USE OF FORAMINIFERA TO IDENTIFY SALT MARSH MIGRATION PATTERNS INTO UPLAND HABITAT IN LONG ISLAND SOUND

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Abstract

When sea level rises, salt marshes can avoid habitat loss from drowning through two mechanisms: vertical accretion and landward migration. Projected rates of sea level rise are likely to cause substantial marsh drowning in Long Island Sound. Therefore, it is critical to know whether landward migration can occur quickly enough to compensate for this loss, but few estimates of landward marsh migration rates exist.

This study investigated the historical landward migration of salt marsh peat over upland soil along five transects at two salt marsh sites in Connecticut. Each transect extended from the high marsh into or near the upland; upland land cover varied from mowed lawn (1 transect) to scrub vegetation (1 transect) to wooded (3 transects). Elevation, tidal hydrology, and vegetation type were collected along each transect, and sediment cores were extracted at regular intervals in an attempt to reconstruct the history of marsh migration. We found that measurements of organic matter in cores were not useful for reconstructing that history. However, we were able to use the variation with depth in the total number of foraminifera as a means to differentiate between marsh peat and upland soil, and thus to delineate the past profile of marsh migration. Radiometric dating of a subset of cores could then be used to provide migration rates over time.

Introduction

Salt marshes provide numerous ecosystem services such as wildlife habitat, water filtration, and shoreline stabilization (Gedan et al. 2011). Many species of commercially harvested finfish and crustaceans depend on salt marshes for food and refuge, and coastal cities enjoy protection from waves and storm surge (Boesch and Turner 1984; Beck et al. 2001; Shepard et al. 2011). Despite their importance, salt marshes have experienced widespread human impacts. Since the arrival of European settlers, an estimated 37 percent of original salt marsh habitat has been lost to development or agriculture in New England (Gedan et al. 2011). Regulations now limit loss of salt marsh habitat from land conversion, but marsh systems are still threatened by a combination of human and natural stressors such as hydrologic restrictions, reductions in sediment supply, over grazing of low marsh vegetation by *Sesarma reticulatum*, and sea-level rise (Gedan et al. 2011; Kirwan et al. 2011).

Salt marsh drowning, often a result of these stressors, is of particular concern in the Northeastern United States where relative sea level rise is occurring at three to four times the global average (Sallenger et al. 2012). To avoid drowning as sea level rises, salt marshes must accumulate sediment (thereby gaining elevation) at a rate equal to or greater than the rate of sea level rise (Warren and Niering 1993; Morris et al. 2002). However, 87 percent of salt marshes in New York, Connecticut, Rhode Island, and Massachusetts exist below the optimal elevation for growth of the low marsh grass *Spartina alterniflora*, suggesting that the majority of Northeastern salt marshes are at risk of drowning from inundation as sea level rises (Watson et al. 2014). Marsh drowning has also been observed at a number of sites in the Northeast, suggesting that marsh accretion is insufficient to prevent marshes from drowning (Hartig et al. 2002; Tiner et al. 2006, Watson et al. 2014).

Therefore, it is critical to know whether a second survival option, salt marsh migration, can happen quickly enough to avoid loss of marsh habitat. With marsh migration, low elevation marsh vegetation migrates into the high marsh zone, and high elevation marsh vegetation migrates into the abutting upland (Warren and Niering 1993). Even though vegetation is lost at the seaward edge of the marsh due to drowning, it is compensated for by increases in low marsh vegetation in the high marsh zone and increases in high marsh vegetation in the abutting upland.

Despite the importance of this survival mechanism, few studies have examined the process of marsh migration into upland habitat. Researchers in New York and Rhode Island found evidence of low elevation marsh plants migrating into the high marsh zone, which corresponded to an imbalance between accretion rates and sea level rise (Warren and Niering 1993; Donnelly and Bertness 2001). However, neither study investigated movement of marsh vegetation into the abutting upland habitat. Desantis (2007) found that increased tidal inundation decreased tree diversity and recruitment along the coast of Florida, although the extent of salt marsh expansion into the coastal forests was not quantified. Efforts to model changes in marsh habitat under different sea level rise scenarios do take into account migration, but the models do not address the potential effect of upland habitat type (Feagin et al. 2010; Geselbracht et al. 2011; Schile et al. 2014).

