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Seasonal and annual variations in the volumetric sediment balance of a macro-tidal salt marsh

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Abstract

This paper examines the spatial and temporal variability in the volumetric sediment balance of Allen Creek marsh, a macro-tidal salt marsh in the Bay of Fundy. The volumetric balance was determined as the balance of inputs of sediments and organic matter via accretion on the marsh surface and outputs of sedimentary material primarily due to erosion of the marsh margin. Changes in marsh surface elevation were measured at 20 buried plates and 3 modified sediment elevation tables from 1996–2002, and detailed margin surveys were conducted in 1997, 1999 and 2001 using a differential global positioning system. Changes in surface area were calculated using GIS overlay analysis and used in conjunction with accretion and erosion data to derive volumetric estimates of gains and losses of sedimentary material in the marsh system.

Currently the volumetric sediment balance at Allen Creek marsh is positive. However the processes of erosion and accretion demonstrate seasonal, annual and spatial variability. Inputs to the system include deposition on the marsh surface from sediment laden waters and from ice rafting of sediments. Sediment is deposited onto the marsh surface year round, even during the winter when vegetation cover is sparse, and the amount of deposition in general is not significantly correlated with the frequency of tidal inundations. Based on the data from 1996 to 2002, the mid and high marsh zones experience mean accretion rates of approximately 1.4 cm year^{-1} whereas accretion rates in the low marsh region are statistically significantly lower (0.8 cm year^{-1}). The absolute amount of accretion varies between seasons and from year to year. The main loss to the marsh is through erosion of the marsh margin cliffs which can remove a comparatively large volume of sedimentary material in one mass wasting event and which also decreases the vegetated surface area available for deposition from sediment laden waters. The volume of material removed from the marsh margin almost tripled between 1997 (169 m^3) and 2001 (502 m^3) following breaching of the side of a tidal creek channel, altering the patterns of margin erosion and deposition in the marsh system. During this time, however, other sheltered areas of the marsh system, such as along the tidal creek banks, showed evidence of new vegetation growth, increasing the amount of vegetated surface area available for deposition.

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The processes of erosion and deposition on the marsh surface exhibit considerable spatial variability, with different regions of the marsh being more or less sensitive to seasonal variability in the dominant controls influencing sediment deposition and erosion in this system, namely wave activity, vegetation, ice and water depths. A key factor in predicting how a marsh will evolve and respond to a number of different controls, *e.g.* sea-level rise or reduced sediment supply, is to quantify both accretion of the marsh surface and erosion of the marsh margin, evaluating the marsh system as a volumetric whole. This study demonstrates that a marsh system should be assessed in three dimensions rather than simply as a surface of accumulation. This is particularly important for open coastal marshes exposed to the erosive action of waves.

Keywords: ice rafting; wave energy; sediment balance; accretion; erosion; Bay of Fundy

1. Introduction

Over the last decade, interest has been stimulated in the controls on the rate of vertical growth of salt marshes and whether vertical growth can keep pace with the predicted rate of sea-level rise (e.g. Reed, 1990, 1995, 2002; Allen, 1990, 1997; French, 1993; Jennings et al., 1993; Kelley et al., 1995; Woolnough et al., 1995; Chmura et al., 2001b; van der Wijen and Bakker, 2001; Temmerman et al., 2003). In the majority of these studies, attention has been concentrated primarily on the ability of salt marshes to trap sufficient sediment and/or to produce sufficient below ground organic matter so that vertical growth can offset drowning from rising sea-level. Many empirical studies indicate that given sufficient supply of sediment, the rate of accretion on many salt marshes is generally greater than the forecast rates of sea-level rise under various global warming scenarios (Patrick and DeLaune, 1990; Cahoon et al., 1996; Callaway et al., 1996; Orson et al., 1998; Chmura et al., 2001a; Chmura and Hung, 2004).

Most studies tend to concentrate on the ability of a salt marsh to maintain its relative position along the coast and the vertical growth rate is largely assumed to be controlled primarily by the rate of sea-level rise (e.g. Allen, 1990; Orson et al., 1998). However, changes in marsh surface elevation have not necessarily been found to be unidirectional, and transgressive/regressive sequences have been recorded in the stratigraphic record (e.g. Allen, 2000, 2003). Cycles of progradation and retreat of the marsh edge have been documented on a number of marsh and intertidal systems (Pringle, 1995; Cox et al., 2003; van der Wal and Pye, 2004; Ollerhead et al., in press). These cycles have been linked to changes in sea level (Allen, 1989, 2000) and in the tidal prism due to human activities such as tidal barrier construction or dredging (e.g. Allen, 2000; French and Birmingham, 2003; van der Wal et al., 2002; van der Wal and Pye, 2004), changes in wind/wave climate (e.g. Allen, 1989; Pye, 1995; Allen and Duffy, 1998; van der Wal and Pye, 2004), sediment supply (Allen, 2000), cliff morphology (e.g. Pringle, 1995; Moeller and Spencer, 2002), intertidal sedimentation (Schwimmer and Pizzuto, 2000; van der Wal et al., 2002), ice (Dionne, 1989, 2000) and changes in the location of the major tidal channel (Pringle, 1995; Pye, 1995; Shi et al., 1995). The importance of marsh edge erosion in 'feeding' the marsh surface has been acknowledged (e.g. Reed, 1988; Allen, 1996) yet few studies have directly quantified this contribution. Only very recently have studies started to incorporate the effect of spatial variations in sedimentation rates on marsh evolution within a topographic marsh gradient (Temmerman et al., 2004a), dividing the marsh into interior and levee or creek sections in their model development (French and Birmingham, 2003; Temmerman et al., 2004a) although the marsh system is still not treated as a volumetric entity. In addition, few of the aforementioned studies needed to address the impact of winter processes such as ice due to their geographical location.

This paper presents results from a component of a larger field research project examining controls on the sediment budget of a salt marsh in the Bay of Fundy. A sediment budget is a useful framework to account for all inputs and outputs of a marsh. A volumetric sediment balance approach represents a useful method to account for changes in a marsh system over time by focusing on net inputs and outputs rather than a detailed accounting of the contribution of individual