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

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Abstract (251 words)

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 hydrogeomorphology. 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 : $2.57 \pm 2.03 \text{ kg m}^{-2} \text{ y}^{-1}$; organic: $0.65 \pm 0.26 \text{ kg m}^{-2} \text{ y}^{-1}$) than in Barnegat Bay (sediment: $0.31 \pm 0.27 \text{ kg m}^{-2} \text{ y}^{-1}$; organic: $0.29 \pm 0.08 \text{ kg m}^{-2} \text{ y}^{-1}$), as were rates of accretion (Delaware Bay: $0.79 \pm 0.06 \text{ cm y}^{-1}$; Barnegat Bay: $0.28 \pm 0.06 \text{ cm y}^{-1}$). 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 y 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.

Keywords: salt marsh, lagoon estuary, coastal plain estuary, radionuclide geochronology

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, 2000; 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 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 sediment 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 tides and storms (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 higher 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 y 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 $3.4\text{--}4.6 \text{ mm y}^{-1}$ (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 $35,000 \text{ km}^2$ watershed area with a suspended sediment load of $\sim 1.3 \times 10^6 \text{ ton y}^{-1}$ (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 10s to 100s 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 1,716 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 10s 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, whereas the mainland marshes at Reedy Creek and Channel Creek emerged from muddy and sandy tidal flat deposits. As per the Delaware Bay marsh study sites, Barnegat Bay marshes are dominated by *S. alterniflora*. Spring tide range in the bay is 0.66 m.

3. Methods

3.1. Hydrogeomorphic analysis

To characterize marsh topography in the vicinity of the coring sites, recent (2008–2013) LIDAR-based digital elevation models (DEMs) produced by the United State Geological Survey (USGS) and the United States Army Corps of Engineers were retrieved from the online Digital Coast Data Access Viewer (<https://coast.noaa.gov/dataviewer/#>). The LIDAR point spacing, horizontal accuracy, and vertical accuracy was 0.5–1 m, 0.6–1 m, and 5.4–10 cm, respectively. From the DEMs a 0.03 km^2 area defined by a 100-m radius around each coring site was sampled, hereafter referred to as the “sample area”. For each sample area, hypsometric curves representing the percent area above a given elevation were generated following the methods of Luo (1998), and the area below mean tide level was masked to remove nearby marsh edges and waterways.

The resulting hypsometric curves are composed of 1000 points corresponding to the number of bins used in the cumulative frequency calculations. For each sample area, the hypsometric integral (HI), the area under the hypsometric curve, was calculated for each sample area as follows:

$$HI = \frac{h_{mean} - h_{min}}{h_{max} - h_{min}} \quad (1)$$

where h_{mean} is the mean elevation, h_{min} is the minimum elevation, and h_{max} is the maximum elevation. This index is a dimensionless number between 0 and 1 that represents the ratio between elevation and relief. Traditionally used to characterize erosional topography and drainage basin maturity, the hypsometric integral can be used as a relative value of slope steepness when comparing land areas (Strahler, 1952). Additionally, DEMs were used to identify the distance to the nearest tidal course from each coring location.

To characterize the tidal characteristics of the marshes, water-level data (6-minute data for 2000–2015) from five USGS gauges were analyzed (Fig. 1 and Table 2). Tidal flooding frequency, the number of times the marsh was flooded during the 15-year period, was calculated as the percentage of high water events exceeding the elevation of the coring site relative to the total number of high water levels. High water events were defined as the observed water level peak resulting from astronomical and meteorologically enhanced tides. Tidal flooding duration, the amount of time the marsh is covered with tide water, was calculated as the percentage of the total time the water height was equal to or in excess of the site elevation. Relative sea-level trends for the study area were obtained from NOAA tide gauging stations (NOAA, 2013): 8531680 (Sandy Hook, NJ), 8534720 (Atlantic City, NJ), 8536110 (Cape May, NJ), 8551910 (Reedy Point, DE), and 8557380 (Lewes, DE). Real-time kinematic (RTK) GPS elevations were taken at each coring site using a high-precision Leica ® Viva GS14 RTK system, with the

exception of MR-3 where LIDAR-based elevation was used. All elevations and water-levels are presented relative to NAVD88 (GEOID13).

3.2. Marsh core sampling

In summer 2012 three coring sites were selected in three different marsh systems within both estuaries (see Table 1 for geographic positions). At each site, one 15-cm diameter core 0.5–1 m in length was retrieved. In the laboratory, cores were extruded vertically and sectioned in 2-cm intervals. One half of each 2-cm soil interval was used in a related study of organic carbon accumulation (Unger et al., 2016), whereas the remaining half was used in this study for gravimetric analysis of soil properties and gamma-ray spectroscopy.

