PIE 2012 Addendum

The NSF program officers asked for an addendum to PIE in order to provide more detail on our plans to strengthen to the component on geomorphology and to better quantify ecological and geomorphic changes over time. The information below was provided to the program officer in a letter.

The development of our thinking about the importance of the geomorphic features in the coastal zone has been aided by our collaboration with Sergio Fagherazzi, a coastal geomorpholgist at Boston University and now (2013) a PIE-LTER PI. Fagherazzi and co-workers (including PIE-LTER PI Linda Deegan, and Boston University marsh geomorphologist Duncan FitzGerald) have been examining the feedbacks between tidal flats and salt marshes on the ETBC Collaborative Research Project: "Feedbacks between nutrient enrichment and intertidal sediments: erosion, stabilization, and landscape evolution" (LENS). Their specific aims have been to: 1) Determine how nutrient enrichment affects sediment erosion and stabilization, and therefore the morphology of tidal flats and salt marshes; 2) Determine how nutrient enrichment alters the landscape and ultimately modifies biogeochemical cycles and ecosystems. This project has been carried out in close collaboration with the PIE large scale nutrient enrichment experiment (TIDE) and the LTER.

As part of this project Fagherazzi and co-workers are developing a set of geomorphic models for the evolution of the intertidal landscape in Plum Island. Both efforts have been supported by PIE-LTER and we have provided logistical help and information needed for the modeling such as detailed bathymetry, LIDAR, biomass, and climate information. As the LENS project ends in 2013, Fagherazzi and his group will continue the research on the geomorphology of Plum Island Sound under the PIE-LTER, developing long-term datasets and numerical models that will be deposited in the LTER database. To this end Fagherazzi's group will also take advantage of a field class for undergraduate students, which is part of the Boston University Marine Program (BUMP). The students have already collected four years of marsh boundary data and geotechnical parameters, and four years of marsh channel morphology.

Geomorphological Approach

The goal of this long-term project as part of the PIE-LTER is to complement the vertical data collected by Morris and provide a three-dimensional description of the evolution of the entire intertidal systems, including salt marshes, tidal channels, and tidal flats (see Fagherazzi et al. 2012 for a review). Our holistic approach to salt marsh evolution is divided in four different tasks that will be combined in a unified framework:

1. Vertical evolution of the salt marsh and feedbacks with vegetation processes
2. Morphodynamic evolution of tidal channels dissecting the marsh platform
3. Erosion and progradation of the marsh boundary
4. Coupling between salt marshes and tidal flats

Vertical evolution of the salt marsh and feedbacks with vegetation processes (Morris)
We believe that MEM model developed by Morris et al 2002 fits into this larger picture of geomorphic change, and that further testing and development of MEM are key aspect of making progress in this area. Most of the current models of marsh evolution use the basic formulation of MEM to calculate biomass and sediment deposition on the marsh platform (including Kirwin and Murray 2007). Morris and co-workers recently were able to couple MEM with the hydrodynamic model, ADCIRC, and use it to understand and forecast geomorphological changes in marsh landscapes (Hagen, S.C. et al submitted). While MEM alone will not allow for the development of creek patterns it is a key aspect to moving forward with a coupled 3-D model of the marsh landscape. In the remaining 4 years of PIE III we will examine three aspects of MEM where more information is needed. First, we will examine whether inter-annual changes in above ground biomass due to changes in sea level are tracked by belowground biomass (through experiments with marsh organs) and whole systems carbon balance (eddy flux tower). Second, we will continue to examine how changes in nutrients affect both marsh above and below ground marsh production (TIDES and marsh organs) and sediment decomposition (through lab experiments on peat lability). Finally, we will continue to examine how above ground biomass influences sediment accretion under a variety of conditions in both *Spartina patens* and *Spartina alterniflora* marshes. We believe these are all areas were we need to increase our understanding of marsh evolution to successfully move exclusively to a 3D model.

