Recent expansion of tidal creek networks in the South Atlantic Bight: an ecogeomorphological responses to sea level rise?

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ABSTRACT: Analyses of aerial photographs show the development of new low-order creeks throughout coastal marshes in South Carolina and Georgia over the past ~50 years. Tidal creeks in both the Santee Delta, SC and near Savannah, GA, are lengthening at a rate of 1.9 m/yr. It is likely that such a widespread phenomena is driven by sea-level change, however, the geomorphic evolution of the creeks is closely linked to ecological factors including burrowing and herbivory by crabs, vegetation density, belowground biomass and, consequently, soil strength. The heads of the creeks are de-vegetated as a result of high densities of Sesarma reticulatum (up to 35 individuals/m^2 in creek heads compared to 2 individuals/m^2 at control sites on the marsh platform). Grazing and burrowing by these crabs removes organic and inorganic matter. This occurs directly by reducing above and belowground biomass (belowground reduction from 1.9 ± 0.7 kg/m^2 to 0.8 ± 0.3 kg/m^2) and indirectly by increasing aerobic decomposition. The result is: 1) reduced soil strengths in the creek head (reduction from 10 ± 7 kPa to 2 ± 1 kPa) and; 2) the deflation of the marsh surface (~ 0.6 m) in the same area which focuses ebb tidal flows into the creek, increasing local velocities and, thus, erosion. A net export of sediment is observed through the creek mouth. The enhanced erodibility of marsh soil, attributable to the fauna, facilitates erosion as creeks grow in response to increasing tidal prisms. The removal of vegetation is also likely to be responsible for the very low sinuosity observed in the creek morphology.