3.3. Soil physical properties

A total of 488 subsamples from the 18 cores were analyzed for soil physical properties. Water content, dry bulk density, and organic content were measured at 2-cm intervals. Water content (W) was determined gravimetrically from the wet and dry weights of oven-dried samples, and organic content was determined by loss-on-ignition (LOI) by combusting 4 g of sediment powder in a muffle furnace at 550°C for 4 hours (Heiri et al., 2001). Dry-bulk density (ρ_d) was computed after Bennett and Lambert (1971) as follows:

$$\rho_d = \frac{1-W}{\frac{W}{\rho} + \frac{1-W}{\rho_s}} \quad (2)$$

where ρ is the average density of pore fluid (1020 kg m⁻³), ρ_s is the density of unconsolidated solids, calculated as $(1-LOI \times 2610) + (LOI \times 1140)$. The values 2610 and 1140 were used as the average particle densities (kg m⁻³) of mineral and organic solids in salt marsh soils (Callaway et al., 1997).

3.4. Radionuclide measurements

Profiles of ^{137}Cs and excess ^{210}Pb ($^{210}\text{Pb}_{\text{xs}}$) activity were constructed from cores to determine rates of mass accumulation (mineral sediment and organic matter) and marsh accretion at the coring sites. These radionuclide chronometers average over 50-y (^{137}Cs) to 100-y ($^{210}\text{Pb}_{\text{xs}}$) time scales and thus provide longer-term estimates of accumulation and accretion than rates derived from sediment traps or marker beds. A total of 485 sample core were analyzed for 24 hours for ^{137}Cs , ^{210}Pb , and ^{214}Bi activity via gamma-ray spectroscopy using Canberra low-energy planar Germanium detectors. Activity efficiencies for marsh soil samples were determined by analysis of a natural matrix standard (SRM Rocky Flats Soil; Nour et al., 2008). The minimum detectable activity for ^{210}Pb and ^{137}Cs was 0.533 and 0.087 Bq, respectively. Uncertainties were calculated as the 1σ counting error. Activity of $^{210}\text{Pb}_{\text{xs}}$ was calculated by subtracting the ^{214}Bi activity, the ^{226}Ra -produced supported ^{210}Pb activity, from the total ^{210}Pb activity ($^{210}\text{Pb}_{\text{xs}} = ^{210}\text{Pb}_{\text{total}} - ^{214}\text{Bi}$). The $^{210}\text{Pb}_{\text{xs}}$ activity uncertainty was computed as the sum of ^{210}Pb and ^{214}Bi activity uncertainties. Because the cores were collected within a period of several weeks and the radionuclide analysis completed within a year of collection, decay corrections were not applied to the ^{210}Pb and ^{137}Cs activities.

3.5. Marsh accretion and mass accumulation rates

Rates of mass accumulation and accretion were computed by linear regression of the entire $^{210}\text{Pb}_{\text{xs}}$ activity-depth profile for the cores. At steady state $^{210}\text{Pb}_{\text{xs}}$ decreases exponentially with soil depth following:

$$A_z = A_0 e^{-\lambda z} \quad (3)$$

where A_z is the excess activity (Bq kg^{-1}) of $^{210}\text{Pb}_{\text{xs}}$ at depth z (m), A_0 is the initial activity at the core top, λ is the decay constant (0.0311 y^{-1}), and S is the accretion rate (cm y^{-1}). The corresponding mass accumulation rate ($\text{kg m}^{-2} \text{ y}^{-1}$) was computed by regression of $^{210}\text{Pb}_{\text{xs}}$ activity versus cumulative mass (kg m^{-2}), the product of dry bulk density and the interval thickness.

Mass accumulation and accretion rates were also computed from ^{137}Cs activity profiles using the activity peak as an indicator of maximum atmospheric fallout in 1963 (Ritchie and McHenry, 1990). The depth (or accumulated mass) of the activity peak divided by the time interval between the year of core collection (2012) and 1963 gives the accretion rate (or mass accumulation rate). Organic matter accumulation (OMA in kg m^{-2}) averaged since 1963 were determined as follows:

$$OMA = \sum_{i=0m}^{1963 \text{ depth}} (OM_i \cdot \rho_{di} \cdot x_i) \quad (4)$$

where OM_i is the mass concentration ($\text{kg organic matter/kg soil sample}$) of combustible organic matter ($LOI/100$) for the i th depth interval, ρ_d is the dry bulk density (kg m^{-3}), and x_i is the interval thickness (m). Similarly, mineral sediment accumulation (MSA in kg m^{-2}) were calculated according to:

$$MSA = \sum_{i=0m}^{1963 \text{ depth}} (MM_i \cdot \rho_{di} \cdot x_i) \quad (5)$$

where MM_i is the mass concentration ($\text{kg mineral matter/kg soil sample}$) of incombustible solids ($((1-LOI)/100)$) for the i th depth interval, and the other terms are described above. Implicit in ^{210}Pb and ^{137}Cs dating methods are the following assumptions: 1) particle mixing by burrowing organisms has not altered the initial age-depth relationship; 2) the radionuclide is chemically immobile; and 3) the sedimentary record is complete and not punctuated by significant non-depositional or erosional episodes. As discussed later these assumptions were verified in this study.

