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COASTAL DEPOSITIONAL SYSTEMS IN THE GULF OF MEXICO

Quaternary Framework and Environmental Issues

Twelfth Annual Research Conference
Gulf Coast Section
Society of Economic Paleontologists and
Mineralogists Foundation

Program with Extended and Illustrated Abstracts

Adam's Mark Hotel
Houston, Texas
December 8-11, 1991

Published December 5, 1991

Distributed by
Earth Enterprises, Inc.
P.O. Box 672
Austin, Texas 78767
U.S.A.

MINERAL AND ORGANIC MATTER ACCUMULATION RATES IN DELTAIC COASTAL MARSHES AND THEIR IMPORTANCE TO LANDSCAPE STABILITY

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ABSTRACT

Marsh deposits may occupy little of a profile, but the environments they represent may be long lived. Marsh longevity depends partly on the deposition of mineral and organic matter to counter relative sea level rise, or submergence. Understanding soil formation in Louisiana's rapidly subsiding coastal marshes may provide insights relevant to other coastal marshes if global sea-level rise increases as expected.

Mineral and organic matter accumulation rates required to prevent flooding stress on marsh vegetation in a submerging environment are partially dependent on whether the marsh is fresh, brackish, or saline. Estimates of the rates of mineral matter accumulation required for a marsh surface submerging at 1 cm yr^{-1} range from 424 gr m^{-2} yr^{-1} in fresh,a to 1,798 gr m^{-2} yr^{-1} in saline marsh. Mineral requirements likely vary in response to the availability of SO_4^{2-}, whicha reduces to a plant toxin, but which is buffered by soil iron. Estimates of the rates of organic matter accumulation required range from 1,969 gr m^{-2} yr^{-1} in fresh to 1,136 gr m^{-2} yr^{-1} in brackish marsh. Organic requirements vary becausea of differences in the decomposition rates of plants in the different marsh types.

Another aspect of increasing rates of global sea-level rise is increased marine influences in tidal fresh and brackish marshes, *i.e.*, increased tidal flushing and availability of sea salts such as NaCl and SO_4^{2-}, which cause shifts in plant communities. This is important because mineral matter accumulation must almost double for *Spartina alterniflora* to occupy brackish marsh areas experiencing increased marine influences. Thus even though vertical accretion may initially keep pace with submergence, we hypothesize that if increasing marine influences accompanies submergence, brackish marsh may be more likely to convert to open water than to saline marsh. This may be a factor in the rapid conversion of Louisiana's brackish marsh to open water. If the rate of global sea-level rise increases, other brackish marshes with low soil bulk density may be similarly threatened.

INTRODUCTION

Subsidence and global sea-level rise combine to submerge coastal marshes. The slow rise of global sea-level since the end of the last ice age allowed coastal marshes to maintain their elevation relative to the rising sea level (see Titus, 1986). This was accomplished by the accumulation of mineral and organic matter which formed new, more elevated marsh soil. Global sea-level rise is currently estimated at 0.24 cm yr^{-1} (Peltier and Tushingham, 1989), buta the rate may increase, and the conversion of marsh to open water would likely follow (Titus, 1986).

An opportunity exists in Louisiana to study the effects of rapid submergence on vertical accretion before rapid submergence is widespread. This is because thick accumulations of under-consolidated sediments cause rapid subsidence rates in some areas of Louisiana (Ramsey and Penland, 1989). This combines with sea-level rise to produce rapid submergence rates, up to 1.17 cm yr^{-1} (Ramsey and Penland, 1989). This may be similar to that expected to occur globally if the rate of global sea-level rise increases as expected. Rapid submergence rates may be linked to the conversion of marsh to open water in Louisiana (Ramsey and Penland, 1989) and in Texas (Morton and Paine, 1990). In Texas, submergence has been estimated at 0.63 cm yr^{-1} (Ramsey and Penland, 1989), and subsurface fluid withdrawal may contribute to subsidence (Morton and Paine, 1990).

Another possible aspect of increasing rates of global sea-level rise is increased flushing of tidal fresh and brackish marshes with water containing sea salts (Titus, 1986). Again, Louisiana provides a chance to study these conditions before they become widespread because marine influences are increasing in the Mississippi River Deltaic Plain, as indicated by the inland migration of saline and brackish marsh vegetation (Chabreck and Linscombe, 1982).

