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Hydrogeomorphic influences on salt marsh sediment accumulation and accretion in two estuaries of the U.S. Mid-Atlantic coast

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ABSTRACT

Salt marshes in two contrasting estuaries of the U.S. Mid-Atlantic coast, Barnegat Bay and Delaware Bay, were investigated to identify relationships between rates of sedimentation and marsh estuarine geomorphic setting. Barnegat Bay is a microtidal lagoon estuary with back-barrier and mainland coastal marshes, whereas Delaware Bay is a micro-mesotidal coastal plain estuary with sediment-rich estuarine marshes. Salt marshes of both estuaries are dominated by *Spartina alterniflora*. An analysis was performed to characterize marsh hypsometry and tidal flooding characteristics, and a coring study was conducted to measure rates of mineral sediment accumulation, organic matter accumulation, and vertical accretion using ^{137}Cs and ^{210}Pb chronology at nine sites in both estuaries. Mineral sediment and organic matter accumulation rates were significantly higher in Delaware Bay marshes (sediment mean and 1σ: 2.57 ± 2.03 kg m^{-2} year^{-1}; organic: 0.65 ± 0.26 kg m^{-2} year^{-1}) than in Barnegat Bay (sediment: 0.31 ± 0.27 kg m^{-2} year^{-1}; organic: 0.29 ± 0.08 kg m^{-2} year^{-1}), as were rates of accretion (Delaware Bay: 0.79 ± 0.06 cm year^{-1}; Barnegat Bay: 0.28 ± 0.06 cm year^{-1}). Regression analysis indicated that marsh accretion rates were positively correlated with rates of sediment and organic accumulation, but the upper limit of accretion was governed by sediment accumulation. Tidal flooding frequency and duration did not correlate with marsh accumulation or accretion rates in either estuary, suggesting that hydroperiod is subordinate to sediment availability in governing rates on 50–100 year time scales. If true, natural and (or) human influences on suspended-sediment production and transport in these estuaries has potential to impact marsh accretionary status and stability, independent of sea-level rise.

1. Introduction

The classic conceptual model of salt marsh development involves tidal flooding of intertidal flats, organic matter production by halophytic vegetation, and allochthonous mineral sedimentation (Redfield, 1972). Describing and parameterizing these processes toward a predictive capability has become a universal goal in marsh ecology and geomorphology, in light of rapid and widespread loss of tidal wetlands worldwide (Nicholls et al., 1999). Numerous researchers have examined the relative contributions of mineral sediment and organic matter in marsh soils for insight on mechanisms of vertical accretion (Turner et al., 2000; Neubauer et al., 2002; Chmura and Hung, 2004; Nyman et al., 2006), whereas others have investigated linkages between measured accretion rates and biotic and abiotic factors of plant growth and sedimentation (French, 2006; Mudd et al., 2009). While there have been advances in salt marsh morphodynamics (e.g., Allen, 2000; Friedrichs and Perry, 2001; Fagherazzi et al., 2012), a general understanding of how rates of marsh sediment accumulation (*mass/area/time*) and accretion (*height/time*) vary with local conditions within a wetland complex versus those associated with regional coastal and estuarine dynamics has been elusive.

Characterization of salt marsh accretion dynamics has been attempted using hydrogeomorphic variables including tidal flooding frequency and duration, marsh platform elevation, distance to tidal water, and suspended sediment concentration. As first proposed by Pethick (1981), sediment accumulation and marsh accretion rates are influenced by the depth and duration of tidal flooding (hydroperiod) and marsh platform elevation such that longer hydroperiods promote sedimentation of particulates by gravitational settling. According to Pethick (1981) and furthered by French (1993), the rate of accretion decreases over time as the marsh builds elevation within the tidal frame, eventually reaching an equilibrium value that approaches the local rate of relative sea-level rise. In support of this simple model, a convincing inverse relationship between marsh elevation and short-term (tidal) sediment deposition rate has been found in some marshes (French and Spencer, 1993; Cahoon and Reed, 1995; Temmerman et

