Reconstructing the history of salt marsh migration into coastal forest

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Introduction:

Coastal wetlands are highly productive ecosystems that provide valuable benefits to society. Tidal marsh ecosystem services such as flood and erosion control, protection from storm surge, water quality remediation, carbon sequestration, and habitat for fish and wildlife have been valued at up to $194,000 ha^{-1} yr^{-1} (Costanza et al. 2014). However, recent climate change research has addressed accelerated rates of sea-level rise (SLR) as a threat to tidal marshes and the services they provide (Blankespoor et al. 2014; Craft et al. 2009; Crosby et al. 2016). New England marshes in particular are faced with rates of SLR that are higher than the global average. Though many anthropogenic factors are known to play a role in marsh loss in New England, evidence suggests that SLR is outpacing the natural vertical elevation gain of marshes in this region (Watson et al. 2017). Therefore, marsh migration, or the landward retreat of salt marshes to higher elevations, is a key mechanism for marshes to survive in the coming decades (Craft et al. 2009).

Understanding how marshes migrate upland is important for wetland conservation, management, and coastal development. Current models have projected the effects of accelerated SLR on salt marsh extent throughout the US coastline (Craft et al. 2009; Schuerch et al. 2018), but are primarily a simple function of elevation and flood frequency data, and therefore assume that marsh migration occurs as soon as a particular elevation becomes inundated with seawater. While these models provide an important basis for understanding priority areas for conservation and management efforts, they fail to incorporate how other environmental factors such as land use type, condition, and large storm events influence the pace of marsh migration. More research is needed to disentangle the processes that may control the lateral position of the marsh-upland boundary.

Several studies have explored marsh migration into coastal forests (Williams et al. 1999; Anisfeld et al. 2016; Doyle et al. 2009) which are the predominant undeveloped upland type along the borders of marshes in southern New England (Field et al. 2016). Unlike grasses or lawns, well-established trees have a history of persistence and resilience, leading to the suggestion that marsh migration can be greatly slowed by forest resistance (Gardner et al. 1992; Williams et al. 1999; Brinson et al., 1995). Therefore, SLR-induced coastal forest retreat may be a much slower process that begins with tree regeneration failure well before tree death (Williams et al., 1999; Doyle et al. 2009).

It is unclear if and how storm events can accelerate marsh migration in coastal forests. The combination of SLR and storm events – "press" and "pulse" disturbances, respectively – are thought to play a role in facilitating landward migration (Fagherazzi et al. 2018 in review). Over longer time scales, SLR into upland areas causes changes in soil salinity, leading to suppression and mortality of existing trees and upland understory, and the eventual colonization of marsh plants (Donnelly and Bertness, 2001). On the other hand, storms generate rapid, powerful movement of water that can cause physical damage and abrupt changes in soil salinity to upland habitat over a shorter time period. This may quickly stunt growth rates, cause regeneration failure, or even push trees past their point of recovery (Gardner et al., 1992; Brinson et al., 1995; Williams et al., 1999).

Despite evidence of forest retreat and marsh migration in the Chesapeake Bay and Gulf Coast (Williams et al. 1999; Schieder et al. 2018), Field et al. (2016) found no indication of salt stress on marsh-bordering trees along Long Island Sound. This is surprising, given that SLR has increased flooding frequencies substantially in this region. Figure 1 demonstrates both the pulse and press aspects of tidal hydrology over the last 38 years in Bridgeport CT. This figure supports the idea that SLR is quite gradual, and can therefore cause change in the position of the wetland-forest boundary over longer time scales—yet episodic storm events may hasten this process. In the case of Long Island Sound, this may mean that marsh migration simply has not been recorded because studies have only provided a snapshot in time and did not capture the effects of a storm event.

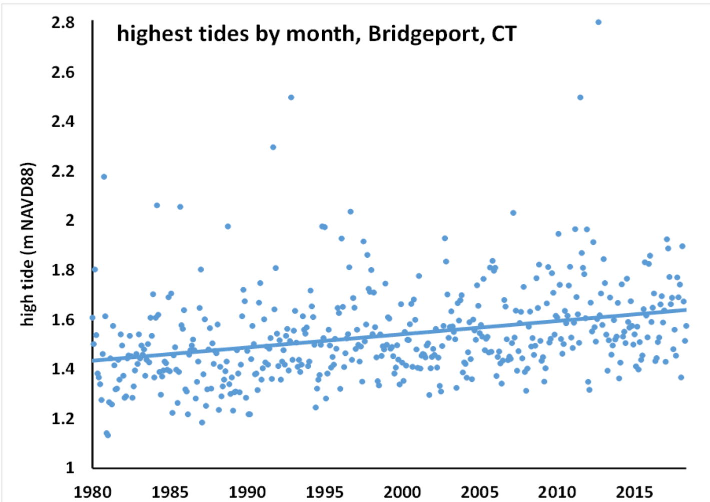

Figure 1. *Highest tides by month for Bridgeport, CT (NOAA data). Note the effects of both SLR (best-fit line with positive slope) and storm events (e.g., Superstorm Sandy, October 2012).*

