*Journal of Coastal Conservation 5: 81-90, 1999*
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# Marsh surface sediment deposition and the role of tidal creeks: Implications for created and managed coastal marshes

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**Abstract.** The need to understand the processes contributing to marsh sedimentation has become more urgent with the recent recognition of the role of tidal marshes as sea defences, as well as the many restoration efforts currently under way. This study was designed to build upon previous sedimentation work at Scolt Head Island by combining techniques for measuring short-term sedimentation with detailed assessment of hydroperiod, previously used only in comparison with longer-term accretion measurements or in micro-tidal systems. Measurements of water level, sediment deposition (at various distances from the creek margin) and suspended sediment concentration (SSC) (creek margin and an interior site) were made at Hut Marsh over three sequential over-marsh tides during May 1994. Sediment trap data show a significant trend of declining sediment deposition away from the creek when data from all three tides are combined. All tides show higher SSC on the flood tide than on the ebb tide at the creek margin location. There is little difference in flood and ebb SSCs at the interior site. An order of magnitude decrease in sediment deposition within 20 m on the creek shows the rapidity with which sediment is deposited on these marshes. Higher tides influence both the magnitude and pattern of marsh surface sediment deposition. Increased creek velocities on higher tides provide more potential for resuspension within the creek and increase the supply of sediment to the marsh surface. This study suggests that the design of tidal creeks may be essential for the development of sustainable coastal marshes in restoration projects.

**Keywords:** Creek; Restoration; Salt marsh; Scolt Head Island; Sedimentation; Suspended sediment concentration.

**Nomenclature:** Nomenclature of phanerogams is as in Adam (1978) and Burd (1989)

**Abbreviation:** HAT = Highest astronomical tide; O.D. = Ordnance Datum; POC = Particulate organic carbon; SSC = Suspended sediment concentration.

## Introduction

Most heavily-populated and economically important coastal lowlands are susceptible to flooding from tidal incursions and are typically protected by 'hard engineering' sea defence structures. Salt marshes fronting such structures are an important component in flood defence. At the coastal scale, the presence of salt marshes within an estuary reduces tidal amplitude by creating frictional drag on the water surface and allowing storage of water on marsh surfaces (Burd 1995). Locally, the vegetated marsh surface dissipates wave energy (Moeller et al. 1996), thus reducing wave run-up and overtopping of defences (Brampton 1992). In addition, the marsh deposit itself provides mechanical support for the toe of the defence. On many coasts, however, incremental land claim has greatly reduced the width of intertidal marsh. Furthermore, many remaining marshes have been undergoing edge erosion, internal break up and disappearance within the last decade, being unable to relocate landwards under accelerated sea level rise forcing because of fixed defence lines at their landward boundary. The loss of fronting marsh exposes sea wall structures to potential undermining and collapse from wave action and generates demands for costly defence re-engineering and new protection structures.

In these circumstances, managed retreat – also known as coastal setback or coastal realignment – has been promoted as a potentially suitable strategy for more sustainable coastal management; schemes based on this philosophy are currently being implemented in England, California and the Pacific Northwest. Managed retreat creates new flood control areas and replacement intertidal habitat between existing, but breached, sea defences and newly constructed landward defences. In most cases, new tidal exchange re-activates previously reclaimed salt marsh. However, dewatering, compaction and soil chemistry changes on enclosure and reflooding (e.g. Portnoy & Giblin 1997), combined with continued vertical accretion of salt marsh outside the reclaimed area, may result in considerable height differences between managed retreat surfaces and natural salt marsh surfaces. For the United Kingdom, Pethick & Burd (1995) suggest typical height differences of 1.0 - 1.5 m while in the peat-dominated tidal marshes of the Sacramento Delta in California, the height difference between natural and recently reflooded marsh substrates can be >4 m (Anon. 1993). If these differences are not made good by rapid sedimentation, a managed retreat site is unlikely to develop into a stable vegetated salt marsh. It is important, therefore, to understand marsh development processes, and how they may be manipulated for management purposes.

One factor in accelerating marsh surface accretion, and rapid vertical development in the tidal frame, is increasing the efficiency of sediment delivery within a site, either through the re-excavation of old tidal channel, or ‘creek’, networks or by the provision of new, artificial creek systems. As marsh channels also dissipate tidal energy (Pethick 1992) and aid plant establishment through drainage and sediment dewatering (French 1995), they are potentially an important, although unfortunately an often neglected (Haltiner & Williams 1987; French 1996) component in managed retreat area design.

Rates of vertical accretion have been measured in coastal salt marshes around the world using various techniques (e.g. Baumann et al. 1984; Stoddart et al. 1989; Dijkema et al. 1990; Chung 1994). These measures have frequently been used to assess the potential for marsh survival in the face of sea-level rise (Reed 1990) or to understand the dynamics of marsh evolution and growth (Allen 1990). These studies have usually integrated vertical accretion over periods from several months to hundreds of years, depending upon the resolution of the measurement technique, over broad geographical areas. More recent studies of marsh dynamics (French et al. 1995; Leonard et al. 1995; Reed 1989b; Leonard 1997) deal with variations in sediment deposition in tidal marshes at tidal-daily or tidal-monthly time scales and over short distances, thus allowing more detailed assessment of the processes contributing to sediment accretion on the marsh surface. For marshes on Scolt Head Island, eastern England, such studies have suggested that proximity to major creeks is a prime control on rates of sediment deposition (French & Spencer 1993; French et al. 1995), although there is some evidence, under calm conditions, of the influence of tidal height on rates of sediment deposition.