Only two studies were found that quantified the rate of salt marsh migration into upland habitat. An aerial photograph analysis by Smith (2013) calculated an average rate of marsh migration into forested uplands in New Jersey of 0.54 m/yr between 1930 and 2006, while a vegetation monitoring study in California found that salt marshes migrated 0.19 m vertically into scrub-covered upland over a seven-year period (0.027 m/yr) (Wasson et al. 2013). Given the likely importance of migration as a salt marsh survival strategy, and the limited research quantifying the rate of migration into upland habitat, the goal of this study is to answer the following question: is there evidence of salt marsh migration into upland habitat in Connecticut marshes?

Methods

Site Description and Transect Establishment

Site Description

Five transects were established at two sites in Connecticut: Hammonasset Beach State Park (HB) in Madison, CT and Carolina Creek (CC) in East Haven, CT (Figure 1). The sites border a diverse set of upland habitats (forest, scrub, and lawn), allowing for comparison of migration patterns into different upland types.

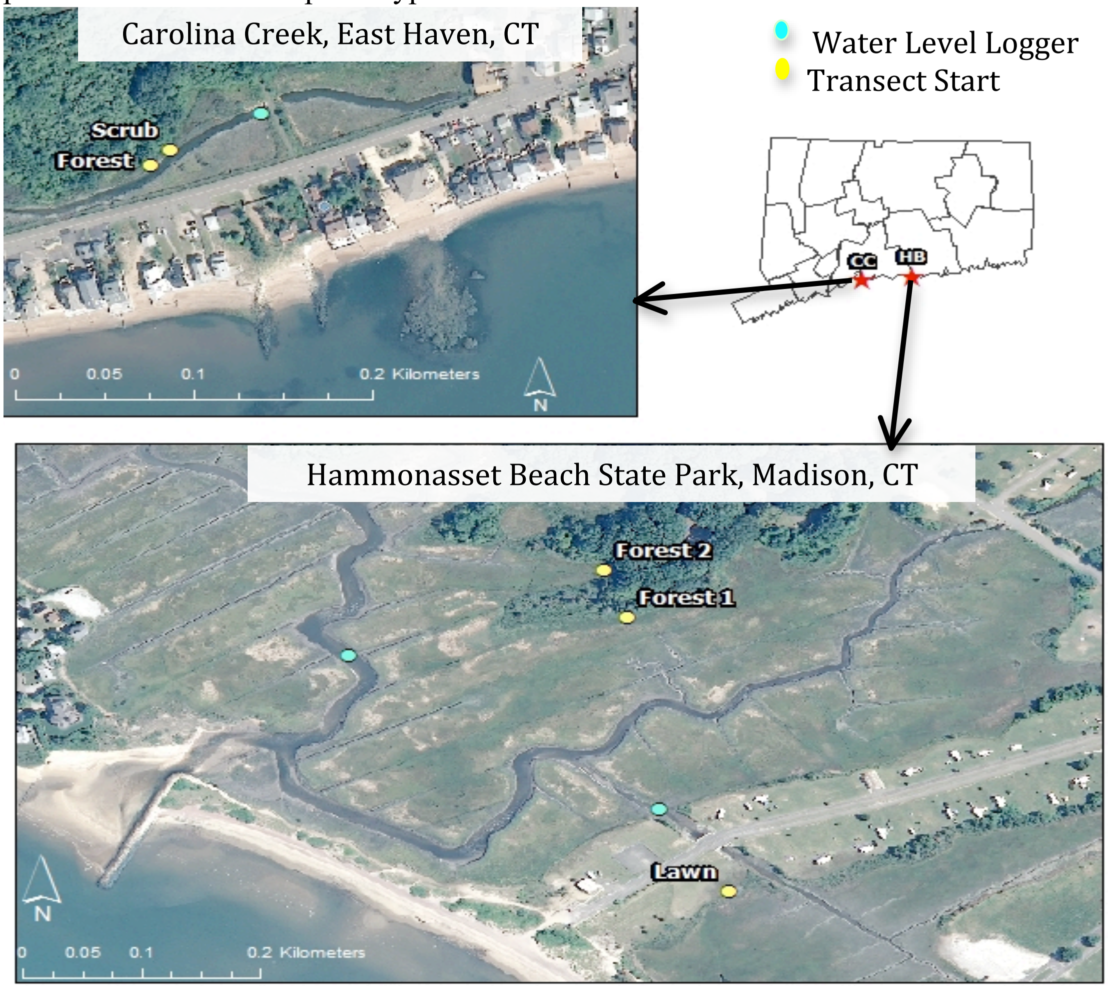

Figure 1. Site and transect locations at Hammonasset Beach State Park and Carolina Creek. All five transects began in the low to high marsh zones and ended in or near the abutting upland. Three transects were abutted by forested upland, one by a scrub upland, and one by a lawn-covered upland. Aerial photographs are from 2010 and accessed from CT ECO.

Aerial photographs[1] from 1974 and 2010, along with site visits in summer of 2014, showed minimal land use change at the lawn/upland borders of each site. The only observable difference was that Hammonasset State Park ceased mowing near the marsh/lawn border, allowing

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[1] Infrared aerial photographs from 1974 and 2010 were collected from the Connecticut Environmental Conditions Online (CT ECO) website (2010) and the UCONN MAGIC Library website (1974). All photographs were captured during summer within an hour of high tide and have a 1 ft. resolution. The 2010 image provided by CT ECO was already georeferenced and orthorectified, while the 1974 image was not. To compare images, ESRI's ArcGIS software version 10.2 was used to georeference the 1974 image to the 2010 image. The 1974 image was transformed using a polynomial transformation and resampled using cubic convolution.

