

Some Influences of Sediment Addition to a Deteriorating Salt Marsh in the Mississippi River Deltaic Plain: A Pilot Study

R. D. DeLaune, S. R. Pezeshki, J. H. Pardue, J. H. Whitcomb and W. H. Patrick, Jr.

Laboratory for Wetland Soils and Sediments
Center for Wetland Resources
Louisiana State University
Baton Rouge, LA 70803

ABSTRACT



DELAUNE, R.D.; PEZESHKI, S.R.; PARDUE, J.H.; WHITCOMB, J.H., and PATRICK, W.H., 1990. Some influences of sediment addition to a deteriorating salt marsh in the Mississippi river deltaic plain: a pilot study. *Journal of Coastal Research*, 6(1), 181-188. Fort Lauderdale (Florida). ISSN 0749-0208.

The effect of adding sediment to deteriorating *Spartina alterniflora* Loisel. salt marsh which was not accreting rapidly enough in relation to submergence was examined. Raising the marsh surface approximately 10 cm with the equivalent of 94 kg sediment m⁻² more than doubled plant above ground biomass production by the end of the second growing season. Similarly, numbers of regenerating shoots increased substantially compared to control plots. Plant tissue content of Fe, Mn, P and Ca increased substantially. Furthermore, uptake of N, Fe, Mn, P, Al, Ca, Mg, and K increased in response to the added sediment. Results presented suggest that if Mississippi River sediment could be reintroduced and distributed into these rapidly deteriorating salt marshes, plant regeneration and productivity would be enhanced thus reducing the rate of wetland loss.

ADDITIONAL INDEX WORDS: Wetlands, marsh deterioration, sedimentation, ¹³⁷Cs, *Spartina alterniflora*, marsh restoration.

INTRODUCTION

Louisiana's Gulf coast is rapidly subsiding with subsequent wetland deterioration evident throughout the coast. Coastal marshes are being lost at rates estimated as great as 130 km²yr⁻¹ (GAGLIANO *et al.*, 1981). Leveeing of the Mississippi River has resulted in the suspended sediment load being deposited on the continental slope. The resultant reduction in sediment input into marshes of the deltaic plain apparently contribute to the rapid rate of marsh deterioration currently occurring in coastal Louisiana. Many factors influence the stability of marsh soils in coastal Louisiana. In the subsiding environments of coastal Louisiana, continued existence of marsh habitat is particularly dependent on the ability of the marsh to maintain its elevation within a specific tidal range through the process of vertical marsh accretion (DELAUNE *et al.*, 1978).

Many Louisiana Gulf Coast marshes are not

accreting or aggrading rapidly enough in relation to submergence or increases in water level to keep the marshes intertidal (DELAUNE *et al.*, 1978; HATTON *et al.*, 1983). The net result is marsh deterioration. Accretion is accomplished through a combination of inorganic sediment accumulation and peat formation. The two are interrelated since the influx of sediments also supplies nutrients for plant growth. Increased plant growth results in greater peat formation and increased stem density, further enhancing entrapment and stabilization of sediment.

Comparison of submergence rates reported for the Louisiana Gulf Coast (DELAUNE *et al.*, 1983; HATTON *et al.*, 1983) to gauging stations at other Gulf Coast states reported by PENLAND *et al.*, (1986), show that Louisiana is experiencing the highest submergence rates in all coastal wetlands bordering the northern Gulf of Mexico. The faster rate of water level increases in coastal Louisiana is attributed primarily to subsidence resulting from compaction

of recently deposited sediment associated with the Mississippi River Deltaic Plain. The Louisiana Gulf Coast is experiencing water level increases several times greater than reported eustatic changes. Appreciable sediment deposition and organic matter accumulation are required to compensate for increases in water level. Aggradation or vertical accretion rates depend on the quality as well as the quantity of material available and are influenced by the distance from the source and local hydrology. The relative contribution of mineral and organic matter to the total marsh segment vary with marsh type (HATTON *et al.*, 1983). Bulk density, an indication of inorganic sediment content, is greatest in salt marsh and progressively lower in inland fresh and brackish marshes. Inorganic sediment constitutes a progressively greater fraction of marsh soil solids in the salt marshes. This is a consequence of the hydrological regime. Tidal action and water exchange provides some reworked mineral sediments to the salt marshes near the coast.