Morphodynamic evolution of tidal channels dissecting the marsh platform (Fagherazzi)
For this task we are using models that simulate the long-term evolution of tidal channels, and how they respond to external drivers like sea level rise, sediment availability, and nutrient loading. The first model addresses the evolution of channel cross sections as a function of water fluxes and vegetation drag (Fagherazzi and Furbish 2001, D'Alpaos et al. 2006) (See Fig. 2). We will add to this model a geotechnical module for the stability of channel banks, including the effect of vegetation. The goal is to understand how the channels are responding to changes in tidal prism driven by sea level rise. The numerical results will be combined to planimetric models for the evolution of the channel network developed in recent years by Fagherazzi's group (Fagherazzi and Sun 2003; D'Alpaos et al. 2006). It is important to note that 3D current models of marsh evolution (e.g. Kirwan and Murray 2007, D'Alpaos et al. 2007) do not address in detail channel morphodynamics and the complex feedbacks between flow, vegetation, and bank stability.

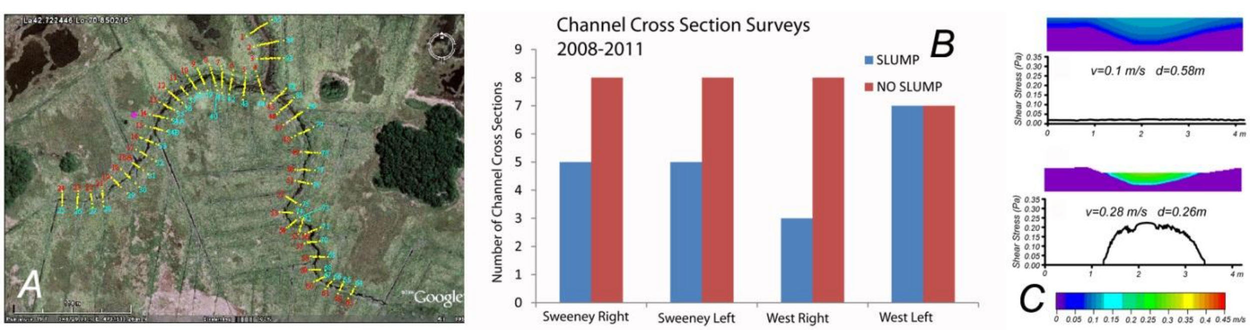

Figure 1 Tidal channel evolution at PIE a) long-term survey of channel geometry (2008-2011); b) quantification of channel slumping at the banks; c) high resolution numerical model for channel flow and its effects on bank stability.

Erosion and progradation of the marsh boundary (Fagherazzi)

We have been collecting data on the dynamics of the marsh boundary for four years at three locations in PIE, including geotechnical parameters and the stabilizing effect of roots (see Fig. 2). We are planning an instrument deployment to quantify the effect of waves and storm surges on scarp erosion. The goal of this task is to determine the processes responsible for the long-term erosion of the marsh and its effect on the overall repartition of the intertidal area between salt marshes and tidal flats (Fagherazzi et al. 2006,2007). The collected data will refine an already existing model for marsh boundary evolution (Mariotti and Fagherazzi 2010). A similar effort is underway at VCR-LTER lead by Fagherazzi and Wiberg, so this project represents an example of cross-site comparison, shedding light on the different response of mesotidal and microtidal systems to global change.