ingrowth of the high marsh plants *Iva frutescens*, *Distichlis spicata,* and *Juncus gerardii.* However, it is not clear whether the marsh vegetation migrated landward and replaced turf grass, or if the cessation of mowing allowed preexisting marsh vegetation to grow taller.

Transect Establishment and Collection of Soil Cores

All transects began in the high marsh zone and ended in or near the abutting upland. The marsh zone and upland were differentiated based on vegetation type during transect establishment. At HB, two transects ended in forested uplands, and one near a lawn covered upland. One CC transect terminated near a forested upland, and the other CC transect ended in a scrub-dominated upland. Four to five soil cores ranging in length from 10 cm to 23 cm were collected at 1 m to 2 m intervals along each transect, depending on transect length and slope. Duplicate cores were collected for later analysis of soil carbon content. Each soil core was inspected visually in the field for changes in color and texture. The surface vegetation present at core extraction points was also recorded. The cores were collected with Russian corers and augers, placed on PVC pipes, and wrapped for storage. Cores were stored in refrigerators to prevent decay of organic matter.

Transect Tidal Hydrology, Elevations, and Flood Frequency

Tidal water elevations at the HB – Lawn transect were collected between May 29, 2014 and November 17, 2014. Tidal water levels at the HB – Forest transects were recorded from June 25, 2014 through August 24, 2014, while CC water levels were measured from July 3, 2014 through October 22, 2014. All water level data were recorded at five-minute intervals using Solinst Leveloggers (model Gold 3001 LT Gold F-15 at HB – Lawn, and 3001 LT F15/M5 at CC)[2]. Data were compensated for atmospheric pressure using five minute barometric data measured at Yale University with a Solinst Barologger 3001 LT F5/M1.5 from May 29, 2014 through August 7, 2014 and November 11, 2014 through November 17, 2014. Hourly barometric data from the National Ocean Atmospheric Administration (NOAA)'s New Haven Harbor tidal gage (station ID 8465705) were used during the intermittent period when barometric data from Yale were unavailable. The elevations of the water level loggers and transects were recorded with a TOPCON GPT-3200NW Series total station and converted into absolute elevations relative to NAVD88 using an RTK GPS.