To identify differences in marsh soil properties and accretion and accumulation within and between the two estuaries, two-sample t-tests ($\alpha = 0.05$) were conducted. While the hierarchical design of this study may lend itself to a nested analysis of variance approach to hypotheses testing, a two-sample t-test is both simpler and, for this design, mathematically equivalent (e.g., Murtaugh, 2007). Rates of mass accumulation and accretion derived using ^{137}Cs and $^{210}\text{Pb}_{\text{xs}}$ methods were compared using paired t-tests. Normality was achieved using simple log or inverse transformations, if necessary. All analyses were conducted using the *R* stats package (<http://cran.r-project.org/>).

4. Results and Interpretation

4.1. Marsh hydrogeomorphic characteristics

Tidal flooding frequency and duration curves derived for the Delaware Bay and Barnegat Bay study areas are shown in Fig. 2. The Delaware Bay coring locations fell in the mid- to upper tidal frame whereas those in Barnegat Bay fell within a broader range. Average flooding frequency were similar at 74 ± 18 % and 76 ± 13 % (error = 1σ and $n=9$) for Delaware Bay and Barnegat Bay, respectively, but flooding duration was less similar at 20 ± 9 % and 44 ± 25 %, respectively (Table 2). The steeper slope of the flooding duration curve in Barnegat Bay suggests that those marshes flood faster and/or drain slower than those in Delaware Bay.

In the Delaware Bay marshes, an average of 45 ± 30 % of the LIDAR sample area was below the mean high water (MHW) datum determined from the water-level records (Fig. 3). By comparison, an average of 25 ± 11 % of the marsh sample area was below MHW in Barnegat Bay (Fig. 4). The LIDAR-based hypsometric curves revealed that the coring sites in Barnegat Bay fell within a smaller range of elevations than those in Delaware Bay, and that there was

considerably more topographic variability within and among the Delaware Bay coring sites (Figs. 3 and 4). This topographic variation is supported by values of hypsometric integral computed from the curves, which indicate mean values of 0.55 ± 11 and 0.40 ± 0.21 for the Delaware Bay and Barnegat Bay sample areas, respectively (Table 2). In both estuaries tidal flooding duration and hypsometric integral were inversely correlated (Fig. 5), suggesting that marsh areas with more relief are covered with tide water for shorter periods of time. Although marshes in both study areas have similar flooding frequencies, Delaware Bay marshes have shorter hydroperiods, flooding slower and draining faster than Barnegat Bay marshes.

4.2. Marsh soil properties

Down-core values of marsh soil water content, *LOI*, and density were similar in marsh soils from both estuaries (Table 1). Overall, water content was 60–87 % and 70–82 %, *LOI* was 14–52 % and 26–45 %, and dry bulk density was $150\text{--}517 \text{ kg m}^{-3}$ and $195\text{--}359 \text{ kg m}^{-3}$ in soils from Delaware Bay and Barnegat Bay, respectively. Marsh soil from Barnegat Bay had a higher density of organic matter than mineral sediment, whereas Delaware Bay marsh soils had a higher density of mineral sediment.

Soil volume composition was used to examine the relative contribution of mineral sediment and organic matter to the total volume, because volume is more closely related to soil structure and marsh accretion than soil mass. In all core samples the volume of marsh soil was mostly water volume (>80 %) with considerably lesser amounts mineral and organic solids (Table 1). Representative volume profiles for cores from both estuaries are shown in Figure 6. Mineral sediment comprised a larger fraction of the soil volume in the Delaware Bay marshes compared to Barnegat Bay, but the volume of organic matter was comparable in soils from both

estuaries (Fig. 6). Hence, soils of estuarine marshes in Delaware Bay are more minerogenic than the comparatively organogenic soils of Barnegat Bay coastal marshes, which is broadly consistent with the physiographic soils classification scheme of Darmody and Foss (1979).

4.3. Marsh accretion and mass accumulation rates

A ^{137}Cs activity peak, corresponding to maximum atmospheric fallout in 1963, was present in all cores with the exception of MR-3 (Fig. 7). In all cores ^{137}Cs was detectable in the uppermost sample (0–2 cm), which, given that global fallout has been negligible since about 1990, suggests that there are sources of legacy ^{137}Cs in the study areas. These sources may include wash-in of ^{137}Cs -laden soils from watershed and sediment eroded from marsh edges and redeposited on the marsh platform. The ^{137}Cs activity peaks are distinct and suggest that these profiles have not been subjected to significant physical or biological mixing. The depth of the ^{137}Cs peak in cores ranged from 9 to 51 cm, which equates to accretion rates of 0.19 to 1.06 cm y^{-1} (Table 3). Overall, accretion rates averaged 0.70 cm y^{-1} ($n=8$) and 0.28 cm y^{-1} ($n=9$) for Delaware Bay and Barnegat Bay, respectively.