The supply and distribution of sediment to interior marshes apparently is not sufficient in many instances to maintain viable marshes. Marsh areas along the Louisiana coast are breaking up internally rather than eroding from the edge (TURNER and RAO, 1987). Marsh deterioration first appears as small ponds which widen with time. STEVENSON *et al.* (1985) also reported that Atlantic coastal marsh erosion begins with the formation of inland ponds which enlarge over time.

An inadequate supply of sediment to interior salt marsh can result in vegetation die-back or marsh deterioration. Soil bulk densities in the rooting zone below 0.20 g cm^{-3} will not support growth of *Spartina alterniflora* (DELAUNE *et al.*, 1979). The mechanism for the marsh deterioration is both biological and physical. Restricted sediment input can reduce both vertical accretion and marsh resistance to hydrodynamic forces such as waves and currents. Submergence or changes in marsh surface water-level relationships can stress or kill marsh vegetation which in turn reduces the organic matter available for accretion processes. Sulfide, at levels toxic to marsh plants, are also found in salt marshes with low inorganic sediment levels (DELAUNE *et al.*, 1983). Iron found in sediment is important in precip-

itating any sulfide formed in marsh soil as a result of sulfate reduction.

In this paper we examine the effect of adding sediment to an inland Barataria Basin *Spartina alterniflora* salt marsh where vertical marsh accretion and sediment input are not sufficient to maintain a viable marsh. Due to rapid subsidence and an insufficient sediment supply Barataria Basin is rapidly deteriorating (Figure 1).

MATERIALS AND METHODS

On July 8, 1986, twelve plywood enclosures were constructed and placed in an inland *Spartina alterniflora* salt marsh of Barataria Basin, Louisiana. Each enclosure was 1.44 m^2 in area and 10 cm high. The enclosures were placed firmly in the marsh surface with sufficient space allowed to avoid complete restriction of drainage. Sediment dredged from an adjacent basin was transported to the marsh manually and distributed within the enclosure. The sediment placed on the marsh was Mississippi River alluvium which was deposited in the basin prior to leveeing of the river. Except for some enrichment in organic carbon, the sediment was similar in composition to present day Mississippi River alluvium sediment (GAMBRELL *et al.*, 1975).

The plot layout was a randomized block design consisting of 4 replications of three rates of added sediment (control (0 kg/m^2), $23.5 \text{ kg dry sediment/m}^2$ and $47 \text{ kg dry sediment/m}^2$). On July 15, 1986 the first treatment was applied to the enclosure with the addition of sediment dredged from a nearby stream bottom. The first rate (23.5 kg m^{-2}) raised the surface 2-3 cm, the second rate (47 kg m^{-2}) raised the marsh surface 4-5 cm. The sediment applied to the marsh consisted of 40% fine sand, 28% coarse-fine silt, and 32% clays and organics.

A second addition of sediment using the same rates (0 , 23.5 and $47 \text{ kg sediment m}^{-2}$) was added to the plots on June 25, 1987 giving a total sediment addition of 47 kg m^{-2} and 94 kg m^{-2} which raised the marsh surface a total of 4-6 cm, and 8-10 cm, respectively, for the two sediment treatments. On November 4, 1987 plants from a 0.25 m^2 section were clipped from each enclosure. Plant above-ground biomass production as affected by sediment addition was determined from plant material clipped at