Interactions between proximity to tidal creeks; marsh elevation; and flooding regimes may, therefore, prove to be critical determinants of the longevity and success of restored or artificially created salt marshes. Assessments of within-marsh sediment dynamics at short (i.e. tidal) time scales might well be used to improve the design and operation of restoration projects as well as furthering our understanding of marsh form and function.

This paper presents results of an intensive study of marsh surface sediment deposition conducted in May 1994. The objectives of this study were to:

(1) determine gradients in sediment deposition away from a marsh creek for an ascending sequence of spring tides;
(2) assess the importance of elevation and hydroperiod in controlling sediment deposition at small spatial and temporal scales;
(3) identify factors controlling sediment deposition and how these relate to marsh morphology.

The study was designed to build upon previous sedimentation work at Scolt Head Island by combining techniques for measuring short-term sediment deposition (Reed 1992; French & Spencer 1993; Murray & Spencer 1996) with detailed assessment of hydroperiod, previously used only in comparison with longer -term accretion measurements (Cahoon & Reed 1995) or in microtidal systems (Reed 1989a).

## Methods

### Study area

The North Norfolk section of the English coastline is characterized by intertidal sand and mud flats and a series of gravel and sand dune barriers. Salt marshes are found on both open coasts and in sheltered back-barrier locations (Fig. 1). The coast is subject to a semi-diurnal, meso- to macro-tidal regime (mean tidal range: 3.2m (neaps) - 6.4m (sprin gs); Anon. 1997). Highest Astronomical Tide (HAT) is 4.0m O.D. (Ordnance Datum, which approximates to mean sea level), although the southern North Sea is susceptible to storm surges which may raise water levels to over 5.0m O.D. (Steers et al. 1979).

At Scolt Head Island, periodic marsh development has been associated with the episodic westward extension of the main barrier (Pethick 1980). Marsh development, from a silty sand flat basement, is typical of systems dominated by external inputs of inorganic sediment (Allen 1990): vertical growth is initially rapid but slows after 100-200yr, depending upon sediment supply (French 1993). Ultimately, marsh surfaces equilibrate at a level determined by the interaction between infrequent sediment inputs from high spring tides and local relative sea level rise – currently 2 mm/yr (French & Spencer 1993). French (1993) has shown this critical level to be ca. 0.8m below HAT, or at ca. 3.2m O.D.