Profiles of $^{210}\text{Pb}_{\text{xs}}$ activity were used to calculate accretion rates for the eighteen cores following Eq. 3 (Fig. 8). With a few exceptions activities decreased monotonically with depth in the soil profile, and the linear regressions were significant ($p<0.05$) with correlation coefficients of $r^2=0.52\text{--}0.94$ (Fig. 8). Accretion rates averaged 0.81 cm y^{-1} ($n=9$) and 0.28 cm y^{-1} ($n=9$) for Delaware Bay and Barnegat Bay marshes, respectively (Table 3). There was no significant difference in at-site rates of accretion determined by ^{137}Cs and $^{210}\text{Pb}_{\text{xs}}$ chronometry (paired t-test, $t(16)=-0.55$, $p=0.59$). Marsh accretion rates in Delaware Bay were more spatially variable than in Barnegat Bay marshes, presumably due to the relatively larger spatial variation in mineral

sediment and organic matter accumulation. Overall, the radionuclide-based accretion rates measured in this study are comparable to similarly determined rates for other salt marsh systems in the U.S. Mid-Atlantic region (Kraft et al., 1992; Velinsky et al., 2011; Kemp et al., 2013; Nikitina et al., 2014).

Mineral sediment and organic matter accumulation rates determined by ^{137}Cs chronometry averaged $2.1 \text{ kg m}^{-2} \text{ y}^{-1}$ and $0.60 \text{ kg m}^{-2} \text{ y}^{-1}$, respectively, for Delaware Bay marshes and $0.31 \text{ kg m}^{-2} \text{ y}^{-1}$ and $0.29 \text{ kg m}^{-2} \text{ y}^{-1}$, respectively, for marshes in Barnegat Bay (Table 3). Sediment and organic accumulation rates based on $^{210}\text{Pb}_{\text{xs}}$ chronometry were similar, averaging $2.7 \text{ kg m}^{-2} \text{ y}^{-1}$ and $0.63 \text{ kg m}^{-2} \text{ y}^{-1}$, respectively, for Delaware Bay and $0.56 \text{ kg m}^{-2} \text{ y}^{-1}$ and $0.27 \text{ kg m}^{-2} \text{ y}^{-1}$ for Barnegat Bay. As was the case with accretion rates, there was no significant difference in at-site rates of sediment (paired t-test, $t(16)=1.37$, $p=0.19$) and organic (paired t-test, $t(16)=0.95$, $p=0.35$) accumulation derived by ^{137}Cs and $^{210}\text{Pb}_{\text{xs}}$ chronometry.

Regression analysis was used to investigate relationships among marsh accretion rates, elevation, and distance from the nearest tidal waterway, the presumed sediment source. Previous studies have shown an inverse relationship between short-term accretion and these geomorphic variables that were interpreted to signify that tidal flooding potential and proximity to sediment sources are strong controls on accretion (French and Spencer, 1993; Cahoon and Reed, 1995; Temmerman et al., 2003). For the long-term rates presented here, no inverse relationship between accretion and distance to tidal water (Fig. 9a) or elevation (Fig. 9b) was found. Similarly, regression of mineral accumulation with distance to tidal water (Fig. 9c) or elevation (Fig. 9d) did not yield an inverse relationship. However, in Barnegat Bay, a direct relationship was observed for accretion and mineral accumulation as well as accretion and distance to tidal water and elevation (Fig. 9).

4.4. Inter-estuary comparison

A goal of this study was to determine if sedimentation rates were significantly different between the two estuaries using simple statistical tests. This was accomplished using a balanced experimental design (*estuary* → *marsh* → *coring location*) and an aggregated, two-sample t-tests. This design accounts for inter-estuary variability observed in the marshes while comparing the rates from Delaware Bay to Barnegat Bay. The ^{137}Cs -based accretion and accumulation rates were used for these tests except for core MR-3, which did not exhibit a ^{137}Cs activity peak; instead, the $^{210}\text{Pb}_{\text{xs}}$ -based rates were used. Test results indicated that mean rates of marsh accretion ($t(4) = -3.79$, $p = 0.019$), mineral sediment accumulation ($t(4) = -3.41$, $p = 0.027$), and organic matter accumulation ($t(4) = -2.87$, $p = 0.045$) were significantly different between the two estuaries. This finding suggests that at least some coastal plain and lagoon-type estuaries may exhibit different rates of marsh accretion associated with higher rates of sediment and organic matter accumulation in estuarine-type marshes of coastal plain estuaries.

5. Discussion

5.1. Feedbacks between mass accumulation and accretion

Regression-based relationships between marsh accretion and mineral sediment and organic matter accumulation are frequently used for insight on biotic and abiotic processes of soil formation (Callaway et al., 2012; Chmura and Hung, 2004; Nyman et al., 2006; Turner et al., 2000). In the present study, accumulated mass and accretion were strongly correlated in marshes of both estuaries (Fig. 10a,b). For Delaware Bay marshes, variation in accumulated mineral sediment and organic matter explained 94% of the variation in marsh accretion rate compared to

60–69% for marshes in Barnegat Bay (Fig. 10a,b). Whereas mineral sediment explained more of this variation for Barnegat Bay marshes, both mineral sediment and organic matter explained variations in accretion similarly in Delaware Bay. Based on the trendline slopes, marsh accretion in Delaware Bay was relatively more sensitive to variations in mineral and organic accumulation. Hence, although organic matter accumulation clearly influences vertical accretion rate in these marshes, the upper limit of accretion is set by the rate of mineral sediment accumulation. These results are broadly consistent with relationships reported for U.S. Gulf Coast (Turner et al., 2000; Nyman et al., 2006) and West Coast tidal marshes (Callaway et al., 2012).