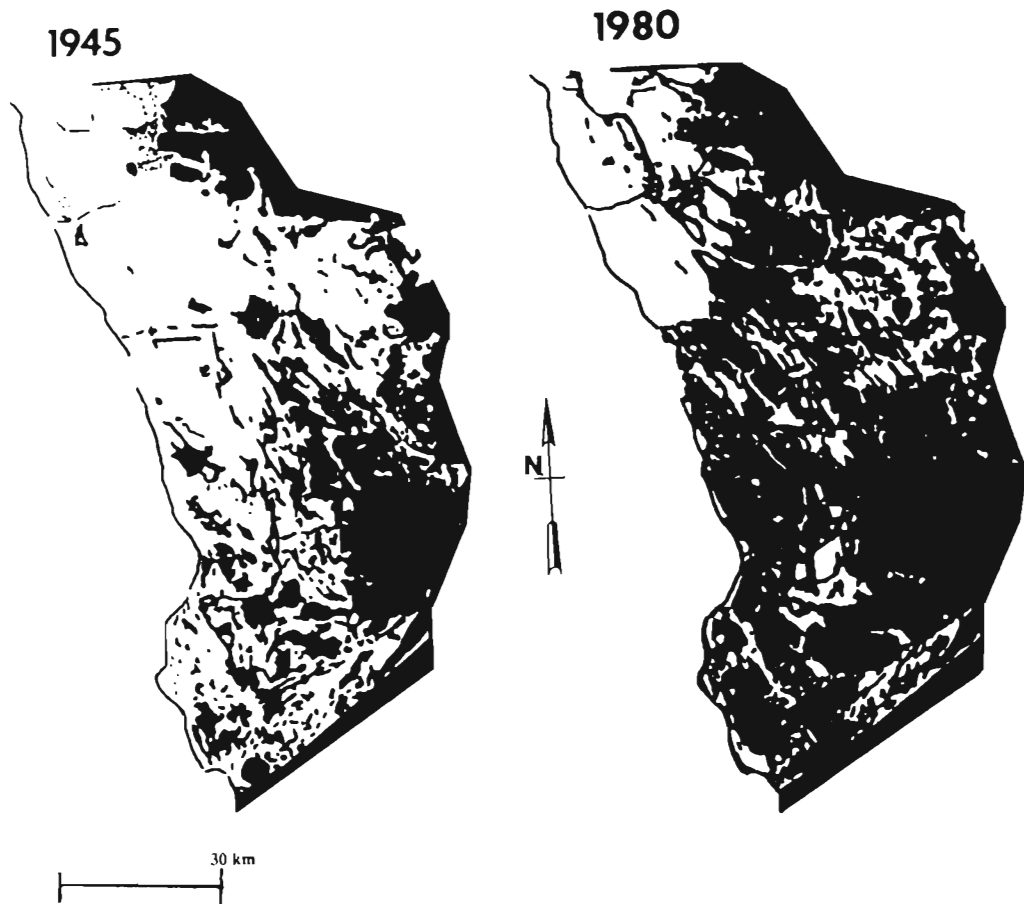


Figure 1. Change in Barataria Basin marsh area between 1945 and 1980, black is open water (after Dozier 1983).

ground level at each 0.25 m^2 plot. Measurements of plant heights were recorded for five randomly selected stems for each sample section. Plant samples were then dried at 70°C to a constant weight and the dry weight was recorded.

Dried samples were divided into subsamples and ground in a Wiley mill (No. 60 mesh) for nutrient analysis. Concentrations of N, P, K, Ca, Mg, Fe, and Mn in the plant tissue were determined. Total nitrogen was determined by the kjeldahl method. Elemental composition of the plant material was determined after digesting in nitric-perchloric-hydrofluoric acid. Element content was determined by ICP equipped with a background corrector.

Vertical marsh accretion rates were determined using the ^{137}Cs dating technique

(DELAUNE *et al.*, 1978) at a stable streamside marsh which is accreting rapidly enough to keep pace with submergence and at the deteriorating inland marsh which received the added sediment. Annual average accretion rates were calculated from the depth in the peat profile of the radioactive element ^{137}Cs . It was first introduced into the biosphere as a result of atmospheric nuclear testing with fallout levels first appearing in 1954 and peaking in 1963 (PENNINGTON *et al.*, 1973). A soil core (15 cm diameter) was taken at each marsh site, sectioned into 3 cm increments, dried, ground, and well mixed. Large diameter cores eliminated any compaction. The ^{137}Cs activity in each section throughout the core was determined by counting the oven-dried sample using a lithium-drift, germanium detector and multichannel ana-

lyzer. Organic matter content was determined by dry combustion procedures. Bulk density was determined from oven-dry sediment in the known volume of each section.