Linear regressions were performed comparing each site's high tide elevations to high tides recorded by a NOAA tide gage in Bridgeport, CT (station ID 8467150). The regression equations were then used to estimate high tide levels from January 1, 2010 through December 31, 2014 based on historical tidal data from the Bridgeport tide gage. A flood frequency analysis (percentage of high tides exceeding a given elevation) was performed on each set of estimated tidal data and was used to interpolate flood frequencies at regular intervals along each transect.

Delineation of Historic Landward Salt Marsh Migration Using Foraminifera

Landward salt marsh migration along a transect should result in a "wedge" of new marsh peat overlaying preexisting upland soil (Figure 2). Therefore, soil cores collected from the lowest elevations of each transect are expected to consist entirely of marsh peat. Cores collected from the higher transect elevations are expected to have a layer of upland soil undelaying newly

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[2] Water levels at the HB – Forest sites were collected using a Solnist Barologger, model 3001 LT F5/M1.5.

developed marsh peat. Soil cores collected from upland habitat are not expected to contain marsh peat.

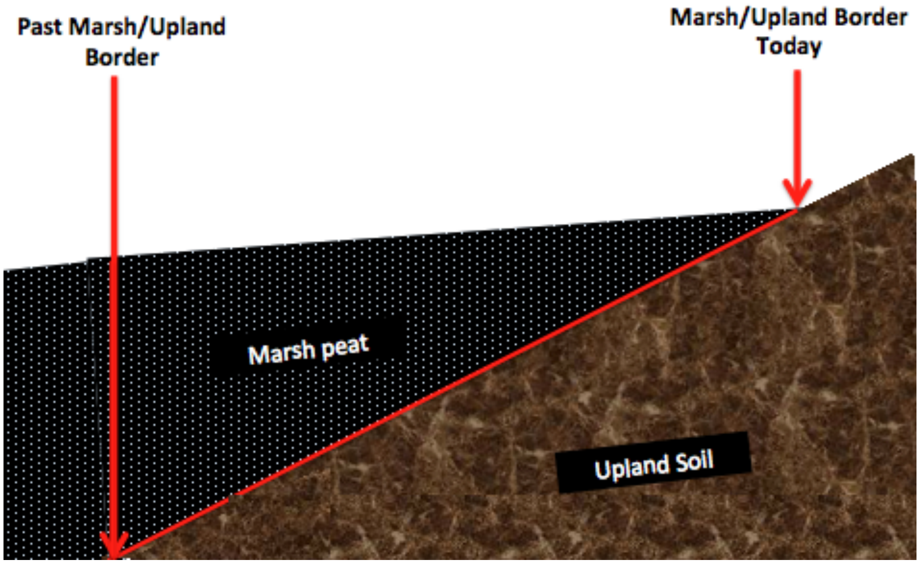

Figure 2. Theoretical soil profile resulting from salt marsh migration. Salt marshes migrating landward will cause peat to develop over upland soil. This will create a marsh "wedge," with new, shallow peat near the upland border and old, deep peat in the lower marsh elevations.

Foraminifera (forams) were used to differentiate between marsh and upland soil in the soil cores collected along each transect. Forams are marine protists frequently used to construct sea level rise histories in salt marshes (Kemp et al. 2012, Scott and Medioli 1978 and 1980, Gehrels 1994, Edwards et al. 2004). While most studies use foram species distributions to determine the past sea level, this study used the presence of forams, regardless of species type, to distinguish between marsh and upland soil.

