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Contributions of mineral and organic components to tidal freshwater marsh accretion

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Abstract

Vertical accretion in tidal marshes is necessary to prevent submergence due to rising sea levels. Mineral materials may be more important in driving vertical accretion in tidal freshwater marshes, which are found near the heads of estuaries, than has been reported for salt marshes. Accretion rates for tidal freshwater marshes in North America and Europe ($n = 76$ data points) were compiled from the literature. Simple and multiple linear regression analyses revealed that both organic and mineral accumulations played a role in driving tidal freshwater marsh vertical accretion rates, although a unit mass of organic material contributed ∼4 times more to marsh volume than the same mass input of mineral material. Despite the higher mineral content of tidal freshwater marsh soils, this ability of organic matter to effectively hold water and air in interstitial spaces suggests that organic matter is responsible for 62% of marsh accretion, with the remaining 38% from mineral contributions. The organic material that helps to build marsh elevation is likely a combination of in situ production and organic materials that are deposited in association with mineral sediment particles. Regional differences between tidal freshwater marshes in the importance of organic vs. mineral contributions may reflect differences in sediment availability, climate, tidal range, rates of sea level rise, and local-scale factors such as site elevation and distance to tidal creeks. Differences in the importance of organic and mineral accumulations between tidal freshwater and salt marshes are likely due to a combination of factors, including sediment availability (e.g., proximity to upland sources and estuarine turbidity maxima) and the lability of freshwater vs. salt marsh plant production.

Keywords: sedimentation; accumulation; soils; wetlands; coastal marshes; sea level changes; United States; Europe

1. Introduction

Tidal freshwater marsh stability and persistence are dependent on the net balance between material inputs (allochthonous particulate matter and in situ production) and material removal (via erosion and organic matter decomposition), which can allow these systems to grow vertically as sea levels increase. Over decades to centuries, rates of vertical marsh growth typically approximate or exceed rates of sea level rise (e.g., Orson et al., 1990; Neubauer et al., 2002; Köster et al., 2007). Because the zonation of plants within tidal marshes is largely a function of the hydroperiod (Odum et al., 1984; Mitsch and Gosselink, 1993), any imbalances between rates of marsh accretion and sea level rise may lead to changes in plant community composition or a shift from tidal marsh to open water habitats. Plants can influence marsh accretion through the production of refractory organic material (e.g., Orson et al., 1990) and can impact soil organic content and short-term (seasonal) rates of sedimentation (Pasternack and Brush, 2001). Further, there can be differences in long-term (decadal) marsh accretion or organic accumulation between different plant zones within the same marsh (e.g., Khan and Brush, 1994; Merrill and Cornwell, 2000). Differences in sediment availability can also impact sedimentation and accretion in tidal freshwater marshes. Darke and Megonigal (2003) reported up to an order of magnitude difference in short-term deposition rates between a pair of tidal freshwater marshes within the same river system; this dramatic between-marsh variability was attributed to proximity to the estuarine turbidity maximum.

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Vertical accretion rates are also sensitive to sediment availability, with both Orson et al. (1990) and Khan and Brush (1994) reporting increases in historical marsh accretion rates following land-clearing activities in surrounding watersheds.

There have been no comprehensive studies to determine if mineral or organic inputs are more important to accretion in tidal freshwater marshes. This contrasts with tidal salt marshes, where the relative contributions of mineral and organic materials to vertical accretion have been well-studied (e.g., McCaffrey and Thomson, 1980; Nyman et al., 1993, 2006; Callaway et al., 1997; Turner et al., 2000; Chmura and Hung, 2004). Future environmental and anthropogenic changes to watersheds and near-coastal waters could significantly alter the dynamics of both sedimentary materials and organic matter production in the tidal freshwater zone. For example, (sub)urbanization, dam construction, and deforestation/reforestation are likely to influence inputs of particulate materials to the tidal freshwater zone and therefore could affect sedimentation onto the marsh surface. Similarly, plant productivity and community composition in tidal freshwater marshes may be altered due to sea level rise, nutrient enrichment, and salt water intrusion (e.g., Pearlstine et al., 1993; Morris et al., 2002; Crain, 2007).