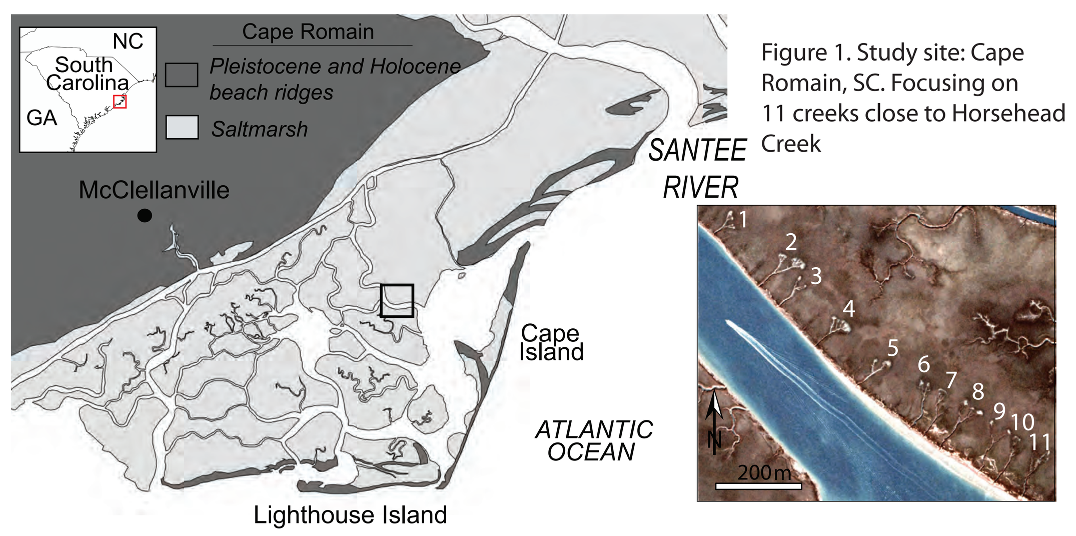
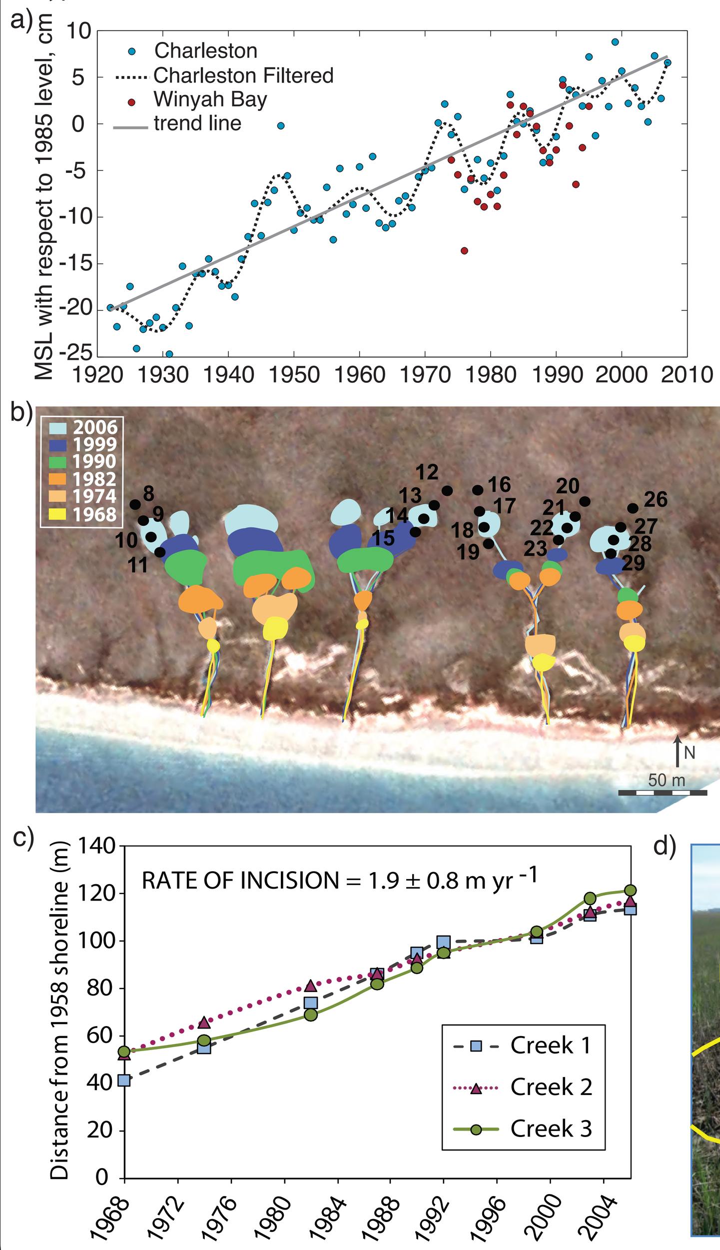
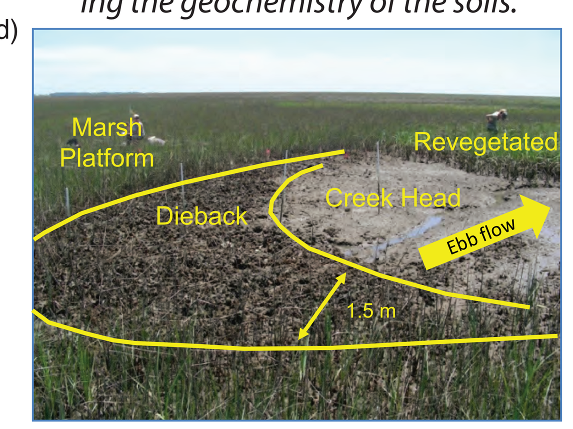


Figure 1. Study site: Cape Romain, SC. Focusing on 11 creeks close to Horsehead Creek

Introduction

Figure 2. a) Sea leveshowing the evolution of creeks in the study area from aerial phtograph analysis c) rate of incision s) image of a typical creek head.





The shoreline of South Carolina (1a) from Charleston to Winyah Bay is experiencing sea level rise of on average 3.2 mm/yr (2a; Hughes et al 2009). In this region, low sinuosity creeks (2b) have been observed incising into the marsh platform at a rate of 1.9 m/yr (+/- 0.8 m; n=100) over the last 50 years (2c). These creeks have a bare heavily burrowed region at the head of the creek (2d) with a region of dieback of the Spartina alterniflora between the bare creek head and the marsh platform. This study aims to determine the mechanisms responsible for rapid creek extension, including the effect of bioturbation and biostabilization.

We hypothesize: Vegetation is removed as a result of crab activity. Removal of vegetation weakens soils facilitating erosion and creek extension. Crab bioturbation is assisting the erosion of material from creek heads and impacting the geochemistry of the soils.

