Cross site analysis and synthesis of the role of vegetation, sediment supply, sea level rise and storminess on intertidal coastal geomorphology

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Main Goals

The proposed research focused on development of a cross site applicable model to Plum Island Ecosystems (PIE), Virginia Coast Reserve(VCR) and the Georgia Coastal Ecosystems (GCE) LTER sites in which the morphological co-evolution of the tidal basin and salt marsh is determined by site specific environmental drivers including tides, wind waves, sediment supply and sea level rise (SLR). The model was built on prior work examining feedbacks between salt marsh platform stability autochthonous soil formation and sediment supply[*Fagherazzi et al.*, 2012; *Kirwan and Mudd*, 2012; *Mariotti and Fagherazzi*, 2013] as well as feedbacks between tidal basin vegetation and sediment resuspension [*Carr et al.*, 2010]. As a result, the model directly incorporated feedbacks that exist between vegetation, hydrologic and geomorphic drivers and synthesized our understanding of how ongoing site specific 1) anthropogenic (sediment supply), 2) pulse (storms) and 3) press (SLR) stressors affect stable states and non-linear transitions of the coupled salt marsh tidal basin system across the three sites.

The proposed research directly addressed the need to characterize the “natural templates vulnerability to climate change.” While this research focuses on responses in the natural template (intertidal ecogeomorpholoy), the coupling to anthropogenic influences on sediment supply allowed for examining how "human and natural templates interact to affect vulnerability to climate change in coastal systems."

Major activities:

We developed simple coupled model (Figure 1) where an idealized back barrier marsh is coupled to an adjacent tidal flat. The flat is connected to some external body of water (tidal channel/ tidal inlet) which acts as a source allochthonous sediment. Ignoring SLR, autochthonous sediment production and allochthonous sediment influx, the model conserves fluid volume between two conceptual boxes with unit width defined by 3 independent variables. These boxes are defined completely by, average marsh platform depth, d_m, and average depth to the tidal flat, d_f, both relative to mean high water (MHW)and the length of the tidal flat, b_f given that the total basin is constrained to a total length L (Figure 1). In this manner, any changes in the tidal flat depth or tidal flat length due to wind wave erosion affects both the depth and width of the marsh platform, and vice versa.

The results of the model were split into two manuscripts. The first manuscript focuses on the base model and the new insights gained from that model alone, predominantly focusing on the dual role of salt marsh retract. The second manuscript focused on the similarities and differences that arise amongst the three LTER sites. In particular how the presence of seagrass, sediment bypass and allochthonous sediment supply affect the long term trajectories of coupled tidal flat salt marsh systems of the PIE, VCR and GCE LTER sites.

Off shore wind data for NOAA sties were compiled and transformed to acquire the predominant wind speed and direction for the three sites for cross comparison to drive the model.