There were statistically significant correlations between accumulated mineral and organic mass in Delaware Bay and Barnegat Bay (Fig. 10c). This relationship likely signifies a biogeomorphic feedback between mineral sedimentation and plants on the marsh platform, a well-known process that has been incorporated in numerical models of tidal marsh sedimentation (Fagherazzi et al., 2012). Feedbacks associated with aboveground plant biomass include reduction of flow velocity and direct capture of suspended matter by the canopy leading to increased mineral sedimentation (Gleason et al., 1979; Nepf, 1999). Other feedbacks between plants and mass accumulation could include any or all of the following: reduced surface-sediment resuspension by root encapsulation (Langlois et al., 2001), increased soil shear strength and erosion resistance by roots (Watts et al., 2003), root growth stimulated by nutrient-rich sediment (DeLaune et al., 1981; Mendelssohn and Kuhn, 2003), and enhanced upward growth to prevent burial (Deng et al., 2008; Langlois et al., 2001). Soil organic matter in the *S. alterniflora* marshes in this study was composed of almost exclusively belowground biomass in the form root and rhizome material as opposed to leaves and stems (Unger et al., 2016), and sedimentation may have enhanced root growth (Boorman et al., 2001). In Barnegat Bay, the weaker

relationship between accumulated mineral sediment and organic matter may have been associated with the relatively low range of sedimentation rates (Fig. 10c).

5.2. *Hydrogeomorphic controls on sediment accumulation and accretion*

Results of this comparative study make clear that mineral sediment availability associated estuarine geomorphic setting has a major influence on sediment accumulation rates which may lead to differences in accretion rates between coastal and estuarine marshes. The notion that mineral sediment accumulation and accretion are inversely related to marsh elevation and distance to the nearest tidal waterway was not supported by the results of this study. The lack of an inverse relationship in this study suggests that tidal sediment delivery and flooding are not dominant controls on accretion and accumulation at the decadal scale. Interestingly, the pattern in Barnegat Bay suggests that accretion and accumulation *increases* with distance from tidal water and elevation (Fig. 9). This relationship could be indicative of flood-induced stress affecting biological production (Snedden et al., 2015), and, consequently, through the biophysical feedback between sediment trapping and accretion.

For example, Barnegat Bay marshes are flooded at similar frequencies but for longer durations than marshes in Delaware Bay, implying that they have greater potential to accumulate mineral sediment, all other factors equal. Accumulation of sediment should be highest at sites that fall lowest within the tide frame where longer duration of flooding creates the longest time available for deposition. However, an inverse relationship between mineral sediment accumulation and marsh elevation was not found in this study. Rates of sediment accumulation were 2–3 times higher in Delaware Bay marshes than in Barnegat Bay, which, lacking a relationship with tidal flooding frequency or duration, implies that higher tidal depositional

fluxes are responsible for the higher rates of accumulation and accretion on the long term. The higher sediment accumulation rates in Delaware Bay marshes are a reflection the larger resident suspended inventory of the bay, along with its higher tide range and wind-wave energy available to resuspend and transport sediment from estuary to marsh.

The lack of a relationship between the previously discussed hydrogeomorphic variables and long-term rates of accumulation and accretion could be attributed to episodic sediment deposition. In U.S. Atlantic-coast marshes, patterns rates of fair-weather sediment deposition are overprinted by the effects of meteorologically enhanced tides, particularly extratropical storms such as northeasters, which flood the marsh platform with high-turbidity water (Moskalski and Sommerfield, 2013; Roman and Daiber, 1984; Stumpf, 1983). In estuaries, episodic deposition during storm events can explain the large difference between short-term and longer averages of sediment accumulation measured by marker beds and radionuclide chronology, respectively (Sommerfield, 2006), and this general condition can be extended to tidal marshes. Hence, numerical models of marsh sedimentation that do not account for episodic deposition by storms are not likely to produce realistic estimates of long-term sediment accumulation, marsh accretion, and elevation change.

5.3. Marsh accretion and relative sea-level rise

While geographically proximal, Delaware Bay and Barnegat Bay represent endmember estuarine environments with regard to salt marsh stability and adaptability in the face of climatic and anthropogenic impacts. Part of the distinction is related to the large difference in marsh sediment accumulation and accretion rates (Table 3). In an assessment of U.S. Mid-Atlantic marsh vulnerability to sea-level rise, Reed et al. (2008) concluded that many marshes may

convert to open water should rates accelerate in the future. To address inundation potential, accretion rates measured for this study were compared to rates of local relative sea-level rise (Fig. 11). This comparison is reasonable given that radionuclide-based rates of accretion average over the same timespan (50–100 y) as the gauged record of sea level. However, it assumes that the marsh landscape and tide gauges are subsiding at the same rate, when in fact differential subsidence associated with different processes and on different time scales (i.e., crustal isostatic adjustment, compaction of marsh soil) can lead to local differences (Cahoon, 2015).