Ecological observations

Ecolcogical observation focused on 11 creeks along the shore of Horsehead creek (1b), each exhibiting 2 or more creek heads. The density of 4 crab species [*Sesarma reticulartum; Uca pugnax; Eurytium limostum; Panopeus herbstii*] was examined in 4 zones [marsh platform; live zone (just beyond the edge of the dieback zone), live/dead zone (on the outer edge of the dieback zone where some vegetation remained alive); dead (no vegetation)]. ***S. reticulartum* were found in very high densities at the leading edge of the dieback zone but minimal presence on the marsh platform (3b). Other crabs showed no significant increase in density in the creek head, however over all crab density was highest in the live/dead zone (3a). An inverse relationship was also seen between burrow density and *S. alterniflora* stem density in the dieback region (3e).**

Vegetation manipulations were carried out from 2007 to 2011, the extension of a control creek was compared to the extension of a creek head where the vegetation had been removed (herbicide; 3c). **The removal of vegetation resulted in a 50% increase in rate of incision over the observational period (3d).**

A mesocosm experiment was carried out to determine the impact of crab density of each species on vegetation density and soil excavation [*Uca* and *Sesarma*: 5 treatments (0, 1, 2, 4, 8), 4 replicates each. *Panopeus* and *Eurytium*:2 treatments (0, 2), 5 replicates for density 2, 4 replicates for density 0]. **Only S. reticulartum were found to have a significant detrimental impact on the vegetation (4 b,c) reducing above and below ground biomass, they were also found to excavate at a higher rate than other crab species (3f, g, h). When combined with crab density data we extrapolate that the highest rates of excavation will occur in the live/dead zone, soil may be overturned multiple times per year (3i).**