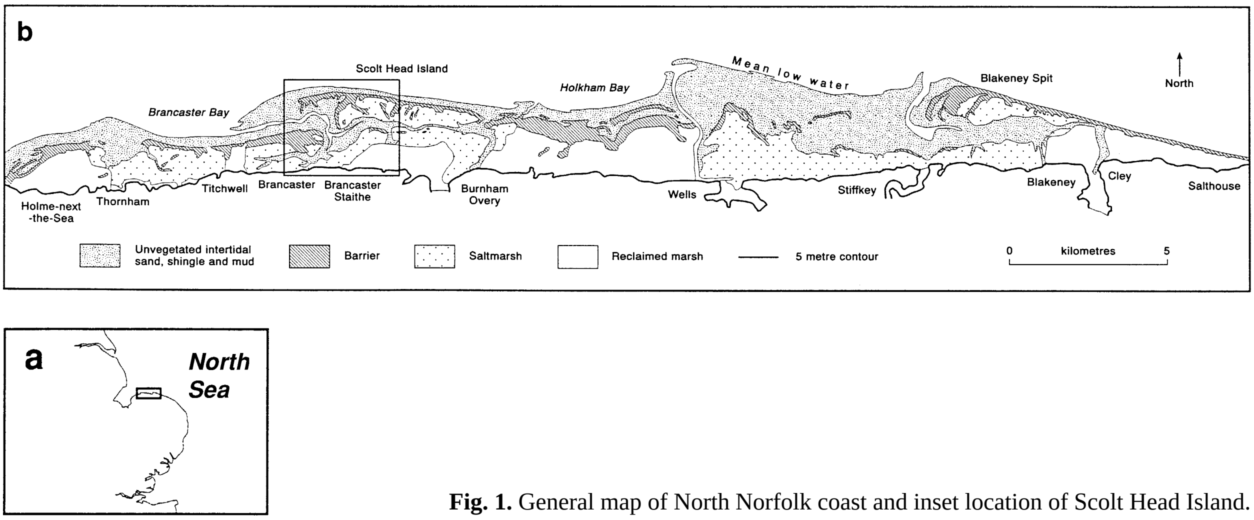

**Fig. 1.** General map of North Norfolk coast and inset location of Scolt Head Island.

The study area of Hut Marsh, a back-barrier marsh ca. 0.54 km$^2$ in extent and enclosed by an outer dune-covered barrier and low shingle/dune laterals at Scolt Head Island (Fig. 2), is ca. 100 yr old and lies, with a surface at 2.6 - 3.2m O.D., at the transition to 'mature' salt marsh. The mean marsh height of 2.8m O.D. is flooded by ca. 200 tides/yr (27% of the annual total; French et al. 1995). During the period of study, high tides reached between 3.14 and 3.39m O.D. Tidal connection to the main back-barrier channel, Norton Creek, is via two dendritic creek systems; this study is concerned with the western network, known as Hut Creek (Fig. 2). The arithmetic annual accretion rate for Hut Marsh (1986-1991) was 4 mm/yr but this hides a great deal of within marsh variability, with rates varying from ca. 1mm/yr for 'high' marsh sites near the seaward enclosing barrier to ca. 8 mm/yr for central marsh areas where the density of large channel systems is high (French & Spencer 1993).

Salt marsh species and plant communities at Hut Marsh can be characterized with the help of Adam's (1978) classification scheme and the National Vegetation Classification as used in the Nature Conservancy Council's Salt Marsh Survey of Great Britain (Burd 1989). Surfaces of intermediate height are characterized by *Aster tripolium, Spartina anglica* and *Suaeda maritima*, with higher surfaces supporting a floristically rich 'General Salt Marsh' (GSM) community of relatively low (typically < 30 cm) height which includes *Armeria maritima, Limonium vulgare, Plantago maritima, Seriphidium maritimum, Spergularia media, Triglochin maritima* and the salt marsh grass *Puccinella maritima*. Here, bushy *Atriplex portulacoides* is typical of the banks of the major creeks. Linear gravel 'laterals' and patches of below-surface gravels are picked out by woody bushes of *Suaeda fruticosa*, flooded only on high spring tides.

### *Study site*

Measurements of tidal flooding and sedimentation at Hut Marsh were undertaken within 20 m of the north bank of Hut Creek (Fig. 2). The marsh surface is at 2.7-2.8 m O.D.; long-term accretion near this location has been recorded (1986-1996) as ca. 6 mm/yr (French & Spencer unpubl.). The vegetation at this site is composed of the woody *Atriplex portulacoides* which forms a canopy typically 25cm high. The arrangement of the various measurements is shown in the inset on Fig. 2. Measurements were taken over three sequential tides: 23/5/94 p m (Tide 1), 24/5/94 a m (Tide 2) and 24/5/94 p m (Tide 3). Relative water level variations for these tides are shown in Fig. 3, as measured in Hut Creek adjacent to the study site.

### *Research design*

Large marsh surface sediment traps were deployed in groups of five at 0, 5, 10, 15 and 20m along a transect from the edge of the vegetation at the creek margin for each flooding event monitored. The traps were 9 cm in diameter and similar to those used by Reed et al. (1997). In addition, 25 4.7-cm traps (after French et al. 1995) were placed at random distances from the creek margin within 20 m of the edge. All sampling sites were positioned with reference to a local island co-ordinate system using an electronic theodolite (to within ± 0.5m) and surveyed heights (with closure errors of less than ± 0.01m) reduced to O.D. through reference to an island benchmark system, itself related to the U.K. Ordnance Survey geodetic system.

Water level variations were measured using a pressure transducer mounted in the base of the creek adjacent to the study site (Fig. 3). PEAKBASE (Reed & Cahoon 1992) was used to calculate hydroperiod parameters