In this paper we describe recent work relevant to soil formation in the rapidly submerging marshes of the Mississippi River Deltaic Plain. We also explore relationships between increasing marine influences, wetland soil formation, and landscape stability. For reasons explained later, we focus on the implications of increased SO_4^{2-} rather than on increased NaCl. This may provide insight into conditions that may become widespread if the rate of global sea level rise increases in response to the greenhouse effect.

SUBMERGENCE AND MARSH SOIL FORMATION

To counter submergence, a combination of mineral and organic matter must accumulate to maintain the marsh surface in the intertidal zone. Otherwise, marsh elevation is too low and plant stress or mortality may occur (DeLaune *et al.*, 1983, Mendelssohn *et al.*, 1981). Mineral matter accumulation varies more than organic matter accumulation (Table 1). The processes of mineral matter and organic matter accumulation differ but are related; mineral matter accumulation enhances organic matter accumulation, and *vice versa.*

Table 1. Rates (gr m^{-2} yr^{-1}) of mineral and organic matter accumulation in inland marshes of the Mississippi River Deltaic Plain.

Source	mineral matter	organic matter
	fresh marsh	
Hatton *et al.* (1983)	280	306
Smith *et al.* (1983)		386
DeLaune *et al.* (1987)		312
	brackish marsh	
Hatton *et al.* (1983)	478	348
Smith *et al.* (1983)		414
DeLaune *et al.* (1987)		262
	saline marsh	
Hatton *et al.* (1983)	1,740	435
Smith *et al.* (1983)		315

Soil Organic Matter Accumulation

Hatton *et al.* (1983) concluded that organic matter accumulation was a main determinant in the vertical growth rate of marshes in the Mississippi River Deltaic Plain. In those marshes, there is less organic matter than mineral matter on a weight basis, but organic matter occupies more volume than mineral matter in fresh and brackish marsh soil (Nyman *et al.*, 1990). Organic matter is believed to contribute greatly to the soil matrix and increase structural strength by forming an interlocking network. The amount of soil organic matter varies from 2.4% by volume in fresh marsh to 5.3% in saline marshes (Nyman *et al.*, 1990).

Soil organic matter accumulation is believed to result from *in situ* production by marsh plants, rather than transportation from other areas. Thus factors which regulate plant growth also affect soil organic matter accumulation. Plant growth also promotes mineral matter accumulation. Plant stems reduce water velocities, which promotes deposition of mineral matter (Gleason *et al.*, 1979, Rejmanek *et al.*, 1988), and algae on plant stems promotes the trapping of mineral matter too fine to settle from the water column (Stump, 1983).

Plant growth is largely controlled by the degree of soil aeration and the amount of reduced sulfur (S^{2-}, HS, and H_2S), which is toxic to plants (Pearson and Havill, 1988, Pezeshki *et al.*, 1988). The two are related because sulfur is reduced in waterlogged soils, but only when sulfate is available. Soil waterlogging is less stressful to marsh vegetation than soil waterlogging and sulfides (Pearson and Havill, 1988, Pezeshki *et al.*, 1988). And because seawater contains more sulfate (SO_4^{2-}) than fresh water, the importance of sulfide toxicity increases from fresh to brackish to saline marshes. At least in saline marsh, soil waterlogging and sulfides combine to severely stress vegetation (DeLaune *et al.*, 1983, Mendelssohn *et al.*, 1981).

The accumulation rate of soil organic matter is also affected by the decomposition rate. Soil organic matter is constantly being oxidized by decomposers, which results in the conversion of organic carbon to CO_2 and CH_4. Soil organic matter decomposition differs among fresh, brackish, and saline marsh (Smith *et al.*, 1983). The differences were partially attributed to the different plants which occupy the marsh types (Nyman and DeLaune, in press). Brackish *Spartina patens* marsh decomposes the slowest, and fresh *Panicum hemitomon* marsh decomposes the fastest.

The amount of organic matter and of organic matter decomposition in fresh, brackish, and saline marsh soils of the Mississippi River Deltaic Plain have been used to estimate the amount of soil organic matter production required for marsh soil formation (Nyman *et al.*, 1990). Brackish marsh has the lowest organic matter requirement (Fig. 1).