At current rates of local relative sea-level rise ($3.4\text{--}4.6\text{ mm y}^{-1}$), the Barnegat Bay marshes examined in this study are at risk of inundation, and more so if sea-level rise were to accelerate in the future (Fig. 11). In contrast, the Delaware Bay marshes are accreting at to above rates of relative sea-level rise and do not appear to be in jeopardy of submergence at current rates. In a review of marsh accretion and elevation change for US Atlantic and Gulf coast tidal marshes, Kirwan et al. (2016) contend that an assessment of marsh sustainability based on compared accretion and sea-level rise rates overestimate vulnerability as it does not take into account landward migration of the marsh and biophysical feedbacks between plant growth and sedimentation. However, such feedbacks require a minimum level of mineral sediment input, which may not exist in some salt marsh systems.

In the case of Barnegat Bay, marsh accretion rates are at or below current rates of relative sea-level rise, partly as a consequence of low rate of sediment accumulation. Being primarily organogenic, these marshes will be prone to reduced plant productivity due to water logging associated with land subsidence and sea-level inundation (Kirwan et al., 2010; Snedden et al., 2015) relative to the rapidly accreting minerogenic marshes in Delaware Bay. The paucity of suspended sediment in the Barnegat Bay estuarine system fundamentally limits the ways in

which the marshes can adjust to increases in tidal flooding frequency and duration, and sea-level rise on the long term. Based on the findings of this study, it can be concluded that accretion deficits that cannot be offset by increased organic accumulation must be accompanied by increased sediment accumulation to avert marsh submergence (Fig. 10c).

An increase in marsh accretion in Barnegat Bay marshes must be accompanied by an increase in allochthonous sediment supply, but this is unlikely as 36% of the shoreline is hardened and 70% of the landward buffer developed (Lathrop Jr. and Bogner, 2001). On the other hand, given that much of the sediment in salt marshes is produced by wind-wave erosion of the marsh edge, if a period of accelerated sea-level rise is met by an increase in the magnitude and frequency of coastal storms, elevated rates of marsh edge erosion could provide the sediment required to maintain accretion in landward marshes (e.g., French, 2006; Mariotti and Carr, 2014).

6. Conclusions

In this study, rates of mineral and organic accumulation in estuarine marshes of Delaware Bay and coastal marshes of Barnegat Bay were determined via ^{137}Cs and $^{210}\text{Pb}_{\text{xs}}$ radionuclide methods to gain insight on accretionary dynamics with regard to estuarine geomorphic setting. Sediment accumulation and accretion rates were significantly higher in Delaware Bay marshes ($2.57 \pm 2.03 \text{ kg m}^{-2} \text{ y}^{-1}$ and $0.79 \pm 0.06 \text{ cm y}^{-1}$) than those in Barnegat Bay ($0.31 \pm 0.27 \text{ kg m}^{-2} \text{ y}^{-1}$ and $0.28 \pm 0.06 \text{ cm y}^{-1}$). This difference is a direct reflection of estuarine geomorphic setting, i.e., a sediment-rich, mesotidal coastal plain estuary versus a sediment-limited, microtidal lagoon estuary, and will factor into the ability of the marshes to adjust to sea-level rise and human pressures. Accretion rates in marshes of both estuaries correlated with rates of organic matter and mineral sediment accumulation, as has been observed in other salt marsh systems. However,

sediment accumulation and accretion rates did not exhibit an inverse relationship with marsh elevation or distance to nearest sediment source, as is commonly assumed in conceptual models of salt marsh sedimentation. Hence, it would appear that marsh sediment accumulation and accretion on timescales of 50–100 y are less influenced by elevation and tidal hydroperiod than mineral sediment availability in contiguous estuarine waters.

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Figure Captions

Figure 1. Map of the U.S. central Mid-Atlantic coast showing the locations of the (A) Delaware Bay and (B) Barnegat Bay estuaries. The six marsh systems studied are shown in solid-lined boxes. See Table 1 and Figures 3 and 4 for core locations. The USGS tide gauges referred to in the text are numbered (1 = Maurice River at Bivalve (01412150), 2 = Sluice Creek near South Dennis (01411435), 3 = Little Egg Inlet near Tuckerton (01409335), 4 = Barnegat Bay at Waretown (01409110), 5 = Barnegat Bay at Mantoloking (01408168)). Tidal marshland is denoted by gray shading (USFWS, 2010).

Figure 2. Plots of marsh flood frequency (A) and duration (B) versus elevation for Delaware Bay and Barnegat Bay study areas. The curves were produced using 6-minute water level records (2000–2015) for the USGS tide gauges listed in the legend.

Figure 3. Elevation maps and hypsometric curves for the Delaware Bay marsh systems. The horizontal extent of each map corresponds to the solid bounding boxes in Fig. 1. The hypsometric curves were computed from elevations within a 100 m radius of each coring site, which are numbered 1–3 in the maps and plotted as solid circles on the curves. Mean high water (MHW) was calculated as the average of high waters from the nearest USGS tide gauge shown in Fig. 1. and listed in Table 2.