RESULTS

Vertical marsh accretion determined from ^{137}Cs dating indicates the deteriorating inland salt marsh to be accreting at the rate of 0.44 cm yr^{-1} . This rate is approximately 0.8 to 1.0 cm yr^{-1} less than the accretion rate needed to maintain a productive salt marsh typical of marsh in the lower portion of the basin. By comparison, the more stable streamside site was accreting at the rate of 1.25 cm yr^{-1} . The deteriorating inland marsh was not only accreting at a lower rate, there was also only a limited amount of inorganic sediment being deposited as indicated by bulk density and organic matter content of the soil profile (Figure 2). The average bulk density in the rooting zone of the inland marsh profile was 0.20 g cm^{-3} . This is the threshold level at which salt marsh will support growth of *Spartina alterniflora* in Louisiana Gulf Coast marsh (DELAUNE *et al.*, 1979). By comparison, bulk densities of the sta-

ble and productive streamside marsh averaged 0.33 g cm^{-3} . The lower section of the profile presented represented what was once a freshwater marsh (DELAUNE 1986), which accounts for lower bulk densities at depth.

The addition of sediment to the deteriorating inland marsh resulted in a significant increase in above-ground biomass of *Spartina alterniflora* (Table 1). The increase was significant at the higher rate of sediment addition (97 kg m^{-2}). An increase was noted at the 47 kg m^{-2} rate which was not significant, perhaps due to the limited number of replications. The number of plant shoots were, however, significantly greater for both levels of sediment input compared to control plots. Such increases in shoot number over time will likely result in significant biomass differences between control and the 47 kg m^{-2} sediment conditions.

The added sediment resulted in increases in nutrient and mineral content of *Spartina alterniflora* plant tissue (Table 2). There was a significant increase in Fe and Mn content of plant tissue taken from the plots receiving sediment input. The result was significant at both treatment levels. The plant tissue content of Fe and Mn essentially doubled from the 94 kg sediment

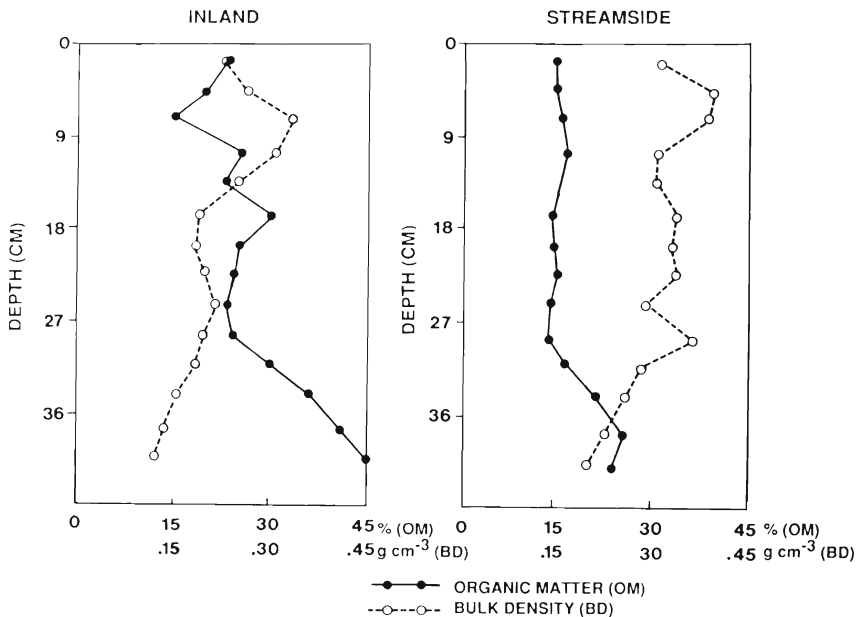


Figure 2. Soil organic matter and bulk density profiles of deteriorating inland marsh and adjacent stable streamside marsh.

Table 1. Plant biomass sampled from control and sediment treated plots.

Sediment Treatment kg m ⁻²	Total above-ground Biomass (g/.25 m ²)	Live plant Biomass (g/.25 m ²)	No. of Plant Shoots	Plant Height (cm)
Control	288 ^a	184 ^a	47 ^a	43 ^a
47 kg sediment m ⁻²	406 ^{a,b}	268 ^{a,b}	69 ^b	41 ^a
94 kg sediment m ⁻²	527 ^b	368 ^b	75 ^b	41 ^a

N.B. Values with the same letter within the same column are not significant at the 5% level.

Table 2. Plant tissue nutrient and mineral content of *Spartina alterniflora* sampled from control plots and plots with sediment added.