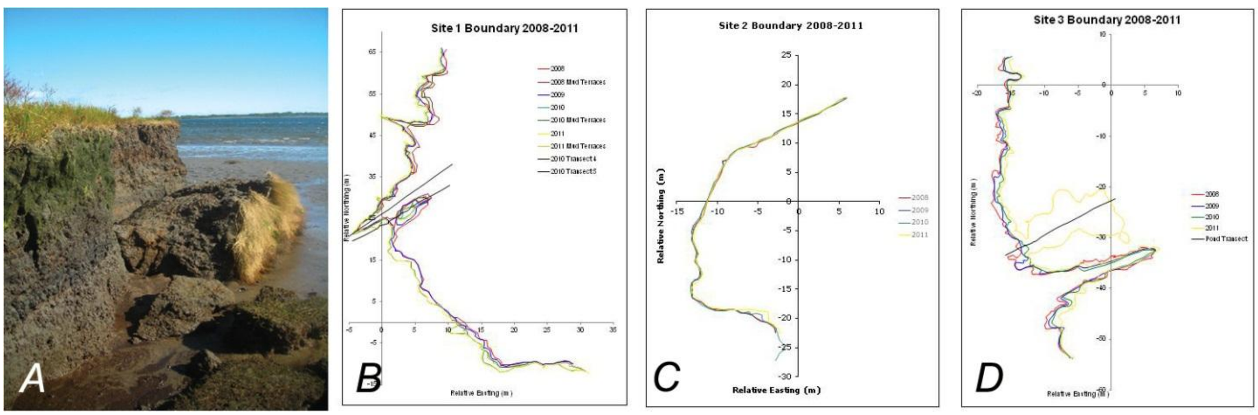

Figure 2 a) Erosion of the marsh scarp caused by wind waves; b), c), d) Long-term measurements of marsh boundary dynamics (four surveys from 2008 to 2011)

Coupling between salt marshes and tidal flats (Fagherazzi)

We agree with the reviewers that to fully answer all of our questions, a 3D model of marsh evolution is needed. We anticipate that future 3D modeling at PIE will build off of the framework established by the LENS project. In particular, Fagherazzi's team is modeling the co-evolution of salt marshes and tidal flats by quantifying the exchange of sediments between Plum Island Sound and the marshes. To this end the 3D sediment transport model Delft3D was set up for the entire Plum Island System, and coupled to the wave model SWAN (see Fig.3). The model will be tested using data collected from a large scale instrument deployment (four acoustic doppler current profilers deployed for two months within the tidal channel network and in the sound, with ISCO samplers collecting SSC and nutrients). We are also determining the potential resuspension of tidal flat sediments, and how this source of material might help the salt marsh to withstand sea level rise. In particular, we are studying how biogeochemical processes affect sediment mobilization and stability in tidal flats, and how sediment availability in these systems might change under different storm conditions and sea level rise. Whereas current models of salt marsh evolution assume a constant input of sediment concentration at the boundaries (Kirwan et al. 2010,Fagherazzi et al. 2012) we believe that sediment supply is dictated by the feedbacks between salt marshes and surrounding tidal flats, and only a coupled framework can determine the fate of salt marshes under global change (e.g. Mariotti and Fagherazzi 2010, Mariotti et al. 2010).

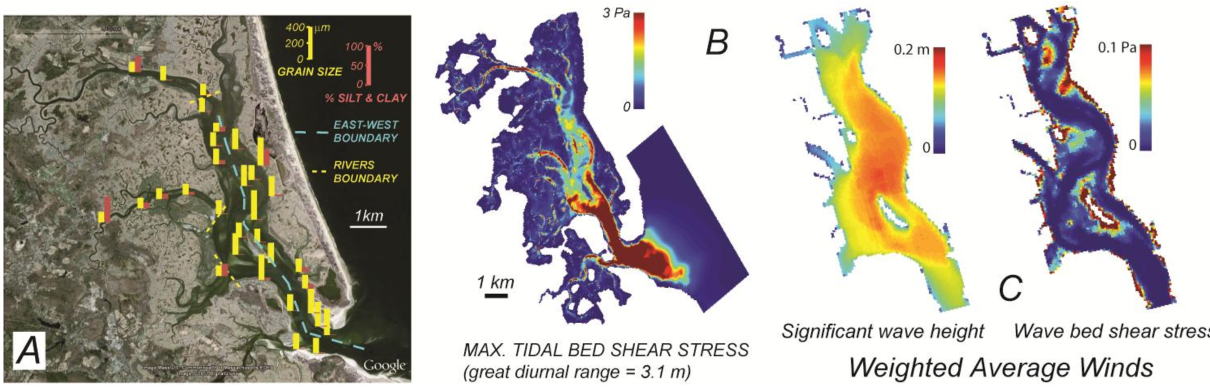

Figure 3. Coupling between PIE salt marshes and tidal flats. a) Sediment distribution in Plum Island Sound b) potential sediment resuspension driven by tidal hydrodynamics (simulation with the model Delft3D) c) potential sediment resuspension in the sound driven by waves (simulation with the model SWAN).