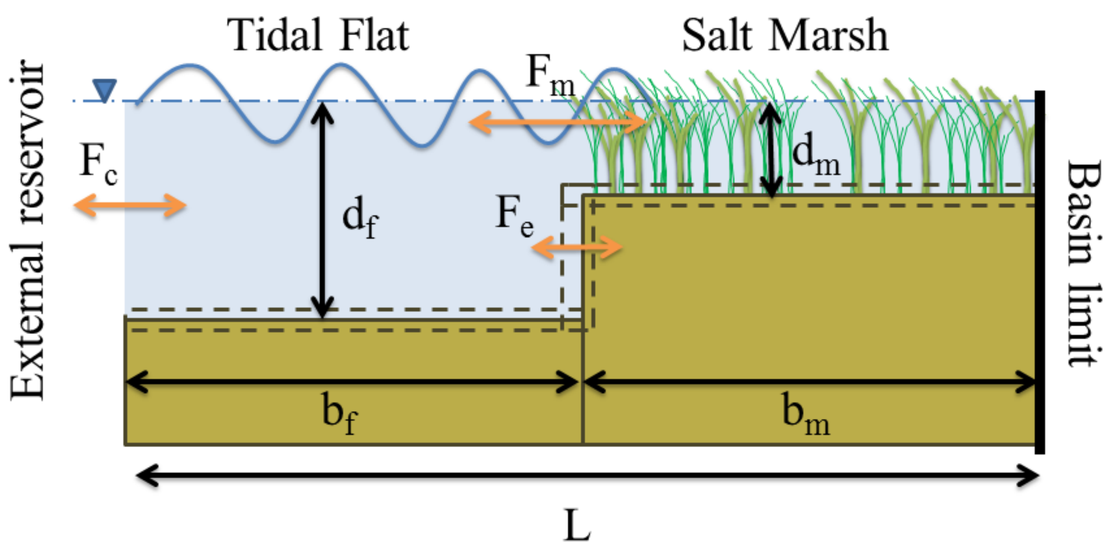

Figure 1. Scheme of the basin. Three independent variables are used to describe the basin geometry: salt marsh depth, d_m, mudflat depth, d_f, and mudflat width, b_f. Assuming a fixed width of the basin, L, the marsh width, b_m, is a dependent variable. The exchange of sediment from the external reservoir and the tidal flat is denoted by F_c, fluxes arising from boundary erosion or accretion, F_e, and F_m is the sediment flux to vertical marsh surface from the tidal flat.

Specific Objectives:

The model directly incorporates feedbacks that exist between vegetation, hydrologic and geomorphic drivers and was used to synthesized our understanding of how ongoing site specific 1) anthropogenic (sediment supply), 2) pulse (storms) and 3) press (SLR) stressors affect stable states and non-linear transitions of the coupled salt marsh tidal basin system across the three sites.

Significant results:

The model was applied to examine potential trajectories of salt marshes on the Eastern seaboard of the United States, including those in the Plum Island Ecosystems (PIE), Virginia Coast Reserve (VCR) and Georgia Coastal Ecosystems (GCE) long term ecological research (LTER) sites. While these sites are undergoing similar rates of relative sea level rise (RSLR), they have distinct differences in site specific environmental drivers including tides, wind waves, allochthonous sediment supply and the presence or absence of seagrass. These differences lead to the emergence of altered behaviors in the coupled salt marsh-tidal flat system. For marsh systems without seagrass or significant riverine sediment supply, conditions similar to those at PIE, results indicated that horizontal and vertical marsh evolution respond in opposing ways to wave induced processes. Marsh horizontal retreat is triggered by large mudflats and strong winds, whereas small mudflats and weak winds reduce the sediment supply to the salt marsh, decreasing its capability to keep pace with sea level rise. Marsh expansion and an eventual lateral equilibrium are possible only with large allochthonous sediment supply. Once marshes expanded, marsh retreat can be prevented by a sediment supply smaller than the one that filled the basin. At the GCE, the Altamaha River allows for enhanced allochthonous supply directly to the salt marsh platform, reducing the importance of waves on the tidal flat. As a result, infilling or retreat become the most prevalent behaviors. For the VCR, the presence of seagrass decreases near bed shear stresses and sediment flux to the salt marsh platform, however, seagrass also reduces the wave energy acting on the boundary of the marsh reducing boundary erosion. Results indicate that the reduction in wave power allows for seagrass to provide a strong stabilizing effect on the coupled salt marsh tidal flat system, but as external sediment supply increases and light conditions decline the system reverts to that of a bare tidal flat. Across all systems and with current rates of sea level rise, retreat is a more likely marsh loss modality than drowning.

Key outcomes:

Marsh erosion allows for wider deeper flats providing increased sediment supply to the marsh allowing for the marsh platform to maintain pace with sea level rise. This behavior describes a prior unrecognized mechanism of marsh resilience to SLR, however this mechanism is at the expense of marsh horizontal expanse. Similarly, the model showed that extensive marshes coupled to small(narrow) tidal flats, are more susceptible to drowning form SLR as marsh boundary erosions does not occur fast enough to provide the require sediment. These results are both affected by sediment bypass, as direct tidal input riverine sediment rather than tidal input form wind suspension. So while the salt marshes of the GCE are extensive with small coupled tidal flats appear to be highly susceptible to drowning by SLR, when sediment bypass is incorporated, these salt marsh tidal flat systems are relatively stable. This also partially explains the limited extent of saltmarshes at PIE, as significant anthropogenic use of the Ipswich river has significantly reduced allochthonous sediment supply.   It is most likely that the salt marshes of the PIE would be more extensive under original flow and sediment supply. Regardless, marsh lateral expansion and marsh platform equilibrium with sea level rise are possible only with large allochthonous sediment supply.