Soil Mineral Matter Accumulation

Soil mineral matter may be from 50% to 90% of the dry weight of marsh soils, but mineral matter occupies only 2% to 7% of soil volume in Mississippi River Deltaic Plain marshes (Nyman *et al.*, 1990). Storm passage is a primary mechanism that delivers mineral sediments to Louisiana marshes (Reed, 1988, Roberts *et al.*, 1989). Increased water levels and wave action in bays and lakes prior to frontal passage transports sediments from water bottoms to marsh surfaces. Following frontal passage, north winds reduce water levels and the marsh surface drains, drying and con-

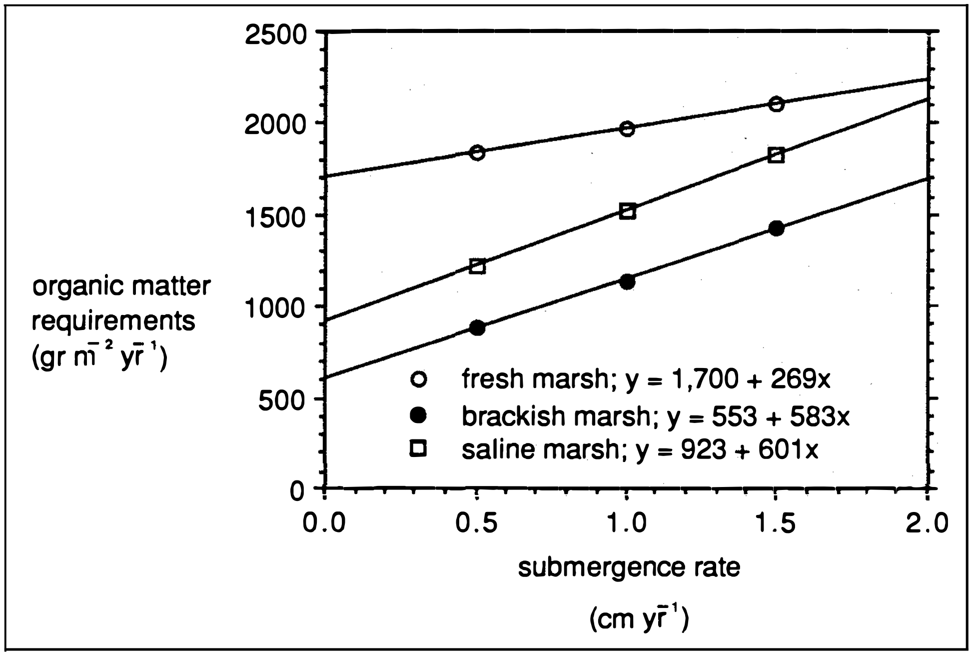

Figure 1. Estimated rates of organic matter incorporation required to counter submergence and decomposition in fresh, brackish, and saline marsh; from data in Nyman *et al.* (1990).

solidating the newly deposited sediments. Drying is important; although Hurricane Juan deposited sediments in some marshes, heavy rains following the hurricane washed away virtually all new sediments (Meeder, 1987).

In addition to contributing to soil volume and marsh surface elevation, soil mineral matter also promotes vigorous plant growth in several ways. Soil mineral matter provides plant nutrients such as calcium, potassium, and phosphorous, and under reduced conditions provides cation exchange and sorption sites for orthophosphate, which restricts phosphate leaching (Patrick and Khalid, 1974). Thus saline marsh in Louisiana is not phosphate limited (Buresh *et al.*, 1980), whereas fresh marsh, which contains less mineral matter, is phosphate limited (Mistch and Gosselink, 1986:267-268).

Another important aspect of soil mineral matter is the iron content. Soil iron precipitates with reduced sulfur, which as noted is a plant toxin. Thus the amount of soil iron has been positively associated with production of the salt marsh plant *Spartina alterniflora* (King *et al.*, 1982) on the east coast, and with *Spartina alterniflora* biomass and height in Louisiana (DeLaune *et al.*, 1990). Soil bulk density is a good indicator of mineral nutrient and iron content, and *Spartina alterniflora* biomass is related to soil bulk density (Fig. 2) (DeLaune and Pezeshki, 1988, DeLaune *et al.*, 1990). A similar relationship between soil bulk density and biomass of the brackish marsh plant *Spartina patens* has also been observed (Nyman *et al.*, unpublished data).

