed of potential hazards on the marsh and from vibrating assembly.

III. MATERIALS AND EQUIPMENT

-Vehicle for transportation to sites with standard safety equipment

-Protective clothing and gear for handling equipment

-Vibracorer with handles and wrenches, alternatively, a manual pipe driver

-Outer aluminum coring pipe - 12 to 30 foot lengths, as appropriate.

-Inner Station Pipe with four notches

-Planks and plywood siding to cover the marsh and protect it from physical disturbance 20 feet around SET station.

-Four blocks to mark station corners

-Sharp shooter shovel (spade) or post hole digger

-Carpenters level

-Hacksaw

-Concrete, water, buckets and trowel for mixing

IV. METHODS

In order to fulfill the objectives of a study to measure changes in surface elevation of sediments, at least two (and preferably three or four) replicate stations must be employed for each type of management regime. Each replicate will be composed of a predetermined (36 per measure) number of sub-samples that are taken over time.

1. Locate the site previously selected and marked for station installation. Place boards around the site to protect the marsh surface within 20 feet of the site. With the shovel or post hole digger, create a small hole 20 by 20 by 20 cm.

2. Select the coring pipe, measure the length of the pipe to the cm and record length.

3a. Attach the pipe to the vibracore plate and any handles as needed. Place the lower end of the core pipe into the small hole and have crew members walk the pipe up into a vertical position as another holds the vibracore cable (to reduce weight and torque on the pipe). Establish the vertical position of the pipe using the level (in two directions). Once level, have the crew gently press the pipe into the ground and begin the vibracore engine. Sink the pipe, using the crew to guide the pipe in a vertical position, and then to pull down the pipe using handles of rope or metal until the point of refusal is reached.

3b. Alternative to the vibracorer, a manual post or pipe driver can be used to install the outer pipe. The pipe is pulled down into the hole as far as possible by the work crew, then the pipe driver is placed on top of the pipe. Alternating lifting and dropping motions sink the pipe to the point of refusal.

4. Once the point of refusal has been reached, cut the coring pipe as close to the surface of the marsh as possible and discard the remaining pipe, following a length measurement. Record the length of the pipe in the ground. Remove excess peat and sediment from the pipe so the inner base pipe fits comfortably into the coring pipe and extends up above the coring pipe about two cm.

5. Mix concrete and after removing inner pipe, pour the concrete into the outer pipe just enough so the inner pipe fits and the concrete comes to the surface. Before the concrete sets, adjust the inner pipe so it's surface is as flat as possible using the level. Mix more concrete with sand and fill outer area around outer core pipe to create a stable base (20 by 20 cm).

6. Once the concrete has hardened, cover the pipe with a PVC or rubber pipe cover.

7. To provide a measure of sediment accretion on the surface of the marsh, install marker horizons near the SET in a location that is not likely to be disturbed. Two sub-samples for each SET should provide sufficient data. Marker horizons may be located 50 cm from the base pipe in a pattern that does not conflict with SET measurements. Feldspar (750 mls) should be sifted evenly over a quadrat (31 by 31 cm, 0.1 m^2) and shaken off live plants so the sediment surface is covered evenly. Alternatively, glitter may be used as a marker, but subsequent sampling is time-consuming (Orson 1998).

8. Mark the site so that no one needs walk on the measurement areas. A method used in New England salt marshes (where ice can be a strong

force) is installation of four concrete blocks at the perimeter of the sampling area. The marsh peat is cut and removed so the blocks fit snugly and match the surface of the peat. Only the top 2 inches of the covered base pipe lies above the marsh surface. The concrete blocks can support planks during SET measurements.

V. TROUBLE SHOOTING / HINTS

1. Determining an acceptable point of refusal can be difficult due to variability in composition of the basement materials (clay, sand, gravel) and obstructions within the peat (woody debris). Long thin iron bars used to reinforce concrete (rebar) can be used to help estimate peat depth and choose a appropriate pipe length. If an obstruction is believed to be encountered, it is best to select a new site where the excavation will not interfere with subsequent SET measurements.

2. The virbating head of the vibracorer is heavy. Because it is attached to the end of the pipe with nuts and the pipe is lifted into position by the work crew, it poses a hazard. The head and attachment can stress and break the pipe, or the nuts can vibrate loose and allow the head to fall down the pipe. For both these concerns, crew holding the pipe should wear hard hats and have a preplanned safety exit strategy to move rapidly away from the pipe.

3. If the top of the base pipe cannot be made to be level easily, a pole can be inserted into the inner base pipe and used as a lever to help level the pipe before the concrete hardens.

VI. STATISTICAL ANALYSIS AND DATA USAGE

No statistical analysis is envisioned for installation procedure. Following measurements, appropriate comparisons of elevation change rates and accretion rates can be made between stations under different conditions (management regime or measures of ecological stress). For planning and designing the array of set stations, each SET station should be considered a true replicate.

VII. REFERENCES

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SURFACE ELEVATION TABLE (SET) Revision 2

UNH, JEL STANDARD OPERATING PROCEDURE JEL SOP 1.26
MEASUREMENT December 2002

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I. OBJECTIVE

Measure changes in elevation of the sediment surface in coastal habitats, such as salt marshes. Short (2-3 years) and long-term (5-20 years) measurements will help assess negative and positive impacts from human and natural processes or events as well as guide management of salt marshes.

