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Ecological and morphological response of brackish tidal marshland to the next century of sea level rise: Westham Island, British Columbia

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Abstract

In response to climatic warming, eustatic sea level has been predicted to rise by about 50 cm in the next century. While feedbacks between vegetation growth and sediment deposition tend to allow marshes to maintain their morphology under a constant rate of sea level rise, recent observations of marsh deterioration suggest that changes in the rate of sea level rise may induce loss of economically and ecologically important marshland. We have developed a three dimensional model of tidal marsh evolution that couples vegetation growth and sediment transport processes including bed accretion and wave erosion. We use the model to simulate the response of marshes and tidal flats along the Fraser River Delta, British Columbia to 100 yr forecasts of sea level change. Under low sea level-rise scenarios, the delta and its marshes prograde slightly, consistent with historical measurements. While accretionary processes greatly mediate the response to increased rates of sea level rise, vegetation zones transgress landward under median and high sea level rise rate scenarios. In these scenarios, low marsh erosion and constriction of high marsh vegetation against a dyke at its landward edge result in a 15–35% loss of marshland in the next century. Several important behavioral changes take place after 2050, suggesting that predictions based on field observations and short term model experiments may not adequately characterize (and sometimes underestimate) long-term change. In particular, the replacement of highly productive high marsh vegetation by less productive low marsh vegetation results in continued reduction of the system's total biomass productivity, even as the rate of loss of vegetated area begins to decline.

Keywords: sea level; accretion; erosion; ecogeomorphology; wave; wetland

1. Introduction

Tidal marshes are among the world's most ecologically productive and economically valuable ecosystems, but have recently been degrading to unvegetated mudflats or open water in many regions (Costanza et al., 1997). Tidal marshes provide habitat and nursery grounds for commercially important fin and shellfish, buffer coastal cities from storms, trap contaminants, and supply abundant organic matter to estuarine and marine environments (e.g. Turner, 1977; Patrick, 1994; Costanza et al., 1997; Mitsch and Gosselink, 2000). High sea level rise rates and low sediment supply rates are at least partially responsible for their recent decline. For

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example, vertical accretion rates that are slower than relative sea level rise rates have resulted in submergence of wetlands in Louisiana and the Chesapeake Bay region, where sediment has been diverted and rates of subsidence are high (e.g. Reed, 1995; Kearney et al., 2002). In other regions, marsh loss is dominated by erosion from waves or channels rather than vertical submergence. In New York and southeast England, the edges of marshes have been retreating in response to increased wave erosion while the interior marshland has been eroding due to channel widening and lengthening (Hartig et al., 2002; Van der Wal and Pye, 2004).

Despite losses of marshland in certain regions, long-term vertical accretion rates typically mimic sea level rise rates, suggesting that tidal marshes are generally in long-term equilibrium with sea level (Friedrichs and Perry, 2001). An increase in the rate of sea level rise typically leads to increased inundation and sediment delivery to the marsh platform, increasing its rate of accretion. An increase in water depth on the platform may also stimulate the growth of vegetation which traps sediment, further enhancing deposition rates (Morris et al., 2002). These positive relationships between inundation and accretion tend to stabilize the response of marshes to changes in rates of sea level rise, allowing a marsh to maintain its general morphology and biological productivity (Morris et al., 2002; Kirwan and Murray, 2005, 2007). However, more frequent and deeper inundation will tend to increase the volume of water flowing through the channel network and may cause the network to expand at the expense of the vegetated marsh platform (Allen, 1997). In marshes subject to wave erosion, greater tidal flat depths may decrease dissipation of wave energy and lead to greater erosion rates near the marsh margin.

A number of one-dimensional numerical models of marsh accretion have been used to explore how a marsh platform will respond to sea level change (e.g. French, 1993; Allen, 1995; Morris et al., 2002). In these models, the marsh platform accretes at a rate proportional to its depth below high tide, a proxy for inundation frequency and duration. These models predict that under a constant rate of sea level rise, a marsh deep in the tidal frame will accrete at rates greater than the rate of sea level rise. Accretion rates decline as the platform gains elevation relative to sea level, until the platform reaches an equilibrium water depth where accretion equals sea level rise. An increase in the rate of sea level rise or a decrease in the rate of sediment delivery will temporarily cause accretion rates to fall behind sea level rise rates, and the platform will deepen. Deepening continues until deposition rates (increasing with depth) match the sea level rise rate and the platform reaches a new equilibrium.

Several complications challenge the ability of existing models to predict how intertidal surfaces respond to environmental change such as changes in rates of sea level rise or sediment delivery. Suspended sediment concentrations, for example, decrease with distance from the nearest channel and strongly influence patterns and rates of platform accretion (Friedrichs and Perry, 2001). This suggests that one-dimensional accretion models cannot fully address marsh morphodynamics. Models with spatially variable accretion rates (e.g. Reyes et al., 2000; Mudd et al., 2004) do capture these effects, but do not allow for changes in the channel network, which could alter the amount of sediment available for accretion. Recent models have started to address the coupled evolution of marsh platforms and channel networks, but these are neither intended nor suited for the prediction of a specific marsh's response to sea level rise (Kirwan and Murray, 2007; D'Alpaos et al., 2007). Following Morris et al. (2002), these models assume that vegetation productivity increases with depth, as observed in a South Carolina *Spartina alterniflora* salt marsh. In other regions, however, increasing inundation appears to decrease productivity (e.g. Reed and Cahoon, 1992). In such cases, accelerated sea level rise may lead to less productive vegetation, which would lead to slower accretion and facilitate more rapid submergence. This response differs fundamentally from the stability predicted by models that involve increasing biomass productivity and accretion. Finally, wave erosion determines the seaward extent of tidal marshland in many locations (e.g. Van der Wal and Pye, 2004). Existing models relate wave erosion to bed elevation and vegetation density, but do not consider sea level rise (van de Koppel et al., 2005). If accelerated sea level rise causes a deepening of intertidal surfaces, as other models suggest (French, 1993; Morris et al., 2002; Kirwan and Murray, 2007), then the rate of wave erosion would be expected to increase with the rate of sea level rise.

Atmosphere–Ocean General Circulation Models (AOGCMs) project an acceleration of global sea level during the current century (IPCC, 2001). Although considerable uncertainty exists, a median scenario of sea level rise involves a global rate change from the late Holocene average of about 1 mm/yr to rates of about 6 mm/yr by 2100, and a total rise of about 40 cm. Higher scenarios involve maximum rates of about 11 mm/yr. Estimating a critical sea level rise rate that would drown marshes remains problematic, and depends on the local sediment supply and properties of vegetation. For example, marshes on the Yangtze River Delta accrete 14–25 mm/yr (e.g. Yang et al., 2003), while widespread deterioration of marshes has already occurred in the sediment starved Chesapeake Bay and Louisiana