Figure 4. Elevation maps and hypsometric curves for the Barnegat Bay marsh systems. The horizontal extent of each map corresponds to the solid bounding boxes in Fig. 1. The hypsometric curves were computed from elevations within a 100 m radius of each coring

location, which are numbered 1–3 in the maps and plotted as a solid circles on the curves. Mean high water (MHW) was calculated as the average of high waters from the nearest USGS tide gauge shown in Fig. 1. and listed in Table 2.

Figure 5. Scatterplot of tidal flooding duration versus the hypsometric integral, the elevation relief ratio for a given site. For both the Delaware Bay (blue) and Barnegat Bay (red) marsh sites, there was an inverse relationship between flood duration and hypsometric integral. See text for further description.

Figure 6. Representative marsh soil profiles for the Delaware and Barnegat bay estuaries showing the volumetric contributions of mineral sediment, organic matter, and water-filled pore space to the total soil volume. The location of the 1963 year-depth is marked by a dashed line. Inventories of mineral sediment and organic matter relative to 1963 are calculated by dividing mass accumulation divided by accretion using the values presented in Table 3.

Figure 7. Depth profiles of ^{137}Cs activity for Delaware and Barnegat bay marsh cores. The dashed line represents the 1963 activity peak used to calculate accretion and mass accumulation rates (Table 3). Note that a ^{137}Cs activity peak was not present in the profile for core MR-3.

Figure 8. Depth profiles of $^{210}\text{Pb}_{\text{xs}}$ for the Delaware and Barnegat bay marsh cores. The dashed line is based on the least-squares regression used to calculate accretion and accumulation rates (Table 3). The coefficient of determination for each regression is shown.

Figure 9. Scatterplots of accretion versus distance to tide water (A) and surface elevation (B) and mineral sediment accumulation versus distance to tide water (C) and surface elevation (D) for the Delaware Bay (blue) and Barnegat Bay (red) marsh sites. While these regressions for Barnegat Bay marsh sites were found to be significant, no significant relationship was found for Delaware Bay marsh sites. Note that the accretion and sediment accumulation rates are referenced to the ^{137}Cs 1963 age-depth horizon in cores.

Figure 10. Scatterplots of accretion rate versus accumulated mineral mass (A) and accumulated organic mass (B), and accumulated mineral mass versus accumulated organic mass (C) for the Delaware Bay (blue) and Barnegat Bay (red) marsh sites. Note that the accretion rates and accumulated mass values are referenced to the ^{137}Cs 1963 age-depth horizon in cores.

Figure 11. Range of accretion rates for the Delaware Bay and Barnegat Bay marsh sites plotted with the range (cm y^{-1}) of relative sea level rise (RSLR) reported for nearby NOAA tide gauges. See text for further discussion.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Table 1

Table 1. Location, length, and physical properties for cores collected for this study. Standard deviation of the down-core mean is shown in parentheses.										
Estuary	Marsh system	Core	Latitude (DMS, N)	Longitude (DMS, W)	Core length (cm)	Water content (% mass)	LOI (% solid mass)	Bulk density (kg m ⁻³)	Organic density (kg m ⁻³)	Mineral density (kg m ⁻³)
Delaware Bay	Dennis Creek (DN)	1	39° 10' 18.46"	74° 52' 32.80"	50	80 (8)	42 (10)	219 (106)	82 (20)	137 (89)
		2	39° 10' 34.41"	74° 51' 43.84"	60	73 (3)	26 (3)	315 (48)	81 (10)	233 (42)
		3	39° 10' 51.83"	74° 50' 19.04"	62	70 (4)	22 (4)	354 (69)	75 (6)	279 (71)
	Dividing Creek (DV)	1	39° 13' 31.09"	75° 06' 27.67"	76	73 (4)	23 (4)	295 (53)	69 (12)	227 (50)
		2	39° 13' 56.52"	75° 06' 59.90"	60	72 (5)	25 (7)	326 (83)	77 (9)	249 (80)
		3	39° 14' 25.89"	75° 06' 12.80"	60	87 (3)	52 (6)	150 (32)	78 (14)	72 (22)
	Maurice River (MR)	1	39° 14' 32.30"	75° 00' 40.59"	74	60 (1)	16 (3)	517 (28)	84 (18)	433 (33)
		2	39° 15' 58.79"	74° 59' 45.43"	78	61 (4)	15 (3)	494 (68)	74 (8)	420 (72)
		3	39° 17' 00.47"	74° 59' 10.15"	76	61 (2)	14 (1)	492 (42)	72 (5)	420 (43)
	Channel Creek (CC)	1	39° 37' 35.10"	74° 15' 25.70"	42	70 (6)	26 (9)	359 (101)	88 (14)	270 (105)
		2	39° 37' 44.45"	74° 15' 27.95"	52	72 (7)	31 (9)	301 (90)	89 (16)	212 (91)
		3	39° 37' 58.70"	74° 15' 33.10"	42	71 (6)	28 (9)	335 (92)	88 (12)	247 (96)
Barnegat Bay	Island Beach (IB)	1	39° 47' 55.35"	74° 06' 08.90"	46	82 (3)	44 (14)	198 (43)	84 (16)	113 (47)
		2	39° 47' 57.49"	74° 06' 05.92"	74	73 (12)	38 (16)	253 (94)	83 (11)	171 (96)
		3	39° 47' 58.74"	74° 05' 57.66"	42	79 (4)	44 (19)	226 (54)	95 (34)	131 (71)
	Reedy Creek (RC)	1	40° 01' 49.35"	74° 04' 44.37"	42	82 (6)	45 (9)	195 (79)	82 (17)	113 (65)
		2	40° 01' 43.86"	74° 05' 03.67"	64	75 (10)	40 (16)	269 (137)	89 (14)	180 (131)
		3	40° 01' 51.80"	74° 05' 09.39"	42	79 (9)	45 (16)	233 (123)	88 (6)	146 (119)

