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Floc size and settling velocity within a *Spartina anglica* canopy

G.W. Graham[a,*], A.J. Manning[a,b]

[a] *Coastal Processes Research Group, School of Earth, Ocean and Environmental Sciences, University of Plymouth, Drake Circus, Plymouth PL4 8AA, UK*
[b] *HR Wallingford Ltd., Howbery Park, Wallingford,OxfordshireOX10 8BA, UK*

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Abstract

There is increasing interest in tidal wetlands as mechanisms for sustainable and long-term coastal defence. The complexities of the interaction between the deposition of suspended particulate matter (SPM) and submerged vegetation, however, is to a large extent poorly understood. Consequently, accurate parameterisation of cohesive sediment settling fluxes in these environments is a crucial requirement for the development of high-resolution numerical models of wetland morphodynamics. A novel laboratory experiment is described in which the turbulent flow structure within a canopy of the halophytic macrophyte *Spartina anglica* is examined, and floc characteristics quantified using a unique floc camera configuration able to measure directly the full spectral floc size (D) and settling velocity (W_s). We provide the first quantitative observations of floc characteristics from shallow ($h<0.5$ m), vegetated flows and investigate the potential influence that variations in vegetative density may have on flocculation, and thus depositional fluxes, in comparison to unvegetated flows.

Turbid mud suspensions with concentrations of 100, 250 and 500 mg L^{-1} were sheared at current speeds of 0.1, 0.2 and 0.3 m s^{-1} through mono-culture arrays of *S. anglica* in an annular flume. Experimental stem densities were set at 200, 400 and 800 stems m^{-2}. Mean absolute velocity exhibits an inverse, approximately exponential relationship with vegetative density. The threshold for maximum current attenuation (an 89–90% reduction of free stream velocity) is 400 stems m^{-2}. D and W_s range over 3 orders of magnitude from 20 to 1265 μm and from 3.96×10^{-3} to 3.37 mm s^{-1}, respectively. Maximum D is larger by a factor of 18 than that observed during the closest comparable in situ study. Our observations exhibit a pronounced positive skew due to incorporation of large, low-density, fast settling aggregates with maximum W_s 33% greater than that used in current exploratory numerical models of saltmarsh surface deposition, and 236% greater than that observed during previous in situ studies. The inability to include the largest macroflocs (>160 μm)—the top 4% of our data set (ranked according to D) comprising 223 individuals between 250.46 and 1265.19 μm with settling speeds of 0.23–3.37 mm s^{-1})—may lead to serious under prediction of total mass settling flux (MSF). Parameterisation and incorporation of these observed distributions for use in numerical models of cohesive sediment deposition on saltmarsh surfaces is a high priority.

Keywords: Saltmarsh; Flocculation; Suspended sediments; *Spartina anglica*; Sedimentation; Annular flume

*Corresponding author. Tel.: +44 1752 232435; fax: +44 1752 232406.
E-mail address: george.graham@plymouth.ac.uk (G.W. Graham).

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1. Introduction

Many wetlands are under threat from erosion and are disappearing at an unprecedented rate. It has been estimated that relative sea level rise will result in the loss of 8–10 × 10^3 ha of intertidal mudflats and saltmarshes in England between 1993 and 2013 (Pye and French, 1992). The current estimate of saltmarsh loss to coastal squeeze and erosion is in the region of 100 ha $year^{-1}$ (UKBAP, 1999).

Increasingly there is interest in sustainable, long-term coastal defence strategies, and tidal wetlands may have the potential to offset, at least locally, adverse effects of sea level rise. The wave damping and current attenuation capabilities of saltmarshes have received considerable research attention (e.g. Möller et al., 1999; Möller and Spencer, 2002). Consequently, they are increasingly being advocated as viable mechanisms for 'natural' coastal defence (Pethick and Burd, 1993). The viability of saltmarshes for coastal defence depends heavily upon their ability to maintain relative elevation within the tidal frame. This relies, in part, upon the accumulation of suspended particulate matter (SPM) at a rate sufficient to keep pace with relative sea level rise (Allen, 2000).

Sedimentation in principally allochthonous tidal saltmarshes (e.g. as in the Tamar estuary, UK) is dominated by the advection of fine (cohesive) sediments from estuarine source waters across the saltmarsh surfaces during flood tide inundation. Deposition rates are regulated by complex interactions between the hydroperiod, import concentrations, saltmarsh surface topography, deposition processes and surface vegetation (Reed, 2003). However, complete understanding of the mechanisms regulating accumulation, and thus the prediction of vertical adjustment within the tidal frame, is still allusive.

A small range of physically based numerical models have been developed to help understand long-term (50–1000 years) vertical saltmarsh dynamics in response to relative sea level and suspension concentration variations, but these are essentially aspatial. Over shorter timescales, the use of 1D spatially distributed modelling approaches for the investigation of governing processes (e.g. the cross shore transect approach to morphological evolution (Woolnough et al., 1995)) have shown that variation in particle size and settling velocity has an important influence on spatial patterning of sediment deposition and the development of geomorphic gradients over short (individual tides—years) timescales.

The inability to model accurately the morphological response is partly because research on the suspended sediment dynamics of shallow vegetated flows is sparse as, in turn, it is dependant upon a comprehensive understanding of canopy fluid dynamics (see Bouma et al., 2007; Neumeier, 2007). In particular, the importance of the within-canopy flocculation processes are poorly understood. Flocculation is a dynamically active process through which the settling velocities of cohesive sediments, and thus vertical concentration gradients, deposition and accumulation, are actively altered via aggregation/disaggregation of suspended particles. Detailed observations of floc sizes and settling velocities, along with an assessment of the spatio-temporal variation in particulate characteristics within vegetated flows, are required for the accurate parameterisation of depositional fluxes.

The presence of vegetative obstructions modifies the mean flow velocities and turbulent intensities in comparison to unobstructed flows (Neumeier, 2007). These alterations, in turn, may affect the flocculation process causing variations in the depositional flux. Sediment accumulation on the bed within canopies may therefore be different from that observed in unvegetated flows. Whilst hydrodynamic modifications to flow through wetland vegetation have been investigated widely (Pethick et al., 1990; Leonard and Luther, 1995; Nepf, 1999; Nepf and Vivoni, 2000; Leonard and Reed, 2002), the possible impacts upon suspended aggregates and, consequently, the depositional flux to the bed, have never been more than speculatively postulated.

Shi et al. (1995, 1996) proposed that the generation of turbulence and consequent variations in shear stresses due to vortex shedding in the lee of vegetative stems may influence flocculation and thus the settling velocity of SPM. Braskerud (2001) suggested that turbulent wakes are likely to promote inter-particle collisions, and thus enhance settling. Floc characteristics (such as size and settling velocity) may well undergo alteration as the ambient hydrodynamics, particularly turbulent shear stresses (TSSs), are modified with flow through vegetation, but there are no studies that have expressly examined this process.

Quantitative observations of floc size, settling velocity and mass settling fluxes (MSFs) within vegetated flows, from which model parameterisations are derived are lacking. French et al. (1993)