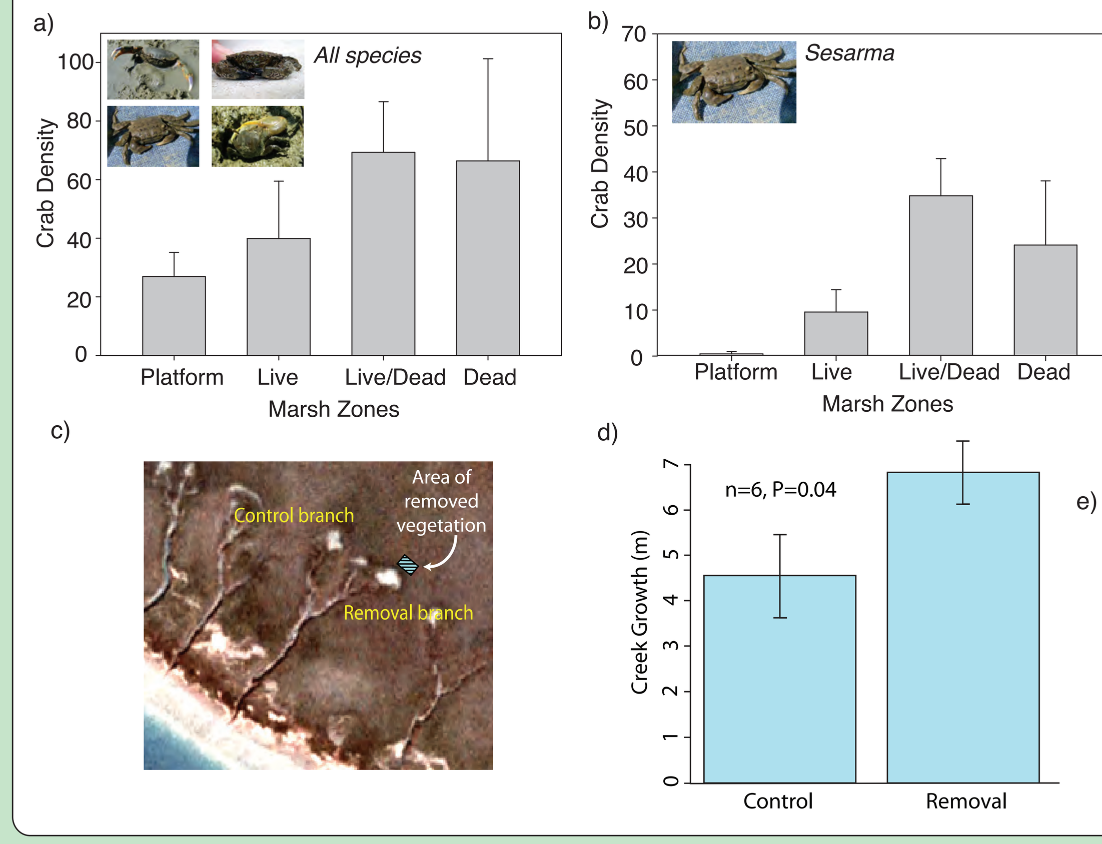
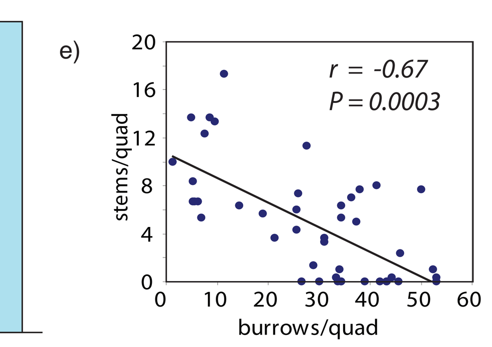
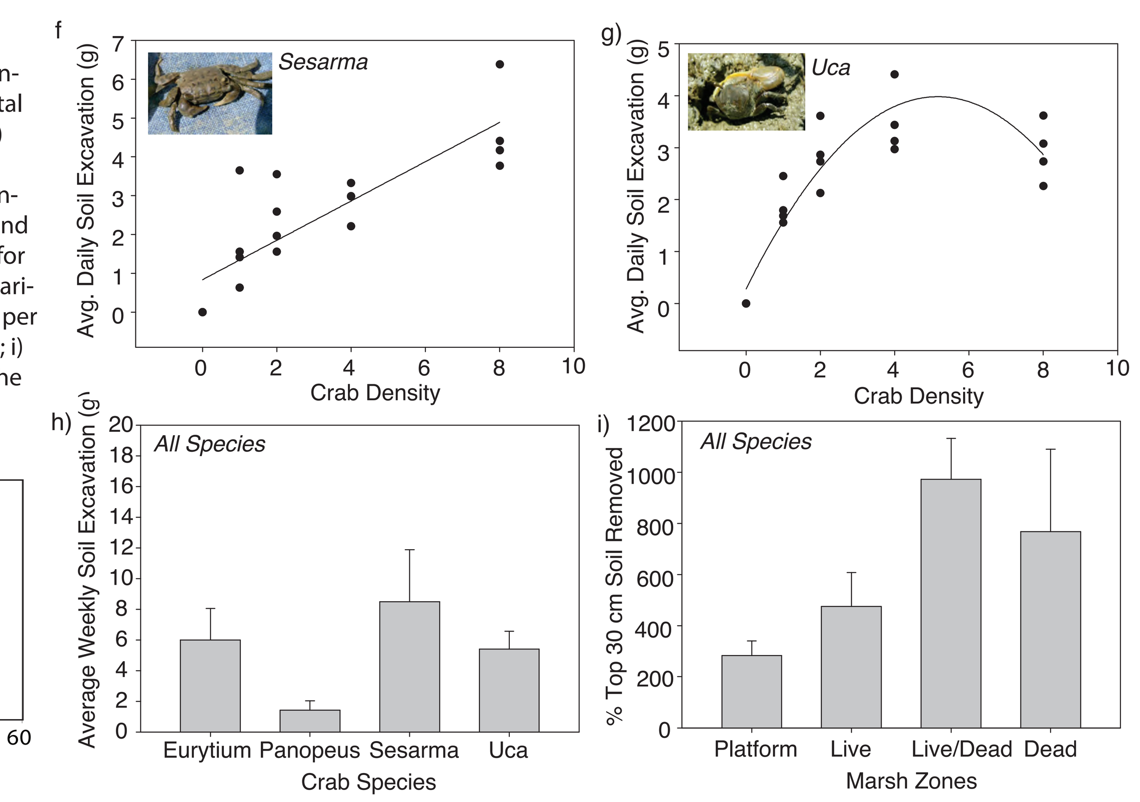