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al., 2003). However, not all marshes exhibit this pattern (van Proosdij et al., 2006), and the same can be concluded for the relationship between sediment deposition rate as a function of distance to the nearest source water (Hatton et al., 1983; Stoddart et al., 1989). In fact, there is evidence to suggest that a given marsh can exhibit different patterns of deposition depending on how and when sampling is conducted. For example, French and Spencer (1993) observed indirect *and* direct correlations between elevation and accretion rates for the same salt marsh sampled at different spatial and temporal scales. Connections between marsh hydroperiod and long-term (decades to centuries) rates of accumulation and accretion are more tenuous (Callaway et al., 1997; Chmura and Hung, 2004; Temmerman et al., 2004). For a Scheldt Estuary salt marsh, Oenema and DeLaune (1988) reported inverse *and* direct relationships between elevation and ^{137}Cs-based accretion rate for the same locations sampled at different times of the year. Hence, it can be concluded that the simple model of Pethick (1981) is not suitable for describing patterns and rates of accretion across the full range of tidal marshes.

Tidal marshes can be divided into coastal and estuarine subtypes on the basis of genesis, morphodynamics, vegetation, and soil properties (Darmody and Foss, 1979). Coastal marshes are found in bar-built or lagoon-type estuaries, either on the back-barrier or mainland shore of the lagoon, and form as a result of tidal and storm sedimentation (Nichols, 1989). On the U.S. Atlantic margin, coastal marshes are most often dominated by the halophytes *Spartina alterniflora* and *Spartina patens* emerging from sandy tidal flats and barrier overwash deposits. Estuarine marshes form in coastal plain estuaries on the flanks of tidal channels and creeks, and may range from salt marshes at the estuary mouth to tidal freshwater marshes at the head (Odum, 1988). Estuarine marshes exhibit a diverse range of marsh vegetation and platform morphology, and have soils enriched with sediments and organic matter derived from fluvial input, erosion within the estuary, and marine sources. Although outwardly similar in appearance, coastal and estuarine marshes have distinctive soil properties related to local hydrogeomorphic properties, vegetative growth factors, and larger scale estuarine dynamics (Darmody and Foss, 1979).

The objective of this study was to investigate relationships between marsh hydrogeomorphic setting, including topography, tidal flooding duration and frequency, estuarine sediment supply, and rates of sedimentation. To meet this objective, salt marshes in two contrasting estuaries on the U.S. Mid-Atlantic coast, Barnegat Bay and Delaware Bay, were investigated using identical methods. Barnegat Bay is a microtidal lagoon estuary with coastal marshes, whereas Delaware Bay is a micro–mesotidal sediment-rich coastal plain estuary with estuarine marshes. It was hypothesized that rates of mineral sediment accumulation and accretion in estuarine marshes of Delaware Bay were higher than in the coastal marshes of Barnegat Bay, because Delaware Bay has a larger suspended load of allochthonous mineral sediment along with a larger tidal range. To test this hypothesis, marsh topography and tidal flooding were characterized, and a coring study was conducted to quantify long-term rates of marsh sediment accumulation, organic matter accumulation, and vertical accretion using ^{137}Cs and ^{210}Pb chronology (50–100 year time scales). Barnegat Bay and Delaware Bay are located on the same segment of the U.S. Mid-Atlantic coast, minimizing variations in marsh accretionary processes related to regional oceanographic and climatic factors. Additionally, salt marshes in these estuaries are characterized by the same halophytic vegetation, reducing some of the variability associated with species-specific biotic factors. By elucidating internal versus external influences on marsh sedimentation rates, the findings of this study have potential to inform conceptual and numerical models of tidal marsh morphodynamics.