Sediment Treatment kg m ⁻²	Tissue nutrient content (µg/g)							
	N	Fe	Mn	P	Al	Ca	Mg	K
Control	7.6 × 10 ^{3a}	222 ^a	19.5 ^a	1256 ^a	279 ^a	1588 ^a	2340 ^a	12890 ^a
47 kg sediment m ⁻²	7.1 × 10 ^{3a}	346 ^b	40 ^b	1544 ^{ab}	364 ^a	1815 ^{a,b}	2380 ^a	14620 ^a
94 kg sediment m ⁻²	7.4 × 10 ^{3a}	397 ^b	47 ^b	1631 ^b	420 ^a	2266 ^b	2270 ^a	12490 ^a

N.B. Values with the same letter (a or b) within the same column are not significant at the 5% level (Duncan's multiple range test).

input as compared to the control. Phosphorus content of plant tissue also increased as a result of sediment addition to the inland marsh. We observed no difference in nitrogen content of plant tissue. This would be expected since plants were sampled at the end of the growing season. However, there was a difference in total uptake of nitrogen between the treatments (Table 3) as a result of plant biomass increase. Calcium content of plant tissue was enhanced only at the highest level of sediment input to the marsh. We observed no significant increase

in potassium, aluminum and magnesium concentration of plant tissue as a result of the sediment addition.

Total nutrient uptake, when factoring in both biomass and tissue concentration as affected by sediment additives (Table 3), show a statistically significant difference among treatments for practically all nutrients. The only exception being for Mg and K which showed no significant difference between the 47 kg and 94 kg additive. Nitrogen uptake was twice the control for the 94 kg additive, (4.01 g N 0.25 m⁻² vs. 2.13

Table 3. Nutrient and mineral uptake by *Spartina alterniflora* in control plots and plots with sediment added.

Sediment Treatment kg m ⁻²	Total nutrient uptake (g/0.25 m ²)							
	N	Fe	Mn	P	Al	Ca	Mg	K
Control	2.13 ^a	0.06 ^a	0.005 ^a	0.36 ^a	0.08 ^a	0.46 ^a	0.68 ^a	3.7 ^a
47 kg sediment m ⁻²	2.83 ^b	0.14 ^b	0.02 ^b	0.63 ^b	0.15 ^b	0.74 ^b	0.98 ^b	5.9 ^b
94 kg sediment m ⁻²	4.01 ^c	0.21 ^c	0.03 ^c	0.86 ^c	0.22 ^c	1.2 ^c	1.2 ^b	6.6 ^b

N.B. Values with the same letter (a) or (b) within the same column are not significant at the 5% level (Duncan's multiple range test).

g N 0.25 m^{-2}). There were similar large increases in total plant uptake for Fe, Mn, P, Al, and Ca.

DISCUSSION

In rapidly subsiding Louisiana's Barataria Basin salt marshes, continued existence of marsh habitat depends on the ability of the marsh to maintain its elevation with respect to increasing water level through vertical accretion (DELAUNE *et al.*, 1978; HATTON *et al.*, 1983). Currently, vertical accretion is not keeping pace with water level increases. In addition to marsh surface water level deficits many areas are not accumulating enough inorganic sediment in the root zone to support *Spartina alterniflora* growth (DELAUNE *et al.*, 1979). As a result, the area is undergoing a rapid rate of deterioration. Marsh accretion necessary to maintain marsh elevation is accomplished through an accumulation of inorganic sediment as well as peat accumulation. Sediment input into these marshes reduces flood stress on plant communities and supplies nutrients for plant growth, both of which increase biomass production, the organic source for peat accumulation. Due to structural aspects of organic matter, organic rich marshes require less inorganic sediment for equivalent rates of vertical accretion than adjacent bay bottoms which contain less organic matter (DELAUNE *et al.*, 1978). However there is a minimum inorganic sediment necessary to maintain a viable *Spartina* marsh. Increased plant growth as a result of sediment input results in greater peat formation and increased stem density, enhancing the ability to further entrap and stabilize sediment.

