Coastal wetlands provide a diverse array of ecosystem services, including cleansing water supplies, buffering from storm and flood damage, and harboring rich biodiversity\(^1\). With the increasing pressure of climate change, rising sea-levels and changing storm frequency and intensity will continue to expose coastal wetlands to greater risk of inundation, erosion, and loss of habitat\(^2\). Understanding vulnerability of coastal ecosystems is essential for management that improves the resilience of wetland ecosystems to climate change\(^3\).

I propose to study the resilience of coastal wetlands by analyzing the effects of sediment load, as driven by past and present land use, on wetland elevation dynamics (formation and subsidence). The core hypotheses to be addressed are 1) that intensive land use practices from colonial era deforestation and agriculture increased sediment deposition and lead to coastal wetland formation; 2) that subsequent reductions in sediment concentration, through dam proliferation, have decreased resilience of coastal wetlands to perturbation; and 3) that coastal wetlands are maintained in their current abundant configuration by an internal positive feedback loop (Fig. 1). By understanding how and where colonial marshes (established after European settlement) formed and how they are maintained, we can better predict the potential extent of wetland persistence and loss in the face of sea level rise (SLR).

**Can coastal wetlands keep pace with sea-level rise?**

As global climate change affects the rate of SLR, long-term persistence of coastal wetlands depends on maintenance of surface elevations relative to sea-level. Marsh platform elevation is sustained through organic matter generation and inorganic sediment deposition, and therefore responds positively or negatively to external forcing factors\(^2, 15, 19\) (e.g. SLR, fire, flooding, or sediment loading). Sediment inputs to a coastal area can determine the ability of marshes to maintain elevation\(^4, 12, 20, 24\). Certain land use practices, including deforestation, construction and agriculture, can increase erosion from a watershed\(^3, 25\) and therefore sediment deposition in coastal wetlands. Some evidence suggests that high sediment loads during European settlement and colonization (from deforestation and agriculture) expanded marshes along the eastern seaboard\(^12, 24\). Since the modern influence of water quality regulations and dams,
sediment concentration from riverine inputs has decreased, possibly reducing the marsh platform elevations and accretion rates in coastal wetlands\textsuperscript{12, 24}. Therefore, upstream land use and channel alterations could affect responses of coastal wetlands to climate change\textsuperscript{12, 20, 24}.

For coastal wetlands, we define resilience to SLR as the capacity to maintain surface elevation: too great an elevation change and the ecosystem becomes terrestrial; too little an elevation change and the ecosystem becomes a sub-tidal flat. Internal feedbacks among vegetation density, elevation and sedimentation have the potential to alter how coastal wetlands respond to external forcing factors such as changing sediment deposition (Fig. 1). Plants build soils both by directly contributing organic matter, and by trapping organic and inorganic sediments\textsuperscript{6, 14, 19, 22}. Crucially, these internal feedback mechanisms can potentially sustain marsh platform elevation even if the sediment inputs that built them are reduced, but may not be able to maintain elevation in the face of rising sea levels. Several models suggest that, for coastal marshes that are sediment starved (external forcing), interruption of the internal feedback loop through disturbance (e.g. removal of vegetation) could cause marsh drowning\textsuperscript{4, 5, 11, 12, 16}, but empirical tests of these predictions are lacking.

If the marshes built by high sediment loads during colonial times are maintained through an internal feedback loop, they are vulnerable to perturbation and state shift. Drowning of marshes in watersheds with low sediment load could create a catastrophic loss of ecosystems and services along the eastern seaboard. This research project aims to improve our understanding of the history and potential future of coastal marshes by addressing two interrelated questions:

**Q1) What external drivers control marsh building (elevation change)?**

- **H1.1:** Sediment deposition from riverine and terrestrial sources is a significant external driver of marsh elevation.
- **H1.2:** Colonial land practices (agriculture and deforestation) increased sediment export in watersheds, building new marshes in coastal estuaries (Fig. 1).

**Q2) How do internal feedbacks influence marsh response to external drivers of marsh building?**

- **H2.1:** Positive feedbacks between elevation and accretion create non-linear responses to SLR and sedimentation (Fig. 1).
- **H2.2:** The internal positive feedbacks in a marsh can maintain marsh elevation under negative external forcing until some high threshold level of forcing.

2. **Approach**

This research project uses a combination of cross-site analysis of marsh age and accretion rates, together with targeted manipulations of vegetation structure along gradients of sediment inputs. This combination of research approaches will be used to evaluate the historic effects of land use history on marsh formation and the resilience of these marshes to SLR.