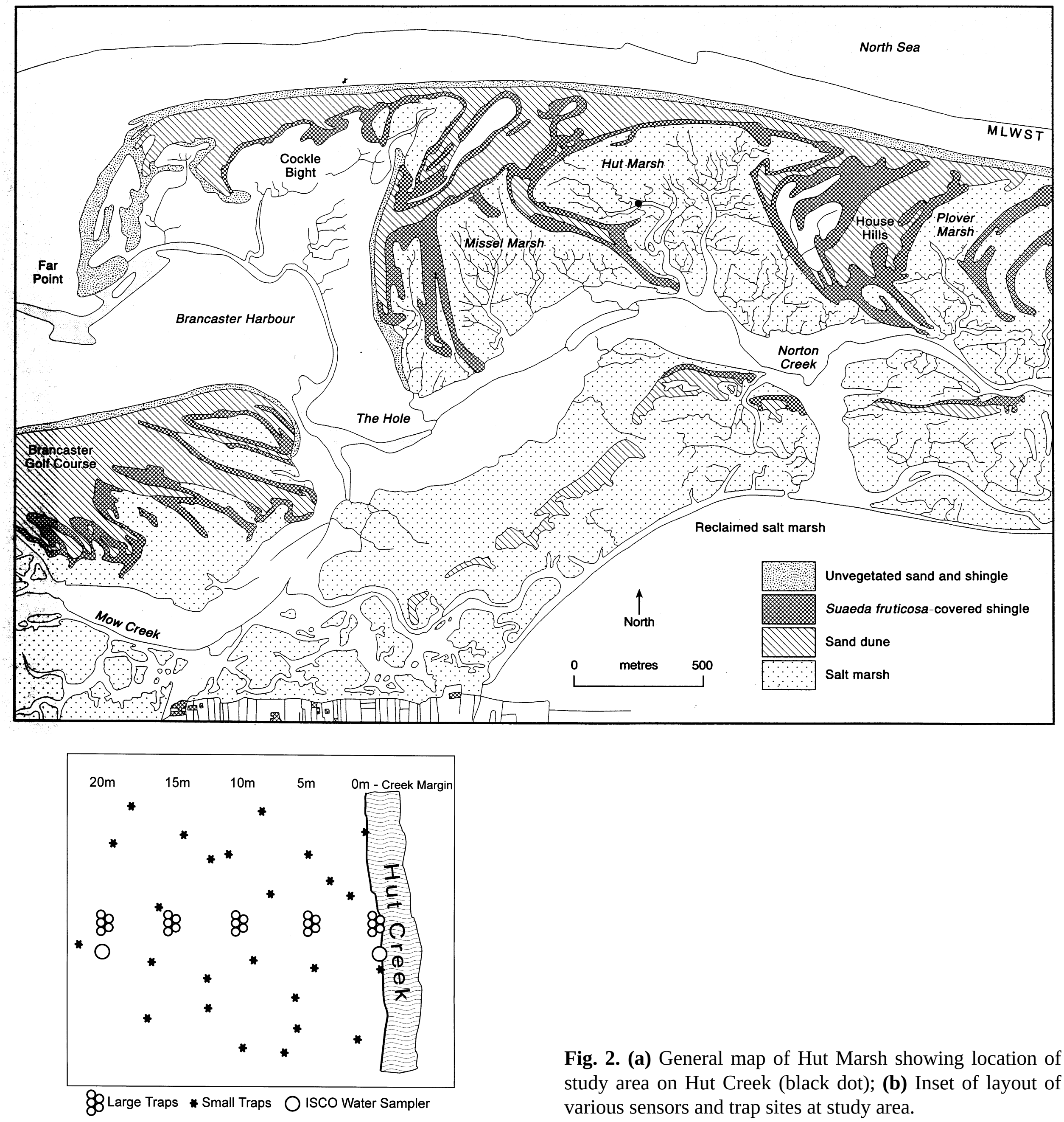

**Fig. 2.** **(a)** General map of Hut Marsh showing location of study area on Hut Creek (black dot); **(b)** Inset of layout of various sensors and trap sites at study area.

(duration and depth of flooding) for each surveyed location of the marsh surface adjacent to the sediment traps. Statistical analyses were performed using Statgraphics Plus (Anon. 1994).

Water samples were obtained at 10-minute intervals using ISCO water samplers with intake hoses positioned approximately 5 cm above the marsh surface. Simultaneous samples were taken close to the edge of the vegetation (creek margin site) and at 20m into the marsh (interior site); the sampling sequence commenced with the initial flooding of the marsh surface when the intakes were flooded. Such at-a-station sampling throughout an inundation period does not necessarily measure the same body of water on the flood as on the ebb. Rather, it characterizes the amount of suspended sediment moving across the marsh surface over time at fixed locations. Thus this approach can be used to show patterns of change between tidal cycles and between flood and ebb tides within a cycle, but not for the estimation of sediment budgets. Water samples were filtered in the laboratory and sediment concentrations expressed as mg/l.

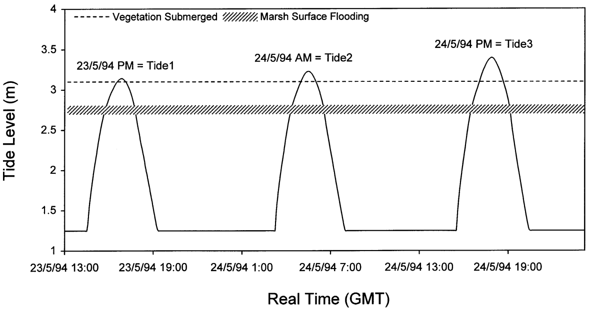

**Fig. 3.** Time-stage plot of pressure transducer record from Hut Creek, including thresholds to marsh surface flooding and height at which vegetation submerged.

Sediment deposition per inundation period at the trap sites was determined by drying and re-weighing filter papers recovered from the traps in the laboratory. Deposition in g/cm$^2$/tide was determined for each type of trap based upon the area of the trap. Large sediment traps were combusted (16 hr at 375 °C) in a muffle furnace to determine the organic/inorganic content of the sediment.

## Results

### *Marsh surface sediment traps*

Regression analysis of data from the large sediment traps, placed at 5m intervals from the creek, shows a significant trend of declining sediment deposition away from the creek when data from all three tides are combined (Fig.4a). However, when individual tides are plotted separately, a significant trend is only apparent for Tide 3, the highest tide of the sequence (Fig. 4b). There are no significant relationships between sediment deposition on the large traps and elevation, duration of flooding or maximum depth of flooding. When organic and inorganic components of the sediment are considered separately, both show a significant decrease with distance from the creek. However, the organic matter content of the sediment deposited on the traps (on a weight percent basis) shows a significant increase with distance from the creek ($p = 0.003$, $r^2 = 0.50$).