Currently, there are diversion plans for re-introduction of sediment and freshwater from the Mississippi River into some of the coastal marshes as a means for mitigating land loss (Figure 3). It is known in a general way that many Mississippi River Deltaic Plain marshes are sediment starved. However, to date there have been no quantitative studies on effect of added sediment on marsh production. The sediment treatment used in these studies may not actually represent the effect of sediment which would enter marshes as a result of Mississippi River diversion. However, it demonstrates how Barataria Basin marshes should respond to such inputs. The results presented quantifies

the significant beneficial effect of added sediment on marsh productivity. Plant biomass production increased significantly following the addition of sediment to the marsh surface. This suggests that marsh deterioration is reversible if there are feasible means for reintroducing sediment into the deteriorating salt marsh of lower Barataria Basin.

Assuming an average accretionary deficit of 0.5 cm yr^{-1} with respect to water level increase in the Basin, as a whole (fresh, brackish and salt marshes) the sediment requirement for the corresponding 164,000 ha marsh areas can be calculated. To increase vertical accretion 0.50 cm yr^{-1} would require $6,600 \text{ kg ha}^{-1} \text{ yr}^{-1}$ of mineral sediment, assuming the average bulk density of 0.20 g cm^{-3} (average for the various marsh habitats), consisting of one-third organic matter. For Barataria Basin marshes, 0.5 million metric ton of sediment per year would be necessary for marsh maintenance. The majority of the sediment would have to be distributed in salt marsh in the lower basin, where aggradation deficits are greater. Such quantity of sediments represents only a fraction of the annual suspended load of the Mississippi River, reported to be 200 million metric tons (MEADE and PARKER, 1985), which is currently being deposited off the Continental Shelf. Fine grain fractions (silt and clays) of sediment being introduced into selected marshes of the deltaic plains over a period of time would increase sediment content of the root zone and in turn increase productivity of marsh macrophytes.

Increased plant production as a result of increased sedimentation is due to several factors. The sediment will increase marsh surface elevation, thus reducing flood stress to the plant community. The physiological tolerance of *Spartina alterniflora* is reported to be adversely affect by intense reducing conditions as a result of flooding (PEZESHKI *et al.*, In Press). Another benefit of sediment to marsh vegetation is the additional nutrient source for plant growth. As shown in these investigations the nutrient status of *Spartina alterniflora* was enhanced from the sediment addition.

Developing methods to reverse the trend of marsh deterioration will not only require an understanding of sediment requirement for maintaining individual marshes, but will also necessitate a better understanding of geological and hydrological factors involved. Proposed

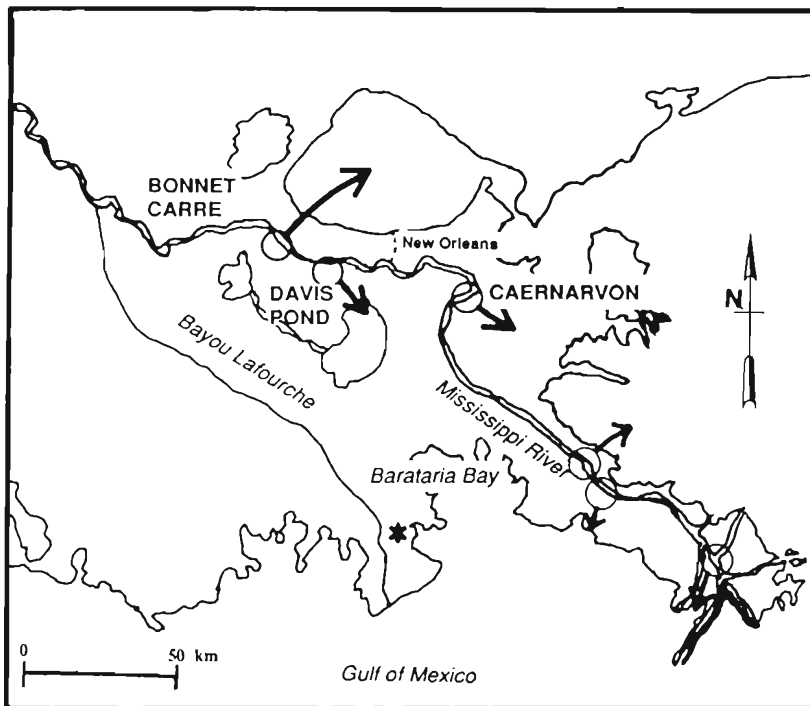


Figure 3. Proposed Army Corp of Engineers diversion projects for reintroducing freshwater and sediment into deteriorating marsh of the Mississippi River Deltaic Plain (asterisk represents study site).

