

Recent volumetric changes in salt marsh soils

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Received 6 April 2006; accepted 2 May 2006

Available online 19 June 2006

Abstract

Salt marsh sediment volume decreases from organic decomposition, compaction of solids, and de-watering, and each of these processes may change with age. Variability in the vertical accretion rate within the upper 2 m was determined by assembling results from concurrent application of the ^{137}Cs and ^{210}Pb dating techniques used to estimate sediment age since 1963/1964, and 0 to ca 100+ years before present (yBP), respectively. The relationship between ^{210}Pb and the ^{137}Cs dated accretion rates (Sed_{210} and Sed_{137} , respectively) was linear for 45 salt marsh and mangrove environments. Sed_{210} averaged 75% of Sed_{137} suggesting that vertical accretion over the last 100+ years is driven by soil organic matter accumulation, as shown for the pre ^{137}Cs dated horizon. The ratio of $\text{Sed}_{210}/\text{Sed}_{137}$ declines with increasing mineral content. A linear multiple regression equation that includes bulk density and Sed_{137} to predict Sed_{210} described 97% of the variance in Sed_{210} . Sediments from Connecticut, Delaware and Louisiana coastal environments dated with ^{14}C indicate a relatively constant sediment accretion rate of $0.13 \text{ cm year}^{-1}$ for 1000–7000 yBP, which occurs within 2 m of today's marsh surface and equals modern sea level rise rates. Soil subsidence is not shown to be distinctly different in these vastly different coastal settings. The major reason why the Sed_{137} measurements indicate higher accretion rates than do the Sed_{210} measurements is because the former apply to younger sediments where the effects of root growth and decomposition are greater than in the latter. The most intense rates of change in soil volume in organic-rich salt marshes sediments is, therefore, neither in deep or old sediments (>4 m; >1000 years), but within the first several hundreds of years after accumulation. The average changes in organic and inorganic constituents downcore are nearly equal for 58 dated sediment cores from the northern Gulf of Mexico. These parallel changes downcore are best described as resulting from compaction, rather than from organic matter decomposition. Thus most of the volumetric changes in these salt marsh sediments occurs in the upper 2 m, and declines quickly with depth. Extrapolation forwards or backwards, using results from the ^{210}Pb and the ^{137}Cs dating technique appear to be warranted for the types of samples from the environments described here.

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Keywords: salt marsh; sediments; subsidence; accretion; *Spartina alterniflora*

1. Introduction

Salt marshes dominated by *Spartina alterniflora* exist at the seaward edge of coastal margins within a restricted range of the tidal variance. This range is up to 2 m in New England marshes (Redfield, 1972), but a mere 10–20 cm in the microtidal environments of the Mississippi River deltaic plain (McKee and Patrick, 1988). Salt marsh sediment accretion (cm year^{-1}) must be sufficient for the emergent plants to

remain within its flooding tolerances as global sea level rises or tectonic movements change, and also as the accumulated sediments compress and decompose (Kaye and Barghoorn, 1964; Turner, 2004). If sediment accretion is not sufficient, then the salt marsh will become open water habitat. Such habitat changes are of concern for many reasons, including those related to fisheries, wildlife and other societal values (Turner, 1997; Balmford et al., 2002).

Salt marsh sediments consist of organic matter from roots, leaves and organic detritus, as well as inorganic minerals, gases and water. The bulk density (BD; $\text{g dry weight cm}^{-3}$) of *Spartina alterniflora* salt marsh sediments is directly proportional to the content of inorganic material in the upper few

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decimeters (Gosselink et al., 1984; Turner et al., 2001). Unlike organic constituents, the inorganic constituents are relatively incompressible, and their volume will not change much with age (e.g., Norfolk, United Kingdom; French, 1993), and in mineral-rich sediments, the inorganic accumulation rate ($\text{g cm}^{-2} \text{ year}^{-1}$) is proportional to the sediment accretion rates. In contrast to inorganic-rich sediments, such as those of much of the Atlantic and Gulf of Mexico coasts of the US, the accretion rate in the upper meter (<1000 years old) is not controlled by inorganic material, but is directly related to organic accumulation (Turner et al., 2001). In these relatively organic-rich sediments, the volume of inorganic and organic constituents is less than 10% (total) and the remaining 90% is composed of void spaces and water.