The addition of seagrass allowed for determining if seagrass acts primarily as a sediment sink, starving the marsh platform of the necessary sediment to maintain pace with SLR, or if the reduction in wave energy due to the presence of extensive seagrass meadows stabilize the marsh boundary. Both situations were found to occur. Seagrasses can starve the marsh platform of sediment, impeding the ability of the marsh to keep pace with sea level rise leading to drowning of the marsh. This occurs at very low external sediment loading and is enhanced when the tidal flat is small and already more prone to drowning. However, as fetch increases, seagrasses act in a beneficial way to the marsh by both maintaining shallower tidal flat depths and reducing wave energy acting on the marsh boundary. As such the presence of seagrass can provide stability to the marsh platform under low allochthonous sediment supply.   This effect is strongly fetch and sediment supply dependent as large external sediment loading and increased fetch (associated with deeper flats, larger waves) both result in more sediment in suspension and poorer light conditions favoring loss of the submerged aquatic vegetation.

How have the results been disseminated to communities of interest?

Papers:

Mariotti G. and J. Carr.(*in review)* Dual role of salt marsh retreat, long term loss and short term resilience. Water Resources Research

Carr J., Mariotti G., Fahgerazzi S., Wiberg P. and k. McGlathery. (*in preparation*) Differences among potential trajectories of coupled salt marsh tidal flats systems on the Eastern seaboard of the United States.

Presentations:

How do how internal and external processes affect the behaviors of coupled marsh mudflat systems; infill, stabilize, retreat, or drown?" Submitted Abstract to the AGU Fall meeting 2013.

Impacts on other disciplines:

The studies here provided insight into the relative importance of vertical and lateral accretion and loss of the salt marsh system when considering a coupled tidal flat and incorporating processes on the tidal flat. This emphasizes the importance of understanding of how benthic vegetation influences the fluid dynamic, sediment and wave characteristics impacting both the tidal flat and marsh. Thus, this study impacts the fields of ecohydrology and opens up more research possibilities that exist when linking and coupling systems with nonlinear dynamics.

What is the impact on society beyond science and technology?

One unique result of this study was that wave erosion of a marsh boundary, while leading to loss of marsh area, enhances the ability of the entire marsh platform to maintain pace with sea level rise. Another counterintuitive result was extensive salt marshes with small tidal flats are actually more susceptible to SLR, especially if future anthropogenic modifications reduce allochthonous sediment supply (sites similar to GCE). As well the large seagrass restoration effort at the VCR will potentially have stabilizing effects on the marsh boundaries through the reduction of wave energy as these systems already have large tidal flats. As a result these nonlinear interactions should be considered for management and conservation practices.

Contribution to the field:

This work highlights the importance of both internal and external processes in the long term trajectories of coupled salt marsh tidal flat systems. Moreover, the work emphasizes the impact that direct anthropogenic interference can have on these system. Prior thoughts indicate that salt marsh systems are highly unstable[*Fagherazzi et al.*, 2012; *Mariotti and Fagherazzi*, 2013], either collapsing or prograding, the results here indicate that under a wide range of SLR and allochthonous sediment supply, stable tidal flat salt marsh systems are possible emphasizing the importance of coupling both horizontal and vertical processes affecting these systems with enhanced stability arising for systems with the submerged aquatic vegetation

References:

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Fagherazzi, S. et al. (2012), Numerical models of salt marsh evolution: Ecological, geomorphic, and climatic factors, *Rev. Geophys.*, *50*(1), n/a–n/a, doi:10.1029/2011RG000359.

Kirwan, M. L., and S. M. Mudd (2012), Response of salt-marsh carbon accumulation to climate change, *Nature*, *489*(7417), 550–553, doi:10.1038/nature11440.

Mariotti, G., and S. Fagherazzi (2013), Critical width of tidal flats triggers marsh collapse in the absence of sea-level rise, *Proc. Natl. Acad. Sci.*, *110*(14), 5353–5356, doi:10.1073/pnas.1219600110.