II. SAFETY

Access to sites may require use of small boats to transport equipment and crew, though use of land vehicles is recommended. All safety regulations and precautions should be observed while in boats. The minimum number of personnel needed for SET measures is recommended at two. In case of an accident to one person, the other individual can follow the necessary accident assessment, first aid and reporting procedures. Radio or cellular phone (vessels) and first aid kit should be available. Protective clothing should be worn that is appropriate for the tasks undertaken. Participating individuals should be instructed of potential hazards on the marsh.

III. MATERIALS AND EQUIPMENT

-Vehicle for transportation to sites with standard safety equipment

-Protective clothing and gear for working on marsh

-Sediment Elevation Table (SET)

-Notebook with map to locate stations and record data.

-Magnetic compass

-Planking and risers to protect marsh surface at stations

IV. METHODS

In order to fulfill the objectives of a study to measure changes in sediment elevation, nine elevations are measured in four directions yielding 36 sub-samples at each station. Measurements taken over time will provide rates of elevation change.

1. Locate station and concrete border blocks. Assemble SET.

2. Place planking to protect area. Two planks with raised ends or risers may be placed on the concrete blocks, and a cross plank put across these will allow access to the entire sampling area. Alternatively, a single plank with risers may be placed adjacent to the base pipe so the risers do not impact measurement areas.

3. Remove cover from the station pipe. Attach SET to station pipe, making sure the table is fully inserted and locked into one set of slots in the station pipe. Determine which set of measures this position represents using the four major and minor compass directions (North, Southeast etc.).

4. Record the species of vegetation present and their relative abundance using percentage of cover for each species. Estimate the cover by eye looking down on the measurement area (bird's eye view). Assume the maximum cover is 100% and last year's dead plants and bare ground are included as part of the total cover. Minor constituents (one shoot or seedling) can be given a nominal cover of 1%. For example, there might be 50%percent *Spartina patens*, 20 % *Spartina alterniflora* 1% *Atriplex patula*, with the other 29% bare or wrack or dead plants from the previous year. Alternatively, a scale such as Braun-Blanquet (Kent and Coker 1992) may be used. The cover estimate is to provide characterization of the type of habitat, not an accurate representation of the entire community.

5. Level the SET arm. Use the turnbuckle to correct height and twist the arm or plate to correct the level from side to side (not as important as height) and lock arm. Loosen the pins by sliding the plate with the knurled nut.

6. Establish the pin positions at the surface of the sediment and clip/lock pins. Examine all the pin heights and assess variability to check for errors in pin setting. This QA/QC procedure often detects errors early, saving time and data.

7. Measure the distance from the plate to the top of the pin. Record direction of set of 9 measures and pin length measurements. Measurements may also be made from the underside of the plate to the sediment surface using the pins. This requires the SET arm is unlocked and twisted to expose the lower portion of the pins and is not recommended.

8. Loosen pins and push them up away from sediment for the next measurement. Lock pins, pull the SET out of the pipe and re-insert the SET into next measurement area clockwise from previous measurement (East follows North). Continue with step #4 until all four areas are measured.

9. Marker horizons placed near the SET an provide estimates of surface accretion rates. Feldspar horizons can be sampled by cutting a wedge of peat from the marsh surface in the horizon plot and measuring the thickness of the sediment overlaying the feldspar marker using calipers. Record the minimum, maximum and the thickness that appears most prevalent (mode). For measurements in particularly soft sediments, a cryogenic corer was developed (Cahoon et al. 1996).

V. TROUBLE SHOOTING / HINTS

1. Position the pins by slowly sliding them down to just touch the surface. To better see the pin make contact with the sediment, brush aside the vegetation without damaging it. This can be done in pairs with one person on the plank and the other on or outside of the concrete border. Consistency is the watchword here, from station to station and year to year.

2. Re-check the level after the pins are all set, but before measurement with ruler. If the plate was moved during the pin setting procedure, it may have affected the level and the pin lengths. If this occurred, lift all the pins 10 cm, re-level and lock the arm, and reset the pins.

3. Depending upon changes to the site, either side of the pins may be measured, but any change to the normal procedure must be carefully recorded in the field notebook. All pins are the same length, so corrections can be made following computer input.

4. QA/QC procedures may be implemented in the field by disassembling the SET and having another person assemble it, place it on the station head, place the pins and measure the pin lengths. This combines measurer and field errors. To just assess differences among measurement persons, establish a SET base at a location in a concrete pad (or other appropriate site) and compare surface elevations among individuals.

VI. STATISTICAL ANALYSIS AND DATA USAGE

Appropriate comparisons of elevation change rates and accretion rates can be made between stations under different conditions (management regime or measures of ecological stress). The 36 measures at each site should be considered sub-samples and the SET stations are the true replicates.

For each SET station, least squares regression analysis can be run to determine the rate of surface change (slope of the line) and goodness of fit (r^2). (If surface measurements over time do not change consistently, other approaches may have to be employed that make logical sense for the question and the site.) The rates of surface elevation change and accretion change then can be analyzed using a Student’s t-Test or in an ANOVA framework, depending upon the complexity of the experimental design.

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Rybczyk J.M. and D.R. Cahoon. 2002. Estimating the potential for submergence for two wetlands in the Mississippi River Delta. Estuaries 25: 985–998.