Soil cores were sliced into 1-cm segments, and every other cm was sieved to isolate material larger than 63 μm and smaller than 500 μm (Scott and Medioli 1980). The total number of forams per wet g of sediment was counted using a Leica S8AP0 microscope. The samples were then dried and weighed to calculate the number of forams per dry g of sediment. Forams were "present," indicating marsh sediment, if a section contained 25 or more forams per dry g. Forams were "absent," indicating upland soil, if a section contained less than 25 forams per dry g.

Soil Organic Content

The organic content of soil was also initially used as an indicator of marsh sediment, since marsh peat tends to be highly organic. Organic content was calculated for every cm of soil in a subset of cores along the CC – Scrub, HB – Forest 2, and HB – Lawn transects, and was computed based on mass loss after combusting the sediment. The cm segments were dried for 48 hours at 105°C and then combusted in a muffle furnace for 16 hours at 500°C. The organic content of each section was calculated as the percent difference in the dry and ashed mass.

Results

Transect Hydrology, Flood Frequency Analysis, and Vegetation

The twice-daily high tides recorded at each site correlate strongly with the high tide readings from the Bridgeport NOAA tide gage (Figure 3). The R^2 values for the HB lawn, HB Forest, and CC water level logger readings with Bridgeport high tides were 0.96, 0.98, and 0.99, respectively. These strong relationships indicate that it is reasonable to conduct a flood frequency analysis for each site using high tide values estimated based on the Bridgeport NOAA tide gage record. The high tide flood frequency analysis for 2010 – 2014 showed that the HB – Forest and HB – Lawn locations are drier than CC (Figure 4).