Submerging fresh, brackish, and saline marshes have different mineral matter requirements. Nyman *et al.* (1990) analyzed 50 cores from throughout the Mississippi River Deltaic Plain and estimated that to vertically accrete at 1 cm yr^{-1}, fresh marsh required 424 gr m^{-2} yr^{-1}, brackish marsh required 1,052 gr m^{-2} yr^{-1}, and saline marsh required 1,789 gr m^{-2} yr^{-1}. These differences were attributed to the greater iron requirement of saline marsh, which resulted from its greater supply of SO_4^{2-}.

Marsh loss may occur if low mineral and organic matter accumulation cause insufficient vertical accretion relative to submergence. In a rapidly submerging marsh in Louisiana, marsh loss was associated with inadequate vertical

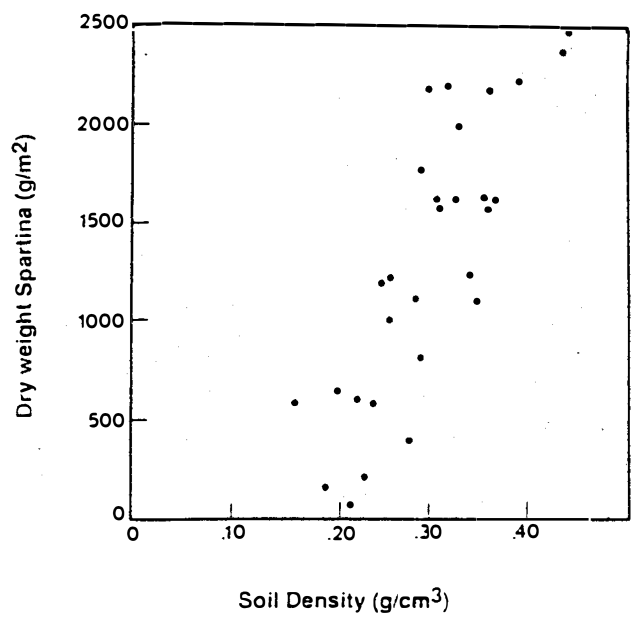

Figure 2. Relationship between soil density and biomass of the saline marsh species *Spartina alterniflora*; adapted from DeLaune *et al.* (1990).

accretion, even though vertical accretion averaged almost 1 cm yr^{-1} (Nyman *et al.*, unpublished data). In that marsh, neither mineral nor organic matter accumulation equalled estimated requirements, and vegetation appeared to suffer from both insufficient elevation and insufficient soil bulk density.

RELATIONSHIP BETWEEN MARSH SOIL, INCREASING MARINE CONDITIONS, AND LANDSCAPE CHANGES

Although brackish marsh appears very likely to survive rapid submergence because of its combination of low mineral matter and organic matter accumulation requirements, it appears poorly suited to survive a different aspect of rising sea-level: increased marine influences. As noted, marine influences may increase in tidal fresh and brackish marshes if the rate of global sea-level rise increases (Titus, 1986). In brackish marshes, mineral matter accumulation averages only 1,052 gr m^{-2} and soil density averages only 0.16 gr cm^{-3} (Nyman *et al.*, 1990). Before *Spartina alterniflora* can establish in brackish marsh experiencing increased marine influences, it appears that the mineral matter accumulation rate must almost double from 1,052 gr m^{-2} yr^{-1}, to 1,798 gr m^{-2} yr^{-1}, and the soil bulk density must almost double as well. Although there have been no direct studies to date, this suggests that if marine influences increase during rapid submergence, brackish marsh may be more likely to convert to open water than to saline marsh; others have reached similar conclusions (Pezeshki *et al.*, 1989).

Increases in marine influences in the Mississippi River Deltaic Plain are indicated by the inland migration of saline and brackish marsh zones (Chabreck and Linscombe, 1982), which may result partly from rapid submergence as well as from wetland loss and canals. If mineral matter accumulation does not greatly increase in low density brackish marshes experiencing salinity increases, the establishment of *Spartina alterniflora* may be prohibited. Such areas might therefore be more likely to convert to open water than to saline marsh. This may partially explain the large amounts of brackish marsh loss observed in Louisiana (*e.g.*, Adams *et al.*, 1976), even though salinity increases *per se* may not have been great enough to harm vegetation (see Wiseman *et al.*, 1990). If the rate of global sea-level rise increases, low density brackish marshes elsewhere may be similarly threatened.

Acknowledgments

This project was supported by the United States Geological Survey, grant number 14-08-0001-23320.

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