The randomly placed small traps provide data concerning 25 separate locations on the marsh surface. There is a significant negative relationship between distance from the creek and sediment deposition for the third, and highest, tide in the series (Fig. 5). Data from this tide also show a significant relationship between sediment deposition and elevation ($p = 0.026$) with higher elevations showing higher sediment deposition, presumably associated with the natural levee of the creek. Elevation, however, only explains 20% of the variation in sediment deposition. For this tide, sediment deposition on the randomly placed traps is also negatively related to duration and depth of the flooding.

### *Water samples*

Suspended sediment concentration (SSC) data for both creek margin and interior water samplers are shown in Fig. 6. Times for high water are taken from the pressure transducer water level record (Fig. 3). All tides show higher SSC on the flood tide than on the ebb tide at the creek margin location. There is little difference in flood and ebb SSCs at the interior site. There was a delay in starting the sampler at the creek margin location on Tide 1 (Fig. 6A) and thus the first sample is missing from the sequence. Some disturbance of the marsh surface may have occurred close to the sampler resulting in high SSC in the first sample and an apparent 'early' increase in SSC

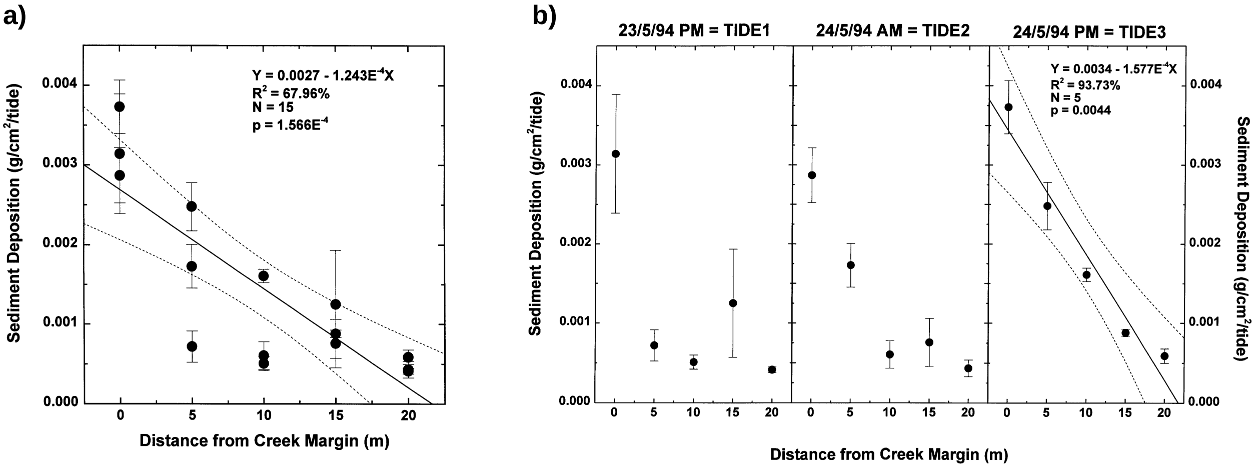

**Fig. 4. a.** Sediment deposition on large traps with distance from creek margin, for all tides. **b.** Sediment deposition with distance for individual tides.

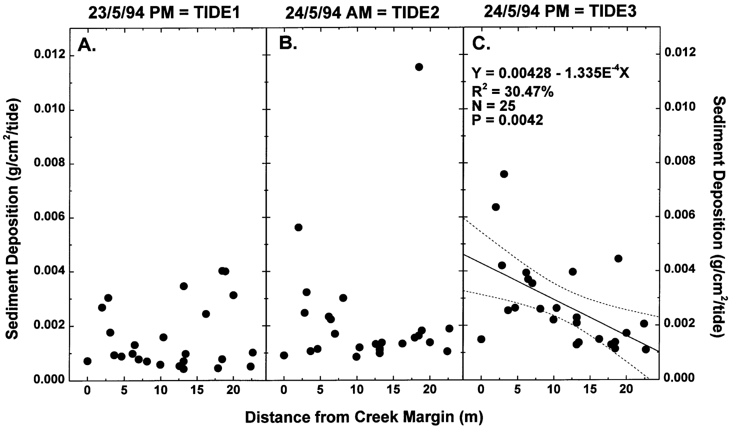

**Fig. 5.** Sediment deposition on small traps at three tides with distance for individual tides.

compared to later tides. Tide 2 (Fig. 6B) and Tide 3 (Fig. 6B) show an increase in SSC 20 - 30 minutes after the first sampling. The time of maximum velocity measured in the creek preceded the submergence of the vegetation at the creek margin site by ca. 10 minutes (Fig. 6). The peak in SSC occurred during this interval on Tide 2 and close to the submergence of the vegetation on Tide 3. On Tide 3 there was also an increase in SSC at the interior site coincident with the peak SSC at the creek margin site (Fig. 6C).

