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The effect of vegetation height and biomass on the sediment budget of a European saltmarsh

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ABSTRACT

Sediment retention in saltmarshes is often attributed to the presence of vegetation, which enhances accretion by slowing water flow, reduces erosion by attenuating wave energy and increases surface stability through the presence of organic matter. Saltmarsh vegetation morphology varies considerably on a range of spatial and temporal scales, but the effect of different above ground morphologies on sediment retention is not well characterised. Understanding the biophysical interaction between the canopy and sediment trapping *in situ* is important for improving numerical shoreline models. In a novel field flume study, we measured the effect of vegetation height and biomass on sediment trapping using a mass balance approach. Suspended sediment profilers were placed at both openings of a field flume built across-shore on the seaward boundary of an intertidal saltmarsh in the Dengie Peninsula, UK. Sequential removal of plant material from within the flume resulted in incremental loss of vegetation height and biomass. The difference between the concentration of suspended sediment measured at each profiler was used to determine the sediment budget within the flume. Deposition of material on the plant/soil surfaces within the flume occurred during flood tides, while ebb flow resulted in erosion (to a lesser degree) from the flume area, with a positive sediment budget of on average 6.5 g m^{-2} $tide^{-1}$ with no significant relationship between sediment trapping efficiency and canopy morphology. Deposition (and erosion) rates were positively correlated to maximum inundation depth. Our results suggest that during periods of calm conditions, changes to canopy morphology do not result in significant changes in sediment budgets in marshes.

1. Introduction

The balance between sea level rise and rates of sediment accretion is a key research question in the broader debate as to whether or not marsh surfaces will be able to keep up with near-future accelerated sea level rise (Orson et al., 1985; Kirwan et al., 2010). Sea level rise poses a threat to intertidal saltmarshes due to seawater inundation beyond the physiological tolerance of the vegetation. However, the ability of marshes to accrete vertically through sediment trapping and root growth allows them to maintain their position in the tidal frame as it is translated upwards, promoting their long-term stability and survival (Morris et al., 2002; French, 2006; McIvor et al., 2013). It has been argued that the presence of vegetation enhances sedimentation on saltmarsh platforms both by attenuating wave energy and slowing water flow (Boorman et al., 1998; Temmerman et al., 2005) and by preventing the resuspension of deposited sediments on, and the direct erosion of, saltmarsh surfaces (Fagherazzi et al., 2012).

The presence or absence of vegetation, as well as vegetation parameters such as height and biomass are thought to be key factors in determining rates and patterns of sediment trapping and deposition, although this relationship is non-linear (Nardin and Edmonds, 2014) and may be dependent on wave and flow conditions. The importance of vegetation structure in marsh functioning is well recognised but its incorporation in realistic representations of the interactions between vegetation and sedimentation is complicated by the immense variability in canopy structure on a range of scales. Marsh vegetation shows great inter-specific variability in stem flexibility (Tempest et al., 2015; Rupprecht et al., 2017) affecting plant-flow interactions and sedimentation. Furthermore, marsh vegetation is regularly subjected to both

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emergent and submerged states and, in the case of the latter, to both ‘normal’ and extreme ‘storm surge’ flow regimes. Vegetation height and biomass varies both spatially and temporally on European saltmarshes. Such canopy characteristics vary with intertidal elevation (Silvestri et al., 2005) and with the seasons. Communities are typically composed of a combination of perennial and annual species with little above ground presence during winter (Watkinson and Davy, 1985) when annual species are absent and perennial saltmarsh species biomass is also much reduced (Hussey and Long, 1982; De Leeuw et al., 1990). Biomass reaches a peak at the end of the northern summer growing season (De Leeuw et al., 1990). In the longer term, saltmarsh canopy height and biomass vary as a function of climate change (Arp et al., 1993; Reef et al., 2016) and eutrophication (Deegan et al., 2007).

While slower flow rates in vegetated areas enhance particle settlements and thus deposition (Neumeier and Amos, 2006), the movements of plants when acted on by waves and currents can scour the surface and significantly enhance erosion, particularly in the pioneer zone and along marsh seaward margins (Temmerman et al., 2007; Feagin et al., 2009). Sheehan and Ellison (2015) observed significantly lower accretion and higher erosion rates immediately following the complete removal of a saltmarsh vegetation cover, although the addition of organic matter to the soil substrate over time contributes to erosion-resistant soils (Feagin et al., 2009). Periods of increased erosion in UK saltmarshes coincide with periods of higher winds and wave heights (van der Wal and Pye, 2004; Wolters et al., 2005); this may also cause increased sedimentation on the saltmarsh platform (Schuerch et al., 2012). There are, however, relatively few studies worldwide on the efficiency with which saltmarshes trap tidally advected material in field conditions (French, 2006; Moskalski and Sommerfield, 2012; Spencer et al., 2015b; van der Deijl et al., 2017). In this study, we aim to close this knowledge gap of the role of vegetation structure on deposition *in situ* through the use of a field flume, in combination with a mass balance approach to determine how changes to canopy morphology affect trapping efficiency in a UK saltmarsh.