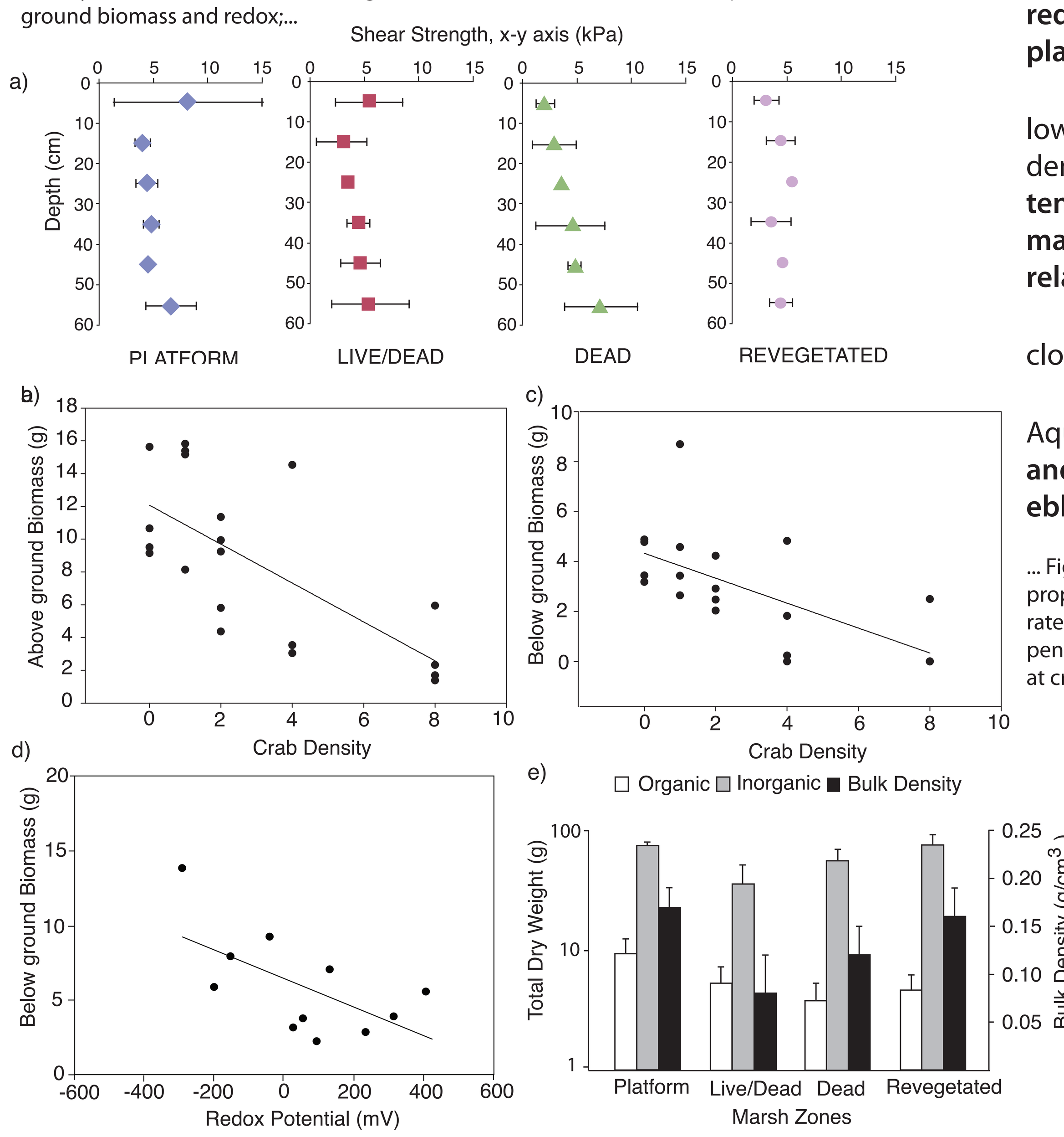
Figure 3 a) crab density in each creek head zone b) sesarma density in each zone; c) experimental setup of vegetation removal; d) vegetation removal impact on creek growth; e) inverse relationship between burrow density and stem density; excavation rates for f) *Sesarma* and g) *Uca*; h) comparison of excavation rate per crab per week for each crab species and; i) cumulative excavation across the creek head.





Physical observations

Figure 4 a) Shear strength of soil in each zone with depth; inverse relationship between Sesarma density and b) above amd b) below ground biomass; d) inverse relationship between below ground biomass and redox;...



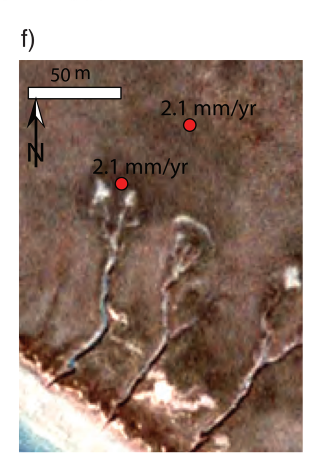
Physical observations included focused on 5 creeks heads (creeks 6, 8, 9 and 10 for geotechnical and 7 for hydrodynamics; 2b). Geotechnical measurements were taken at 4 points along 5 transects from the marsh platform through the creek head into the revegetated area behind the creek head. Measurements included shear strength (Seiken shear vane). **Strength was found to be significantly reduced in the top 10 cm of the dead zone, where there is no vegetation, compared to the marsh platform (reduction from 10 ± 7 kPa to 2 ± 1 kPa; 4a).**