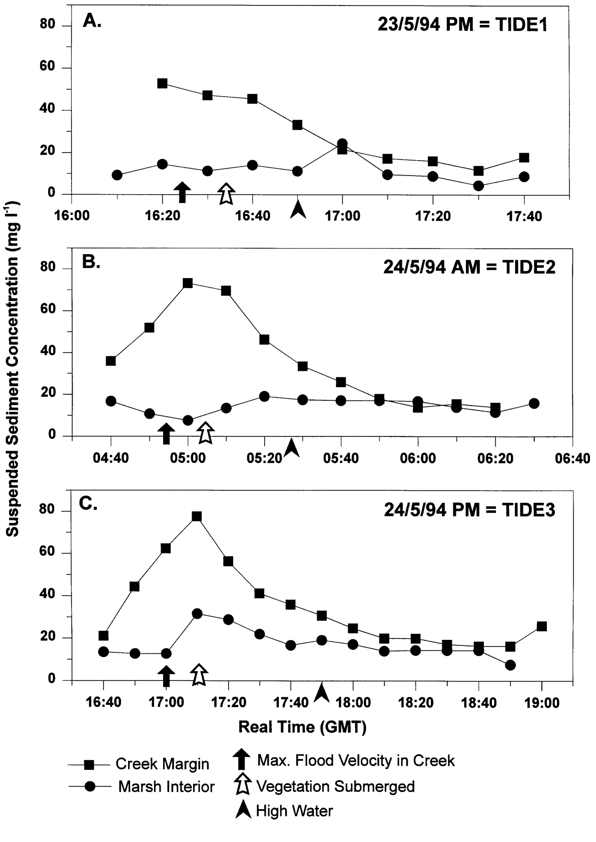

**Fig. 6.** Suspended sediment concentrations in water samples at levee (distance from creek margin = 0m) and marsh interior (distance from creek margin = 20m) sites with time. **A.** Tide 1; **B.** Tide 2; **C.** Tide 3.

When these observations of SSC are combined with measurements of flow across the marsh surface (Leonard unpubl. data) vertical sediment fluxes can be calculated using the approach of Leonard et al. (1995). Where this analysis is applied to the portion of the tidal cycle following peak SSC-values (Fig. 6), the results show that the net change in sediment held in suspension in the water column during the inundation event is 10.0 g/m$^2$ for Tide 2 and 21.8 g/m$^2$ for Tide 3. These results agree well with the mean sediment deposition calculated from the five arrays of large traps (12.8 g/m$^2$ on Tide 2 and 18.6 g/m$^2$ for Tide 3). This analysis assumes that very little deposition occurs during the initial stages of flooding - the time of highest input of material from the creek.

## Discussion

### *Marsh surface sediment deposition*

The pattern of declining sediment deposition away from the creek found in this study is similar to that identified in other studies at Hut Marsh (Stoddart et al. 1989; French & Spencer 1993; French et al. 1995). The order of magnitude decrease in sediment deposition within 20 m on the creek shows the rapidity with which sediment is deposited on these marshes. This is confirmed by the SSC-data from the creek margin and interior sites. Despite concentrations greater than 50 m/gl being delivered to the marsh surface from the creek, water reaching the sampler 20 m from the creek shows SSCs of generally less than 20 mg/l. Integration of calculated vertical sediment fluxes for Tides 2 and 3 confirm that this loss of material from suspension is likely to be a result of direct settling to the marsh surface. Leonard & Luther (1995) found that turbulent