Identifying areas of coastal forest dieback to investigate the cause, location, and timing of tree death would greatly inform our understanding of the processes behind marsh migration. Many studies have used aerial photography analysis or models to examine changes in marsh area over long time scales (Schieder et al. 2018; Smith 2013). This work will use dendrochronology to provide novel information about tree survival and death from both press and pulse forces, and will therefore assist in untangling the order of the processes involved in marsh migration.

Objectives and Hypotheses:

The overarching goal of this research is to identify and reconstruct the history of marsh migration into coastal forest along Long Island Sound. This study will take place at Hammonasset Beach State Park in Madison, Connecticut, where I have identified two marsh-bordering stands of interest within the park, both of which consist solely of Eastern Red Cedars (*Juniperus virginiana)*. The "stressed" stand contains both live trees in varying states of health and dead standing trees (snags). The "reference" stand consists of no visually apparent evidence of tree stress or death. This research will achieve three main objectives:

- **Objective 1: Demonstrate that salt marsh is migrating into coastal forest at locations along Long Island Sound. H_1**: I hypothesize that saltwater intrusion due to SLR is stimulating tree death and marsh migration at the "stressed" stand of coastal forest.
- **Objective 2: Explore how "press" (SLR) and "pulse" (storm) disturbances facilitate marsh migration. H_2**: I hypothesize that tree death in the "stressed" stand was caused by a storm event, supplemented by declining growth rates due to SLR prior to the storm event (Figure 2). **H_3**: I hypothesize that the growth rates of live trees in the "stressed" stand are declining over time, though stunted by occasional shocks (storm events) and a recovery period (Figure 3).
- **Objective 3: Understand how environmental and physiological factors lead to differential tree death in a stand within the context of marsh migration. H_4**: I hypothesize that factors such as elevation, flooding frequency, soil texture, and tree size, height, and growth rate drive differences in tree fate (live/dead) within the stand.

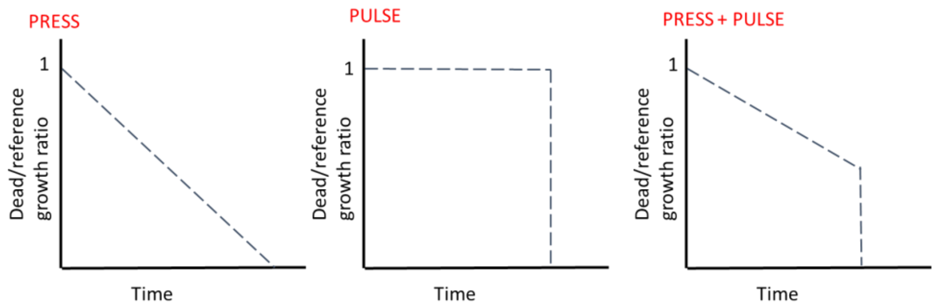

Figure 2. *Conceptual diagram of the hypothesized timeline of tree growth rates leading up to tree death. Left: SLR steadily decreases tree growth rates in the "stressed" stand relative to the reference stand; middle: a storm event leads to tree death in previously un-stressed trees; right: both press and pulse forces contribute to tree death (H_2).*

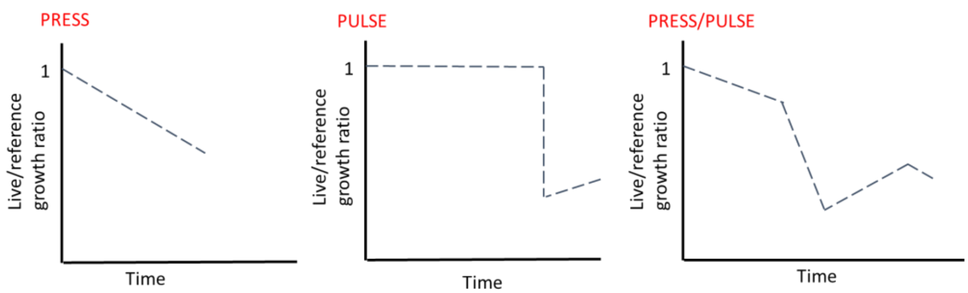

Figure 3. *Conceptual diagram of the hypothesized timeline of live tree growth rates in the "stressed" stand. Left: Live trees in the "stressed" stand have lower growth rates due to SLR; middle: live trees in the "stressed" strand were affected by a storm event, followed by recovery; right: both press and pulse forces are at play (H_3).*

Methods:

In summer 2018, I identified the "stressed" and "reference" stands, established transects, tagged individual trees at every three meters along each transect within each stand, and surveyed tagged tree elevations. Objective 1 is a between-stand comparison ("stressed" v. "reference"), Objective 2 compares between and within stands, and Objective 3 is a within-stand comparison.