Table 2

Table 2. Hypsometric and tidal flooding characteristics for the marsh coring sites. See Fig. 1 for names and location of tide gauges used to calculate flooding characteristics. Lidar elevations used in calculation of the hypsometric integral (HI) were from the USGS and USACE and were retrieved from the Digital Coast Data Access Viewer (<https://coast.noaa.gov/dataviewer/#>).

Estuary	Marsh system	Core	Elevation, RTK-GPS (m NAVD88)	HI	Flooding frequency (%)	Flooding duration (%)	USGS Tide Gauge
Delaware Bay	Dennis Creek	1	0.733	0.64	59	13	2
		2	0.757	0.71	51	11	
		3	0.514	0.36	95	34	
	Dividing Creek	1	0.871	0.59	49	9	1
		2	0.657	0.53	81	20	
		3	0.629	0.59	84	21	
	Maurice River	1	0.679	0.60	78	19	1
		2	0.352	0.49	98	35	
		3	0.724 ^a	0.44	72	16	
Barnegat Bay	Channel Creek	1	0.279	0.71	80	25	3
		2	0.284	0.66	80	24	
		3	0.312	0.60	76	22	
	Island Beach	1	0.083	0.27	73	46	4
		2	0.146	0.29	57	30	
		3	0.126	0.39	62	35	
	Reedy Creek	1	0.104	0.24	71	46	5
		2	-0.103	0.11	96	88	
		3	-0.070	0.30	94	84	

^a Lidar-based

Table 3

Table 3. Summary of accretion, mineral sediment accumulation (MSA), and organic matter accumulation (OMA) rates determined using ^{137}Cs and excess ^{210}Pb ($^{210}\text{Pb}_{\text{xs}}$) methods for this study. The ^{137}Cs rates were based on the 1963 year-depth corresponding to peak ^{137}Cs activity.								
Estuary	Marsh system	Core	^{137}Cs			$^{210}\text{Pb}_{\text{xs}}$		
			Accretion (cm y^{-1})	MSA ($\text{kg m}^{-2}\text{y}^{-1}$)	OMA ($\text{kg m}^{-2}\text{y}^{-1}$)	Accretion (cm y^{-1})	MSA ($\text{kg m}^{-2}\text{y}^{-1}$)	OMA ($\text{kg m}^{-2}\text{y}^{-1}$)
Delaware Bay	Dennis Creek	1	0.44	1.01	0.44	0.41	0.57	0.34
		2	0.77	1.87	0.66	0.66	1.57	0.54
		3	0.77	1.83	0.62	1.19	3.37	0.91
	Dividing Creek	1	0.44	1.12	0.38	0.68	1.54	0.48
		2	0.81	2.29	0.63	-	-	-
		3	0.35	0.31	0.33	0.28	0.21	0.22
	Maurice River	1	0.94	4.05	0.89	1.06	4.66	0.90
		2	1.06	4.20	0.83	1.03	4.38	0.77
		3	-	-	-	1.52	6.47	1.10
	means $\pm 1\sigma$		0.70 $\pm$ 0.26	2.08 $\pm$ 1.40	0.60 $\pm$ 0.20	0.81 $\pm$ 0.41	2.66 $\pm$ 2.15	0.63 $\pm$ 0.30
Barnegat Bay	Channel Creek	1	0.31	0.57	0.34	0.31	0.86	0.28
		2	0.35	0.72	0.38	0.42	0.91	0.38
		3	0.35	0.59	0.36	0.40	1.01	0.36
	Island Beach	1	0.31	0.21	0.31	0.30	0.35	0.26
		2	0.27	0.15	0.25	0.29	0.50	0.24
		3	0.23	0.15	0.36	0.27	0.36	0.26
	Reedy Creek	1	0.23	0.19	0.21	0.28	0.32	0.24
		2	0.19	0.11	0.16	0.23	0.42	0.21
		3	0.27	0.15	0.24	0.17	0.25	0.15
	means $\pm 1\sigma$		0.28 $\pm$ 0.06	0.31 $\pm$ 0.24	0.29 $\pm$ 0.08	0.30 $\pm$ 0.08	0.55 $\pm$ 0.29	0.27 $\pm$ 0.07