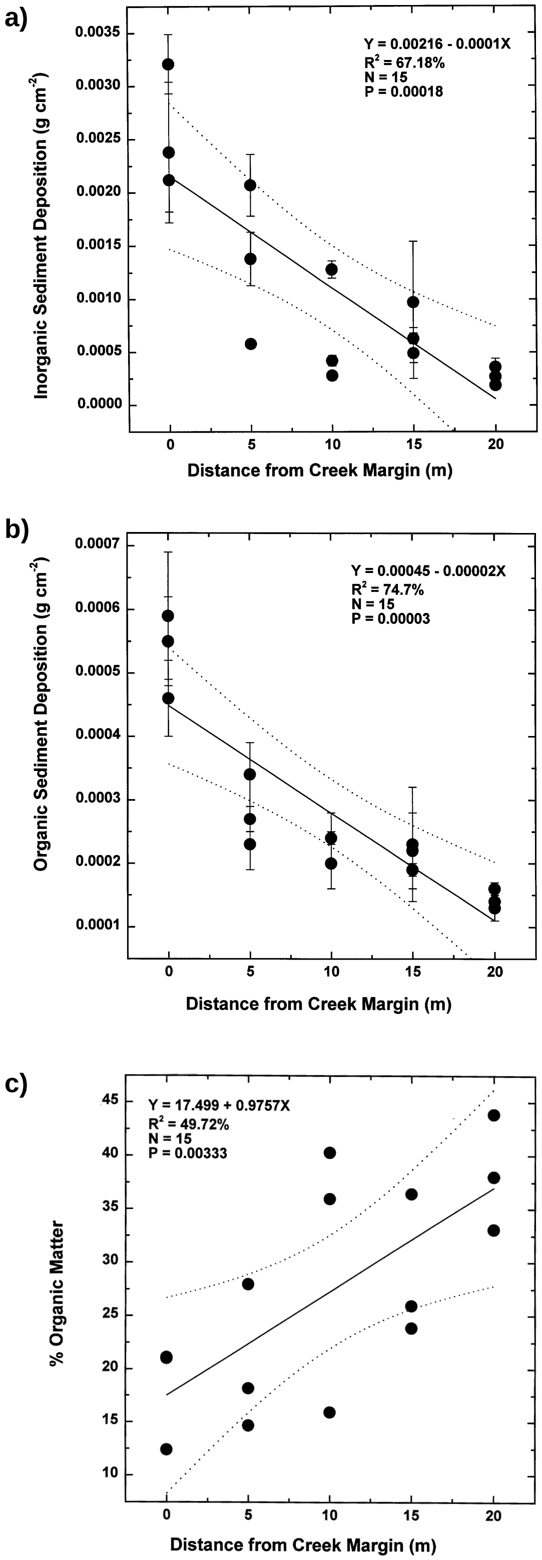

**Fig. 7.** Sediment deposition by sediment type. **(a)** Inorganic sediment deposition with distance; **(b)** Organic sediment deposition with distance; **(c)** Percentage organic matter in sediment deposited with distance.

energy decreased away from the creek edge in Florida *Juncus romerianus* marshes leading to increased deposition within 7m of the creek margin. Additionally, proximity to the creek appears to be a greater control on sediment deposition in this area of Hut Marsh than the depth or duration of marsh flooding. This pattern is also similar to that identified by Leonard (1997) in her studies of a North Carolina marsh where significant differences in SSC between creek margin and interior marshes were also reflected in differences in sediment deposition rates between the two areas.

The influence of marsh elevation and flooding characteristics on sediment deposition is shown in data from the randomly placed small traps. These data encompass a wider array of elevations on the marsh surface than the large traps and show that higher areas show higher rates of sediment deposition. This is in contrast to the generalized relationship for elevation and sediment deposition for the entire Hut Marsh area found by French & Spencer (1993). At that scale, higher relative elevations are in high marsh areas flooded rarely by tides with sediment deposition being potentially limited by both the opportunity for deposition and the availability of sediment (Reed 1989b). At the meso-topographic scale of the study site on Hut Marsh the highest areas are closest to the creek where the proximity to sediment source overrides small differences in elevation (and flooding duration) between the natural levee and the interior marsh.

French & Stoddart (1992) hypothesized that two discrete sediment subpopulations are mobilized by tidal flows: a suspended sand fraction, representing infrequent, local entrainment of channel floor sediments and a suspended silt fraction, derived both from external sources and from the resuspension of within-channel sediments. This second component can be divided into a fine, quasi-continuously suspended sediment background population of individual particles (2-5 mm in diameter) and a sub-population of larger composite particles, incorporating both inorganic and organic components. Sediment quality data indicate that much of the sediment that is deposited in the region close to the creek is inorganic sediment (Fig. 7a). Although the actual amount of organic matter deposited decreases with distance from the creek (Fig. 7b), a trend similar to that identified by French & Spencer (1993), the organic matter content of the deposited sediment increases from 15-20% on the creek margin (0 m trap) to 40-45% 20m away (Fig.7c). These findings confirm earlier research at *Salicornia* Marsh, Scolt Head Island which suggested that the organic fraction is more readily transported (French et al. 1995), and studies from Florida that show increases in the relative proportion of organic material in suspension during the course of a tidal inundation event

(Leonard unpubl.). Thus, organic particles are therefore more likely to reach interior marshes. Slow deposition of this fraction combined with contributions of particulate organic carbon (POC) from plant detritus may explain the dominant export of POC observed on other Scolt Head Island marshes (Murray & Spencer 1997).

### *Tidal creek - marsh surface interactions*

Traditional views of salt marsh sedimentation envisage the advection of simple populations of fine sediments with low settling velocities into marsh interiors with deposition restricted to the 'slack water' periods at or near high water (e.g. Orme 1990). More detailed studies, however, have emphasized the continuous settling of variously sized suspended sediment populations (e.g. Stumpf 1983) introduced into marsh systems by stage-related flood tide velocity pulses in adjacent channels (French & Stoddart 1992). Such transients, as Fig. 3 shows, typically last for ca. 30 minutes and are followed by rapid flow decelerations to high water.

The differences in relationships between sediment deposition and distance among tidal cycles, in conjunction with changes in suspended sediment concentration patterns among tides, points to a change in the dynamics of sediment deposition as tidal range increases. Increased tidal range in over-marsh tides on Hut Marsh is frequently associated with increasing magnitude of flood velocity pulses on Hut Creek (Stoddart et al. 1989). In this study, the highest SSC measured on the marsh surface coincides not with the first inundation of the marsh surface, as observed in other studies (Leonard et al. 1995), but in association with the peak velocity in the creek or the 'flood velocity pulse' (Bayliss-Smith et al. 1979; French & Stoddart 1992). This occurs after the marsh surface is flooded but before the vegetation is submerged at the study site. Over the three tidal cycles shown here, the magnitude of this flood pulse increased from 0.39 m/s on Tide 1, to 0.49 m/s on Tide 2 to 0.60 m/s on Tide 3 (Fig. 3). This study shows increasing SSC on the marsh surface (creek margin in Fig. 6) as the magnitude of the flood pulse increases.