2. Study area

The Delaware Bay and Barnegat Bay-Little Egg Harbor estuaries are located in New Jersey (USA) and fall within the Atlantic Coastal Plain physiographic province (Fig. 1). Sea-level rise and coastal transgression following the Wisconsin deglaciation was a major influence on the development of estuaries and tidal wetlands in this region. Widespread expansion of coastal and estuarine marshes took place 6 ky partly in response to decelerating rates of eustatic sea level rise (Fletcher et al., 1990). Salt marshes became established on the present-day coast around 1–3 ky in response to relative sea-level rise and inundation of coastal lowlands (Fletcher et al., 1992; Oertel and Kraft, 1994). For the southern New Jersey coast and eastern Delaware Bay, the rate of relative sea-level rise between 2 ky and 1900 CE was 1.3 mm y^{-1}, and most of this was due to subsidence with relaxation of the proglacial forebulge (Horton et al., 2013; Nikitina et al., 2015). According to local tide gauge records, rates of relative sea-level rise are 3.4–4.6 mm y^{-1} (NOAA, 2013).

2.1. Delaware Bay Estuary

The Delaware Bay Estuary is a 2000 km^2 coastal plain estuary extending 215 km from the head of tide in Trenton, New Jersey, to the bay mouth at the Atlantic Ocean (Fig. 1). The estuary has a 35,000 km^2 watershed area with a suspended sediment load of ~1.3×10^6 ton y^{-1} (Mansue and Commings, 1974). Holocene transgression of the ancestral Delaware River valley along with landward migration of sediment depocenter contributed to the emergence of tidal wetlands that fringe the estuary and its numerous sub-estuaries (Fletcher et al., 1992). The upper-middle estuary floor is composed of mud and sandy mud, whereas the bay floor has a sand and gravelly sand bottom (Biggs and Beasley, 1988). The estuary exhibits classic gravitational circulation driven by freshwater outflow with seaward and landward mean flows in the upper and lower water column, respectively. Associated with the two-layer circulation is a broad turbidity maximum that serves as an internal source of fine-grained sediment to the estuary floor and fringing tidal wetlands (Cook et al., 2007). Suspended sediment concentrations within the turbidity maximum zone reach several 10 s to 100 s of mg l^{-1} (Sommerfield and Wong, 2011). Cross-estuary circulations along with shoaling wind waves contribute to high suspended-sediment concentrations over the broad subtidal flats flanking the axial channel (McSweeney et al., 2016).

Estuarine marshes selected for this study were located on the wetland coast of lower eastern Delaware Bay and are associated with the subestuaries Dividing Creek (DV), Maurice River (MR), and Dennis Creek (DN) (Fig. 1). These marshes are separated from the tidal wetlands by a narrow barrier beach and dominated by the halophyte *S. alterniflora*. In this area of Delaware Bay, the waters are shallow (<4 m depths) with a 1.6-m spring tidal range.

2.2. Barnegat Bay-Little Egg Harbor Estuary

The Barnegat Bay-Little Egg Harbor estuary is a 264 km^2 back-barrier, lagoon-type estuary on the coast of New Jersey (Fig. 1). The bay formed during the late Holocene (5–7 ky) following the development of wave-dominated barrier islands (Oertel and Kraft, 1994). The estuary is 67 km in length and separated from the Atlantic Ocean by a barrier island (Fig. 1). The estuary has a 1716 km^2 watershed with low freshwater and suspended sediment input (Hunchak-Kariouk and Nicholson, 2001). Tide water is exchanged through three inlets, the largest of which is the central Barnegat Inlet (Kennish, 2001). Transport of waterborne materials in the estuary is influenced by tides and local wind forcing (Defne and Ganju, 2015). Suspended sediment concentrations in the bay are on the order of a few to several 10 s of mg l^{-1} (Defne and Ganju, 2015), and the bay floor is composed of fine and medium sand (Psuty, 2004).

The salt marshes investigated were located in north and central Barnegat Bay at Reedy Creek (RC), Island Beach (IB), and Channel Creek (CC) (Fig. 1). Island Beach marsh, located on the back barrier island adjacent to Barnegat Inlet, was established on an overwash fan,