Mississippi River diversion projects should reduce marsh deterioration at selected sites, however, additional studies are needed on the mechanism of transport and dispersal of fine grain sediment being introduced in order to maximize marsh regeneration.

ACKNOWLEDGEMENT

Funding in part was provided by U.S. Geological Survey. (Contract # 14-08-6001-23320)

LITERATURE CITED

- DELAUNE, R.D.; BURESH, R.J., and PATRICK, W.H., JR., 1978. Sedimentation rates determined by ^{137}Cs dating in a rapid accreting salt marsh. *Nature*, 275, 532-533.
- DELAUNE, R.D.; BURESH, R.J., and PATRICK, W.H., JR., 1979. Relationship of soil properties to standing crop biomass of *Spartina alterniflora* in Louisiana marsh. *Estuarine and Coastal Marine Science*, 8, 477-487.
- DELAUNE, R.D.; BAUMANN, R.H., and GOSSE-LINK, J.G., 1983. Relationships among vertical accretion, coastal submergence, and erosion in a Louisiana Gulf Coast marsh. *Journal of Sedimentary Petrology*, 53, 147-157.
- DELAUNE, R.D.; SMITH, C.J., and PATRICK, W.H., JR., 1983b. Relationship of marsh elevation, redox potential, and sulfide to *Spartina alterniflora* productivity. *Soil Science Society America Journal*, 47, 930-935.
- DELAUNE, R.D., 1986. The use of $\delta^{13}\text{C}$ signature of C-3 and C-4 plants in determining past depositional environments in rapidly accreting marshes of the Mississippi River Deltaic Plain, Louisiana, U.S.A. *Chemical Geology* 59, 315-320.
- DOZIER, M.D., 1983. Assessment of change in the marshes of Southwestern Barataria Basin, Louisiana using historical aerial photographs and a spatial information system. M.S. Thesis, Louisiana State University, Baton Rouge. 102p.
- GAGLIANO, S.M.; MEYER-ARENDT, J.J., and WICHER, K.M., 1981. Land loss in the Mississippi Deltaic Plain: *Transactions Gulf Coast Association of Geological Societies*, 31, 295-300.
- GAMBRELL, R.P.; KHALID, R.A.; VERLOO, M.G., and PATRICK, W.H., JR., 1975. *Transformations of heavy metals and plant nutrients in dredged sediments as affected by oxidation-reduction potential and pH*. Part II. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Ms.

- HATTON, R.S.; DELAUNE, R.D., and PATRICK, W.H., JR., 1983. Sedimentation, accretion and subsidence in marshes of Barataria Basin, Louisiana. *Limnology and Oceanography*, 28, 494-502.
- MEADE, R.H. and PARKER, R.S., 1985. Sedimentation in rivers of the United States. National water supply summary. *U.S. Geological Survey Water-Supply Paper*, 2275.
- PENLAND, S.; RAMSEY, K., and MCBRIDE, R., 1986. Relative sea level rise and subsidence measurements in the Gulf of Mexico based on National Ocean Tide Gauge Records. In: Estuarine and Coastal Management—Tools of the Trade. *Proceedings of the Tenth National Conference of the Coastal Society*. New Orleans, Louisiana.
- PENNINGTON, W.; CAMBRAY, R.S., and FISHER, E.H., 1973. Observations on lake sediments using fallout ^{137}Cs as a tracer, *Nature*, 242, 324-326.
- PEZESHKI, S.R.; DELAUNE, R.D., and PATRICK, W.H., JR., (In Press). Effect of fluctuating rhizosphere redox potential on carbon assimilation of *Spartina alterniflora*. *Oecologia*.
- STEVENSON, J.; KEARNEY, M., and PENDLETON, E., 1985. Sedimentation and erosion in Chesapeake Bay brackish marsh system. *Marine Geology*, 67, 213-235.
- TURNER, R.E. and RAO, Y.S., 1987. New holes in an old marsh. In: Turner, R.E. and D.R. Cahoon (eds.), *Causes of Wetland Loss in the Coastal Central Gulf of Mexico*. Volume II: Technical Narrative. Final report submitted to Minerals Management Service, New Orleans, pp. 357-386.