Additional flow data obtained from an electromagnetic current meter on the marsh surface (French unpubl.) for this study period also showed an increase in the velocity of flows across the marsh with tidal range. Higher velocities across the marsh surface may reduce the efficiency of sediment deposition, enabling more sediment to reach interior marsh areas, as shown in the water sample data for Tide 3 (Fig. 6c). This is also demonstrated in the sediment deposition data from the large traps which show higher sediment deposition adjacent to the creek on Tide 3 compared to previous tides but little increase in sediment deposition at 20 m from the creek, despite higher SSC (Fig.4b). This study suggests, therefore, that higher amounts of sediment transported to interior marsh areas on Tide 3 must have ultimately been deposited as the SSC of water leaving the marsh surface on the ebb is similar for Tide 3 as for previous tides (15-20 mg/l) (Fig. 7a-c).

### *Summary and implications for management*

Higher tides influence both the magnitude and pattern of marsh surface sediment deposition. Increased creek velocities provide more potential for resuspension within the creek and increase the supply of sediment to the marsh surface. Although much of this sediment, especially the inorganic fraction, is deposited close to the creek, as occurs on lesser over-marsh tides, more sediment is carried to interior marsh areas with higher marsh surface flows. Thus although changes in elevation within the low marsh exert less control on sediment deposition than proximity to the creek, the magnitude of the marsh surface flooding (i.e. the elevation of the marsh plain in relation to high tide) remains an important factor. This study demonstrates the increased efficiency of sediment movement to interior marsh areas as the height of high tide increases. Increased water depths on the marsh surface as well as stronger marsh surface flows maintain sediment deposition close to the creek as well as distributing sediment across the marsh plain.

The sustainability of any created or managed marshes requires that the marsh substrate build vertically at a rate at least equal to local rates of relative sea-level rise rates. Even without the subsidence experienced in many coastal areas (El-Sayed 1996; Wells 1996) this calls for ca. 2 mm/yr of accretion to keep pace with current eustatic sea level rise. In coastal salt marshes, natural processes of sediment deposition are the dominant means by which this is achieved (Frey & Basan 1985). The maintenance and promotion of these processes must be considered in the design and management of marsh reclamation projects.

Studies of marshes where impaired tidal hydrology has been restored show that the recovery of salt marsh functions (e.g. fish utilization, vegetative community distribution) is dependent upon the degree of flooding depth, duration and frequency (e.g., Burdick et al. 1997). While marsh elevation in the tidal frame is the essential control of these hydroperiod parameters, sedimentation rates in newly re-flooded intertidal areas are the critical determinant of elevation as well as being important in the long-term sustainability of the systems. This study has confirmed proximity to tidal creeks as a factor in sedimentation in macro-tidal coastal marshes and studies from other systems (e.g. Leonard 1997) indicate this to be a fundamental aspect of coastal salt marsh sediment dynamics. Haltiner et al. (1997), however, have documented where poor design of a tidal creek in a marsh created with dredged material, in combination with a low elevation, resulted in erosion rather than sedimentation in parts of the marsh system. Similarly, although creeks were created in the Orplands managed retreat site, variations in creek complexity between ‘cells’ are thought to be the cause of differences in creek velocity patterns (Emerson et al. 1997). This study has shown that delivery of sediment to the marsh surface is linked to velocity pulses within marsh creeks, suggesting that the appropriate design of creeks in restoration projects is critical to their geomorphic function.

Although created tidal creeks have been shown to provide equivalent habitat for juvenile fish as natural creeks (Miller & Simenstad 1997), the provision of creek systems within created marshes, for either ecological or geomorphic reasons, has been limited. Williams & Florsheim (1994) noted the difference in creek system development between restored marshes in San Francisco Bay which reached marsh plain elevation via natural sedimentation and those where dredged material was originally placed at or near the expected marsh plain elevation. The development of these creeks provides for a, perhaps, slower developing system but one where marsh creeks exist and can function in supplying sediment to the developing marsh surface. The critical role of creeks in providing sediments for deposition on the marsh surface suggest that these design criteria may be essential for the development of sustainable coastal marshes and managed retreat or other restoration projects.

**Acknowledgements.** This study forms part of a wider programme of collaborative research in coastal wetlands between the University of New Orleans, Cambridge University and University College London. We are grateful to I. Moeller for field assistance and to English Nature for permission to undertake research in the Scolt Head Island National Nature Reserve. L. Leonard acknowledges the financial support of U.S. Geological Survey, Center for Coastal Geology and Regional Marine Studies, Richard P. Stumpf, Project Manager.

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Received 2 March 1998;
Revision received 25 May 1999;
Accepted 11 June 1999.