Objective 1: Demonstrate that salt marsh is migrating into coastal forest at locations along Long Island Sound.

To address this, I will compare elevations, flood frequencies, soil salinity, the presence or absence of dead trees, and the presence and type of marsh vegetation in both the "stressed" and "reference" stand. SLR-induced marsh migration in the "stressed" stand will be indicated by a lower elevation, higher flood frequency (flooded at least annually by seawater), greater soil salinity, and the presence of marsh vegetation when compared to the "reference" stand. Tree elevations were measured during summer 2018 with RTK-GPS surveying equipment. Flooding frequencies will be calculated from high tide water level data recorded by a water-level logger deployed in the field. Soil salinity will be measured in the field with a conductivity probe at four locations around the base of each tagged tree. Each tagged tree will be assigned a condition rating to indicate its visual health status. Lastly, marsh vegetation found within a 1 m radius of each tree will be identified and recorded.

Objective 2: Explore how "press" (SLR) and "pulse" (storm) disturbances facilitate marsh migration.

I will use dendrochronology to obtain information about tree age and growth rate at both the "stressed" and "reference" stands. Tree cores will be collected near the base of each tagged tree using an increment borer. From each core, growth rings and subsequent growth rates will be measured using ImageJ and R software. Tree age and growth rate will be used in conjunction with elevation and historical water level data in order to test the hypotheses shown in Figures 2 and 3, and find associations between particular storm events (e.g., Superstorm Sandy, October 2012) and the health of trees.

Objective 3: Understand how environmental and physiological factors lead to differential tree death in a stand within the context of marsh migration.

Environmental factors (tree elevation, flooding frequency, and soil texture) and tree physiological factors (growth rate, height, and diameter) will be measured for each tagged tree within the "stressed" stand. Soil texture will be determined from two grab samples collected around the base of each tree, and a composite sample will be sieved in the laboratory. Tree height will be determined using a hypsometer, and diameter at breast height will be measured with a diameter tape. A logistic model will be used to determine which of these factors best predict tree fate.

Benefit to Coastal Wetlands:

The movement of marshes upland into higher elevations is essential for the long-term sustainability of these ecosystems. This research will advance our understanding of the timescale in which marsh-bordering forests respond to saltwater inundation, and ultimately improve model estimates of marsh migration rates. This research aims to provide a more detailed understanding of the impacts of storm events on marsh migration, which has been repeatedly noted in the literature as important, yet is understudied. As storm events are projected to increase and intensify, it is imperative that we know how they affect the future of our marshes and coastal forests. Lastly, this work can inform coastal developers as well as forest and coastal managers. As marshes transgress, forested areas that may be currently available for development could eventually become critical marsh habitat. This work can help guide future conservation efforts which will involve the collaboration between forestry and coastal wetland spheres.

Budget:

Materials/Supplies ($900): Materials to collect and analyze samples such as re-sealable bags, tins, vials, diameter tape, increment borer and core sleeves, glue, sandpaper, and an electric sander. *Travel ($460):* Travel from New Haven, CT to the field site in Madison, CT is 22 miles each way. I would use these funds for gas for my personal vehicle (~3 days/wk for 6 weeks, a total of 792 miles x standard mileage rate of $0.58 per mile). *Field & Lab Assistance ($3,600):* Though this project doesn't require expensive instrumentation to process samples, it involves extensive time in the laboratory and field in order to core and count rings of hundreds of trees. For this reason, a large portion of these funds would be used to hire an undergraduate assistant (25 hrs/wk for 12 weeks at $12/hr) to help me with field and laboratory work.

Broader Impacts:

Though I plan to disseminate my findings to the scientific community by presenting at scientific conferences and publishing in academic journals, this research also presents an opportunity to engage with the public along the Connecticut shoreline about SLR and the future of salt marshes. In summer 2019, I plan to coordinate outreach efforts with Meigs Point Nature Center, an educational center within Hammonasett Beach State Park. I plan to suggest a fact sheet or educational poster about salt marshes and SLR along Long Island Sound, as well as a summer series of marsh tours at Hammonasett. I also plan to attend Madison Land Conservation Trust board meetings to discuss marsh migration and the importance of preserving marsh-bordering forested areas.

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