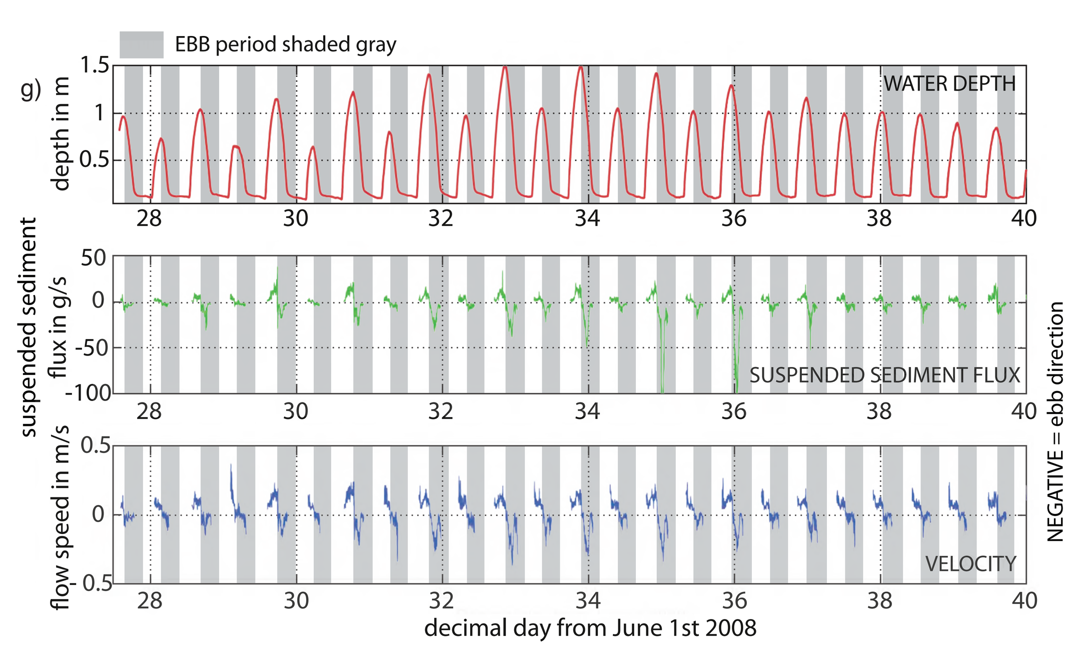
Bulk density, inorganic/organic component of the soil (Loss on Ignition), redox potential and belowground biomass were also measured in each core. Both the mesocosm and field experiments demonstrated lower below ground biomass in the creek head. **The bulk density and inorganic content were reduced in the dieback zone where burrowing is highest, but some belowground biomass exists. In the weak dead zone bulk density and inorganic content are increased. An inverse relationship was seen between redox potential and biomass.**

Accretion rates on the marsh platform determined using ^{210}Pb were found to be 2.1 mm/yr both close to the creek head and on the marsh platform. This is a relatively low rate for a low marsh.

Measurements of water and suspended sediment flux were taken at a creek head using a Nortek Aquadopp and an optical backscatter sensor. **An ebb asymmetry was observed in the flow regime and a net loss of sediment was observed with high sediment fluxes occurring during peak spring ebb flows.**

... Figure 4 ontd. e) geotechnical properties of each zone; f) accretion rates (210Pb); g) water depth; suspended sediment flux and velocity at creek 7 mouth.





Conclusions and conceptual model

-- Removal of vegetation facilitates creek growth.

-- Burrowing and herbivory by *S. reticulartum* removes above and belowground biomass (*S. alterniflora*).

-- Burrowing by crabs also dislodges a large amount of sediment, particularly in the outer regions of the dieback zone.

-- Intense crab bioturbation (*S. reticulartum*) significantly changes the biogeochemical properties of the soil (redox potential, belowground biomass, bulk density and soil strength). This is described in the conceptual model (5).

-- Oxidized conditions in the upper 10-20 cm of the marsh induced by burrowing causes enhanced degradation of *S.alterniflora* belowground biomass (roots and rhizomes), which reduces the structural integrity of the soil (Howes et al 2010).