Integrated modeling framework for salt marsh evolution (Fagherazzi, Morris, others)
The plan is that during PIE IV the four research activities outlined above will be merged in a comprehensive model for salt marsh evolution (Fig. 4). The model will address the full trajectory of the system under different scenarios of global change. The model will also determine the response of the marshes to anthropogenic disturbances like nutrient overloading and reduction in sediment availability. By combining the vertical dynamics of the marsh platform with the horizontal dynamics of marsh boundaries and channel evolution, our approach will: a) determine all the fluxes of sediments and organic material critical for marsh survival; b) represent the full three dimensional morphology of the marsh and its evolution in time.

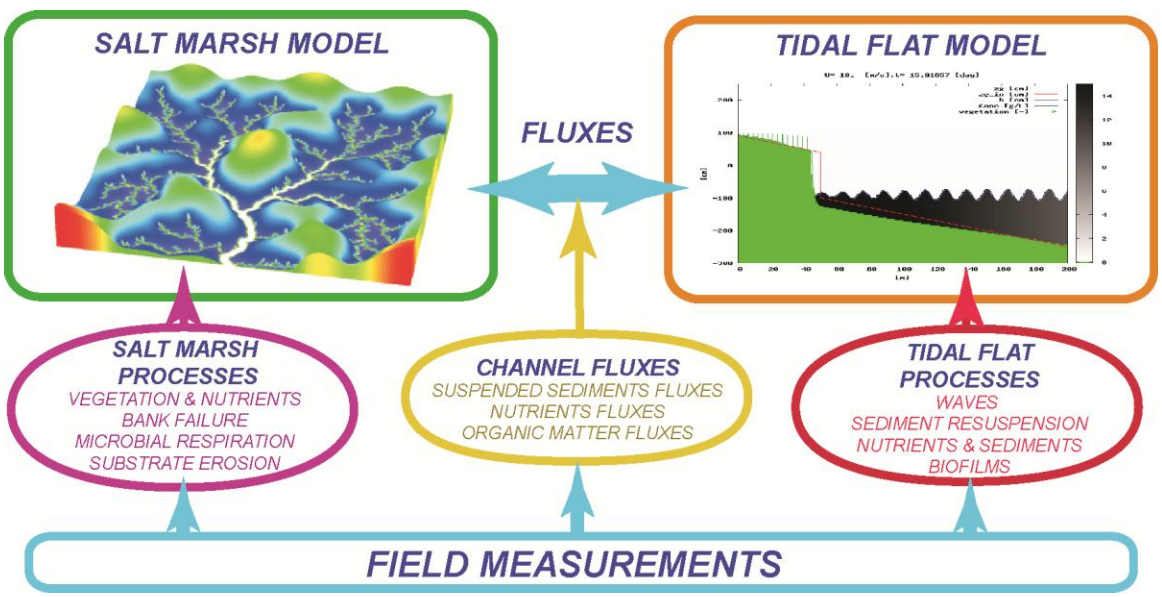

Figure 4 Modeling framework. All geomorphic models will be integrated and validated with field measurements.

The reviewers commented that a comparison of a historical map with an aerial photograph with a few summary statistics was inadequate to support the notion of rapid change driven by sea level. Again, we agree. A more quantitative description of marsh change over time is proposed for the next 4 years but at the time of the proposal submission we did not have the complete data in hand, nor had we analyzed it all. New LIDAR data (flown in 2011) is expected to be available shortly. This data can be compared to the 2006 data we have, giving us a very detailed short term (5 year) window on change. The other available aerial and remote sensing data will give us a longer term, decadal perspective. We believe we have sufficient expertise to analyze these data. Our LTER co-investigators at the School of Geography at Clark University, which has a strong program in geo-spatial image analysis and developed IDRSI, and continued collaborations with partners such as Thomas Millette (Holyoke College) and Vinton Valentine (previous post-doc on the PIE LTER) provide additional expertise to complete these analyses.

If funded, we will be sure to include this information for the mid-term review panel, and discuss how we see our program progressing in the future.

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