2. Methods

2.1. Setting and physical environment

The field study was undertaken on the UK east coast at Tillingham, Dengie Peninsula (51.69425°N 0.94206°E, Fig. 1A), between the estuaries of the Rivers Blackwater and Crouch. The saltmarsh is a near-horizontal platform of clayey silts, ca. 200 m in width, at an elevation of 1.9–2.5 m above Ordnance Datum Newlyn (ODN; where 0.0 ODN approximates to mean sea level). The tidal mudflat immediately seaward of the marshes are at elevations of 0.9–1.9 m ODN and show a ‘mudmound topography’ of shore-normal sinuous ridges and runnels in the transition zone between the saltmarsh and the flat tidal mudflat. The runnels narrow shorewards into small creeks which dissect the marsh surface (Möller and Spencer, 2002). The Dengie Peninsula coast is macrotidal, with a mean spring tidal range of 4.8 m (Reed, 1988). The southern North Sea is, however, particularly susceptible to storm surges which raise water levels well above expected tidal levels. Thus the storm surges of 1953 and 2013 reached 4.4 m ODN at West Mersea, Blackwater estuary (Spencer et al., 2015a), resulting in water depths of ca. 2 m over marsh surfaces. The wave climate is moderate with a maximum recorded significant wave height (H_s) of 0.65 m at Sales Point on the northern limit of the Peninsula (Herman, 1999).

The main sediment sources for the marshes in East Anglia are thought to be the erosion of coastal cliffs in Norfolk and Suffolk, and to a much lesser extent, fluvial inputs from East Anglian rivers, and offshore seabed erosion (McCave, 1987). The cliff sediments are unconsolidated Quaternary sediments with a high proportion of inorganic mud. Suspended sediment concentrations in the southern North Sea are highly seasonal, with more than a fourfold increase in sediment concentrations in winter compared to summer (Prandle et al., 1997). Our experiment was undertaken during summer, when sediment supply to the marsh is lowest, but vegetation biomass is highest.

2.2. Experimental design

The experiment was carried out during the spring tide period between the 2–9 July 2016. We selected an area towards the seaward fringe of the saltmarsh at Tillingham and enclosed it within a plywood flume channel secured to the marsh surface with wooden stakes. The flume was 1000 mm in width, 1820 mm in length and the vertical walls were 900 mm high, with symmetrical funnel shaped openings at each end (Fig. 1B). It was placed across-shore (E-W), corresponding to the main direction of tidal flow. One profiling turbidity sensor (Argus Surface Meter (ASM) IV) and one pressure sensor (Solnist Levellogger Edge, Model 3001) were placed in the centre of both openings. The ASM IV turbidity profilers are titanium rods consisting of a series of 144 optical backscatter (OBS) sensors arranged as an array, with a 10 mm vertical spacing. The profilers and pressure sensors were programmed to record a depth-averaged turbidity profile (10 measurements over 10 s) and a water depth every 30 s.

2.3. Hydrodynamic measurements

The hydrodynamic conditions during the experiment were primarily deduced from the water levels recorded by the pressure sensors. The continuous (or still) water levels and the maximum tidal inundation depth were derived from a smoothed water level curve, which was calculated using a moving-average filter with a window size of 15 min (=30 data records). A proxy for wave heights was calculated for every tidal inundation as the standard deviation of the differences between the recorded and the still water level (smoothed water level curve) and validated with actual wave measurements, using a PTX1830 pressure transmitter (Möller, 2006) during a previous measurement campaign. Validation of the wave proxy resulted in a highly significant correlation between the wave proxy calculated from the smoothed water curve and the measured wave heights measured using the PTX1830 of the form (*wave height (cm)* = 6.465 x *wave proxy*, $R^2 = 0.92$, $p < .001$). Wind conditions were obtained from two UK Met Office coastal meteorological stations in Essex, one at Walton-on-Naze and one at Shoeburyness (Southend-on-Sea). Average daily wind speeds (measured at Walton-on-Naze, Essex and at Shoeburryness, Essex) ranged between 10 and 21 km h^{-1} with a predominant W/SW direction (UK Met Office, www.metoffice.gov.uk).

2.4. Sediment budget measurements

In order to calibrate the ASM sensor turbidity readings to g m^{-3}, water samples (1 L) were collected at 4 cm above the marsh surface using an automated water sampler (ISCO 6712, Teledyne Isco, Lincoln NE, USA) in the pioneer zone of the saltmarsh during two spring tide periods in April (7–11 April 2016) and July (21–24 July 2016). In each calibration period, three samples were taken, 30 min apart, during each inundation over eight consecutive inundations (N = 24). Following collection, the samples were filtered through pre-weighed GF/C filters, which were then dried at 105 °C for 24 h and re-weighed. Measured sediment concentrations in the water samples were compared to the simultaneously measured turbidity