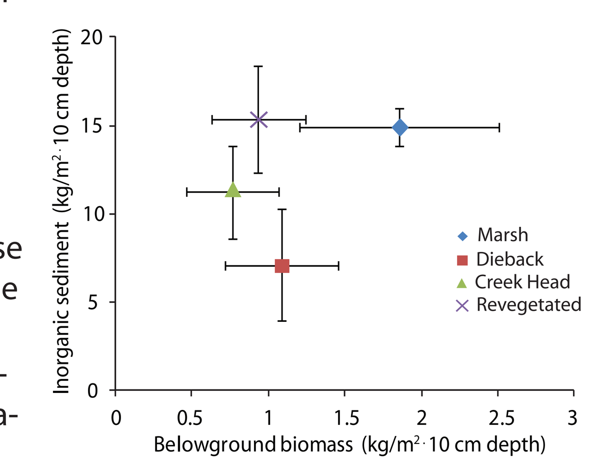
-- Crab activity increases the erosion potential of sediment in creek head areas, documented by a reduction in shear strength.

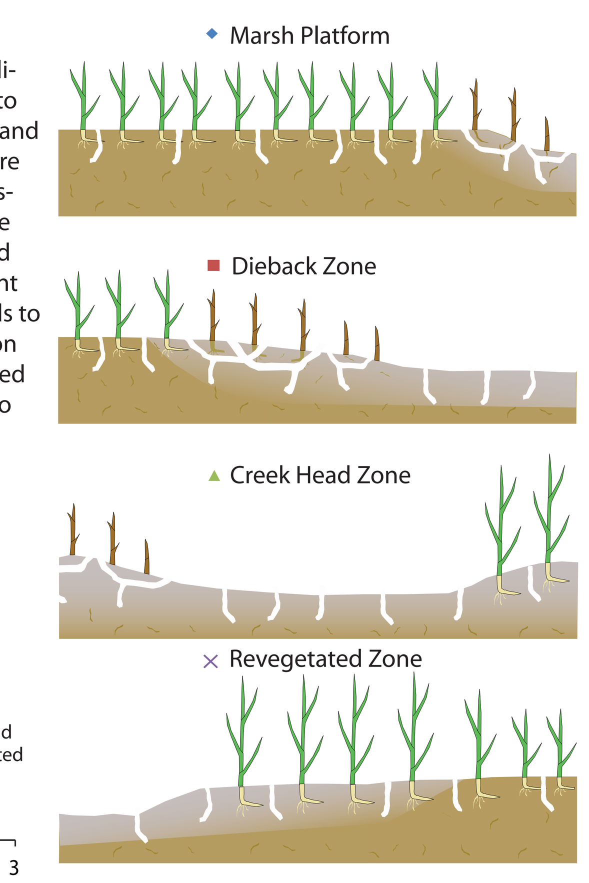
-- Accretion rates at the site are lower than rates of sea level rise, implying even higher rates of relative sea level rise at the site.

Channels forming in regions without vegetation are likely to be less sinuous than those forming in regions of vegetation (Garofalo, 1980). This may explain the low sinuosity of the channels, which are then stabilized as the region is revegetated.

Pervasiveness of similar tidal creek morphology in southeast Atlantic saltmarshes suggests this is a ubiquitous process for marshes with a moderate tidal range undergoing sea-level rise

Figure 5. Conceptual model of bioturbation facilitated creek incision. a) Marsh platform proximal to creek head is vegetated by Spartina alterniflora and moderately bioturbated by Uca sp. crab; b) severe bioturbation and herbivory of creek edge by Sesarma reticulatum and oxygenation of subsurface contributes to loss in belowground biomass and weakening of remaining sediment; c) subsequent loss in elevation from deflation and erosion leads to focusing of tidal flows and allows creek extension into area; d) former creek head area is revegetated with tall-form S. alterniflora as creek continues to incise marsh platform





Citations and Acknowledgements

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Funding for this study was provided by NICCR/Dept of Energy TUL-539-06/07 and TUL-603-09/10, and by Fish and Wildlife Cost Share Award 40181AG046.
We gratefully acknowledge the assistance of Alex Kolker; Nick Howes, Chris Hein, Andre Schein, Michelle Jordan, Erica Ross, Brittany Schhwartz, Bob Baldwin, the Belle Baruch Marine Laboratory, and the Pate Estate