The objective of this study was to determine the relative contributions of mineral and organic accumulations to vertical accretion in tidal freshwater marshes. Here, I use *accretion* to refer to a vertical increase in marsh elevation. *Mineral* and *organic accumulations* represent the mass of mineral (i.e., inorganic) or organic matter deposited on the marsh surface during tidal flooding via sedimentation (defined below) or produced in situ (e.g., belowground root production). *Sedimentation* is the deposition of water column particulate matter (both mineral sediments and organic material) onto the marsh surface. Each of these terms can be expressed as a rate by normalizing accretion, accumulation, or sedimentation to a relevant time scale. Because tidal freshwater marshes are located closer to upland sediment sources, I hypothesized that mineral accumulation would be more significant in tidal freshwater marshes than has been reported for saline marshes (e.g., Turner et al., 2000). Further, I expected that the importance of organic accumulation to marsh accretion would be greater in the northeastern U.S.A. (due to cooler temperatures limiting decomposition) and Louisiana (due to sedimentation onto natural levees and water control structures that limit sediment delivery to interior marshes) than in sediment-rich Southeast U.S.A. tidal freshwater marshes.

2. Materials and methods

Tidal freshwater marsh accretion rates and soil properties (organic content and bulk density) were compiled from the literature. Data were located for marshes distributed along the Atlantic coast of the U.S.A. (from Maine to Georgia), for several locations in coastal Louisiana, and for a single tidal freshwater marsh in Belgium (Table 1). Between one and three cores were taken from most marshes. No non-tidal sites were included. Only measured accretion rates are included in this compilation; thus the accretion rates of 0.13–0.36 cm y^{-1} derived from a mechanistic model for a Massachusetts, U.S.A. tidal freshwater marsh were not included (Morris and Bowden, 1986; Bowden et al., 1991). Soil properties are reported only for sites where accretion rates were measured; additional tidal freshwater marsh soils data can be found elsewhere (e.g., Appendix 1 in Craft, 2007).

2.1. Analytical methods

The majority of the accretion rates analyzed in this study were determined using ^{210}Pb ($n = 46$ samples) or ^{137}Cs ($n = 24$) geochronological dating techniques. The remaining accretion rates were calculated using pollen microfossils ($n = 3$), identifiable plant detritus (i.e., macrofossils; $n = 2$), or a sand layer that was deposited at a known date ($n = 1$) (Table 1). For ^{137}Cs, only accretion rates based on the 1963/64 ^{137}Cs peak are analyzed herein, although several sources also calculated rates using the 1954 date of first appearance (Orson et al., 1990, 1992; Neubauer et al., 2002). Khan and Brush (1994) calculated "instantaneous" accretion rates for selected 1 cm increments; this analysis reports only the average rate since the 1964–1966 layer (i.e., that closest to the 1963/64 ^{137}Cs peak). Plant macrofossils combined with aerial photographs that documented plant species changes were used to calculate accretion rates since 1958 in a tidal freshwater marsh in the Scheldt estuary, Belgium (Temmerman et al., 2003). Orson et al. (1990) measured sediment deposition above a 2 mm thick sand layer that was deposited on the marsh in 1965/66 during installation of a pipeline across the marsh.

The ^{210}Pb and ^{137}Cs dating approaches are most applicable over different time scales and therefore could provide different estimates of vertical accretion within a single site if compaction and decomposition differed in importance between shallower and deeper soils or if accretion rates have changed over time. However, when ^{210}Pb and ^{137}Cs were analyzed on the same marsh core, accretion rates from the two techniques were generally comparable (e.g., Orson et al., 1990, 1992; Church et al., 2006), but occasionally differed by ~0.5 cm y^{-1} (Church et al., 2006). In some cases, an accretion rate could be calculated using one radioisotope but not the other (Köster et al., 2007). Working with a database of salt marsh and mangrove samples, Turner et al. (2006) determined that the ratio of accretion rates from the ^{137}Cs and ^{210}Pb approaches (that is, Sed_{137}/Sed_{210}) varied non-linearly as a function of soil bulk density. Applying the Turner et al. relationship to the bulk densities for the ^{210}Pb-dated cores analyzed herein resulted in a median Sed_{137}/Sed_{210} ratio of 1.06 (10th and 90th percentiles of 0.93 and 1.59, respectively). Given the similarity of the calculated Sed_{137}/Sed_{210} ratio to 1.0, no correction was made to adjust the ^{210}Pb-based accretion rates to the common time frame shared by the ^{137}Cs-based rates and the other dating methods used in this study.

Soil parameters (e.g., dry bulk density and soil organic content) were often reported along with accretion rates. Where these data were available, I extracted depth-specific information from figures and tables and calculated average soil