Numerous litterbag decomposition and chemical studies have demonstrated that organic matter turnover and decomposition is significant and has an important controlling factor on the chemistry of salt marsh soils (Sherr and Payne, 1978; Howes et al., 1981; White and Howes, 1994). This organic decomposition, as well as pressure-induced decreases in plant and mineral void spaces and de-watering, tends to decline with age, and therefore burial depth (e.g., Kaye and Barghoorn, 1964). These losses in soil volume can be accelerated by altering the local hydrologic regime under the influences of canals and waterways (Turner, 1997), weirs, flap-gates, impoundments and even mosquito ditches (Stearns et al., 1940; Turner, 2004), and possibly as a result of eutrophication (Valiela et al., 1976; Morris and Bradley, 1999). It is important to know how soil volume changes with age, soil depth and sediment type to accurately predict the effectiveness of various wetland restoration schemes, the impacts from an anticipated acceleration of sea level rise due to global climate change, or changes in sediment loading. Furthermore, knowledge of the variance in soil volume of dissimilarly composited soils can yield insights into the precursors of modern surface geomorphologies and in deconstructing the sequence of layered deposits (Allen, 1999).

One way to contribute to our knowledge of changes in salt marsh soil volume and constituents with aging is to estimate the net sediment accretion and accumulation rates (cm year^{-1} and $\text{g cm}^{-2} \text{ year}^{-1}$, respectively) in different soil horizons. The use of *in situ* marker horizons added at the surface (typically for less than 1 year) may be problematic. A practical issue is that the labeled horizons may be difficult to relocate after several years or the accretion rate may be small relative to the precision and accuracy of the measurement method. The material initially deposited above the labeled surface layer may be remobilized by storms, organisms, or sub-surface chemical reactions, and the amount accumulated varies spatially over weeks, seasons and years, and at a rate that is usually much less than 2 cm year^{-1} . Studies using white clay or glitter markers to measure short-term sediment accretion rates typically have widely-varying and higher rates of compaction in the first year compared to the estimates integrated over many years (Cahoon and Turner, 1989). Two techniques yielding results that integrate sediment accretion rates over decades involve dating salt marsh sediments with ^{137}Cs and ^{210}Pb

radioisotopes. The peak in ^{137}Cs fallout (resulting from weapons testing and subsequent atmospheric fallout) was in 1963/1964. Detecting this peak provides a dated stratum to estimate net sediment accretion above it, but not below it. ^{210}Pb dating techniques are based on a constant supply of ^{210}Pb from the atmosphere to the marsh surface. The time period that the ^{210}Pb -based dating technique is nominally valid for is from 0 to 100+ years before present (yBP), or even 200 years (McCaffrey and Thomson, 1980), and dependent on the sensitivity of the detector, and background noise, among other factors. Calculations of vertical accretion rates are based upon the decay constant of ^{210}Pb , where the excess ^{210}Pb activity (total – background) is plotted logarithmically versus depth to obtain an average sedimentation rate (Nittrouer et al., 1979). The activity of ^{210}Pb in the first few centimeters near the surface can aid in determining how much sediment mixing is occurring, but may also complicate the interpretation of accretion rates in the same layer, and so the commonly applied application of this technique is to estimate accretion rates below the mixed layer. Scientists have applied these two techniques for more than 3 decades to measure sediment accretion rates and to establish pollutant loading histories (Armentano and Woodwell, 1975; Delaune et al., 1978; Bricker, 1993).

The set of assumptions that constrain the interpretations for these two dating techniques are not the same (Hancock et al., 2002). Both the ^{137}Cs and ^{210}Pb dating techniques assume that there is no significant vertical movement of ^{137}Cs or ^{210}Pb once deposited. The ^{137}Cs is bound mostly to minerals, especially clays, but the ^{210}Pb is associated with organic material. If ^{137}Cs migrates downward in sufficient amounts then the 1963/1964 peak in ^{137}Cs activity will be displaced, and the true sedimentation rates will be overestimated. Documenting the ^{137}Cs activity throughout the profile is important in the interpretation of results. A high ^{137}Cs activity at the surface suggests either erosion of the layer deposited after 1963/1964, or re-mobilization of sediments originally deposited in 1963/1964, but at another location (Milan et al., 1995). If the surface layer is eroded after 1963/1964 and the ^{137}Cs peak persists, then the accretion rate will be underestimated unless methodological approaches are applied, such as x-ray radiography or determination of the total ^{137}Cs inventory (Milan et al., 1995). The organic component that the ^{210}Pb is bound to may be diluted by the addition of root materials, and leached or otherwise lost by decomposition. Both ^{137}Cs or ^{210}Pb may be mixed vertically in the surface layer by physical and biological processes that may discriminate between inorganic and organic materials. An additional complication is that changes in sediment accretion over 100+ years may be mis-interpreted as a difference in compaction or post-depositional organic decomposition, instead of being recognized as a regional instance of a fluctuating sedimentation rate. In this case, many samples from several regions should provide a statistical distribution that evens out the high and low regional differences in sedimentation rates determined by either ^{137}Cs or ^{210}Pb techniques. The ^{14}C dating technique is rarely applied to sediments younger than a one or two centuries yBP, but the results

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