**Synthetic analysis - Basal ages of marshes and land use:** I will use a cross site comparison to understand where and how marshes formed under various land use histories (Q1; Fig. 2). If fluvial sediment deposition controls marsh building, then wetland basal age (date corresponding with beginning of marsh layer in sediment core) will be significantly, positively correlated with initiation of intensive land use and high sediment concentration (H1.1). Additionally, if land use contributes to sediment deposition in marshes, then colonial wetland
Using dated sediment cores from coastal marshes around the United States, I will collect data from three sources: 1) basal ages published in existing literature, 2) unpublished basal ages obtained through correspondence and collaborations with other institutions, and 3) supplementation of collected information by taking additional cores. I have identified existing cores or basal age data from marshes around the country (Fig. 2). To supplement existing cores, I will collect Vibracores from marshes that need greater spatial resolution to supplement gaps in the data record or systems with interesting land use history and sediment concentration (e.g. Albemarle-Pamlico Estuary; Fig. 2). The depth at which salt marsh vegetation (rhizomes) appears will be determined and radio-carbon dated to establish the age of the wetland\(^5\). The combination of existing information and supplementary cores will allow me to acquire information from marshes across the eastern seaboard with different sediment loads and watershed land use histories.

To understand how basal ages relate to land use, I will use existing literature, historical maps and remote sensing images to determine watershed land use change of the dated marshes. I will determine area of deforestation in the 18\(^{th}\) and 19\(^{th}\) centuries and how the watershed has changed since that time. I will test if wetland formation and the onset of colonial deforestation are positively correlated across the eastern seaboard. The geographic range of this study will also distinguish between watershed types that have generated colonial wetlands. By plotting a histogram of basal age of the marshes studied, I expect a bi-modal distribution, illustrating the two different periods of marsh building in the United States: pre-European settlement and the colonial era.

To determine what role internal feedbacks play in marsh building (Q2), I will examine relationships between local SLR and marsh elevation change. If internal feedbacks do maintain marsh elevation (H2.1), then I will observe a positive relationship between local SLR and accretion rate. However, if positive feedbacks can also destabilize marshes, then this same relationship will be negative at high rates of SLR. I will perform a literature search of accretion rates, subsidence rates and local SLR for marshes globally. Additionally, accretion rates acquired from sediment cores will be included in this analysis. The information collected will be used to statistically analyze and model relationships and trends between rates of elevation change and local SLR. This analysis will be compared to existing models of feedback between vegetation, sedimentation and SLR.

**Experimental Manipulation of North Carolina Marshes:** I will test the ability of the internal feedback mechanism to maintain marsh elevation by experimentally manipulating marshes with different sedimentation rates in the Ablemarle-Pamlico Estuary, North Carolina (Q2; Fig. 2). This estuary is part of the EPA’s Climate Ready Estuary program and provides an excellent opportunity for experimental analysis. The 5 rivers that feed the Ablemarle-Pamlico Estuary (Chowan, Neuse,Pasquotank, Roanoke, Tar-Pamlico, and White Oak) form the second largest estuary in the United States, after the Chesapeake Bay.

If internal feedback mechanisms stabilize marshes under negative external forcing, then low sediment concentration marshes will transition to another state (mudflat) and elevation after disturbance relative to the control marshes (H2.2). To disrupt the internal feedback mechanism, I will remove vegetation to determine how marshes respond over a gradient of sediment inputs. I will select treatment and control sites in marshes of the Albemarle-Pamlico estuary with varying rates of sediment deposition. The research sites will include marshes downstream of a dam removal project (Milburnie Dam – Fall 2013) on the Neuse River. With the removal of the dam, a pulse of sediment will move downstream and possibly increase sediment deposition into the future and providing an excellent site to look at the effects of dam removal on coastal ecosystems and sedimentation. In addition to the disturbance experiment, I will monitor the sediment accretion in downstream coastal marshes with the removal of the dam.

At each site, I will take baseline measurements of environmental conditions in each plot, including: physiochemical porewater measurements, accretion rates (through feldspar marker horizons), Surface Elevation Table (SET) measurements of elevation, % organic matter, bulk density, sediment concentration in marine and riverine water, root cores, and above-ground biomass\(^1,3,13,22\). I will then disturb the treatment plots by clipping all vegetation along a 10 meter wide transect, spanning high to low marsh. After the vegetation removal treatment is performed, measurements taken during baseline observations will be repeated. These variables will be measured quarterly for 3 years, with vegetation treatment maintained yearly. By looking at marshes with low sediment deposition, I will determine if disruption of the internal feedback loop can cause state shift.
References Cited


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