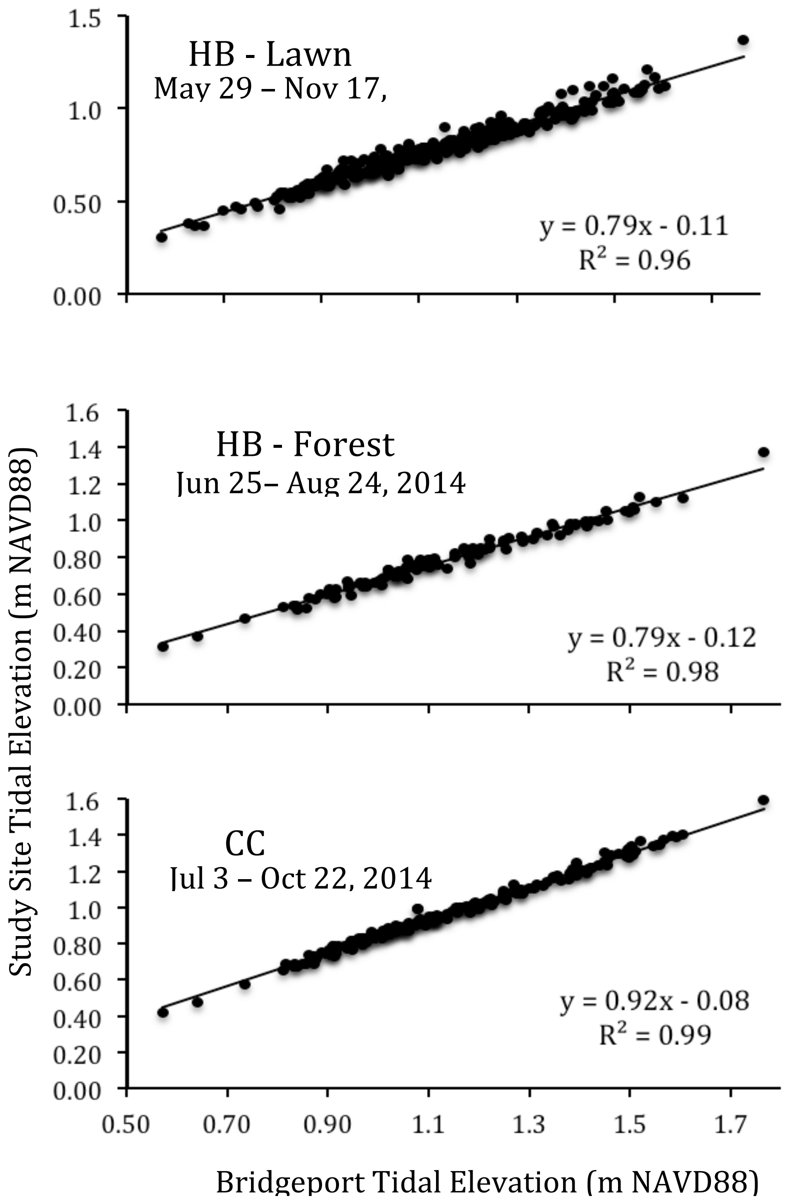

Figure 3. Regression of daily high tide elevations recorded by the HB –Forest, HB– Lawn, and CC water level loggers against Bridgeport daily high tides, May – November 2014.

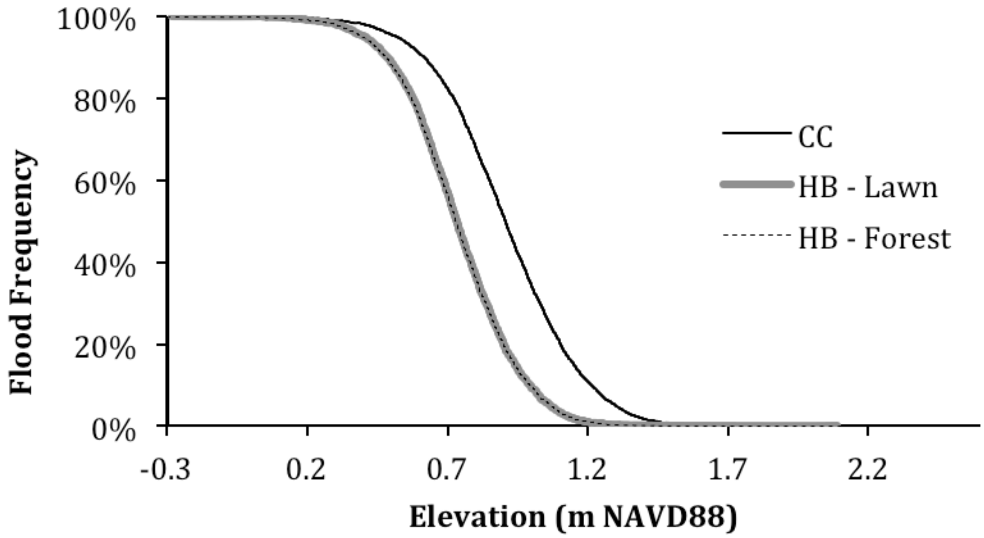

Figure 4. Flood frequency of high tides 2010 - 2014 at Carolina Creek and Hammonasset Beach State Park. Flood frequency refers to the percentage of high tides that exceed a given elevation. High tide elevations for the time period 2010 - 2014 were estimated using the regression equations from Figure 3.

The surface vegetation along each transect corresponded to flood frequency. Transect points with flood frequencies above approximately 10 % contained the marsh plants *Spartina alterniflora*, *Distichlis spicata* and *Juncus gerardii* (Figure 5). Transitional zone marsh species, such as *Iva frutescens,* were found along HB transects at flood frequencies as high as 27 % and as low as 1 %. *Phragmites australis* was present at CC, but was not present at the HB transects.

Visible signs of landward salt marsh migration, such as marsh plants growing with dead or dying upland vegetation, were only observed along the HB – Forest 1 transect, where *I. frucescens* was observed growing among dead *Juniperus* trees. For transects that extended into upland vegetation (HB – Forest 1, HB – Forest 2, and CC – Scrub), the absence of forams in the surface layer of soil corresponded with an absence of marsh vegetation (Figure 5). This supports the use of forams to differentiate between marsh and upland soil in soil cores.

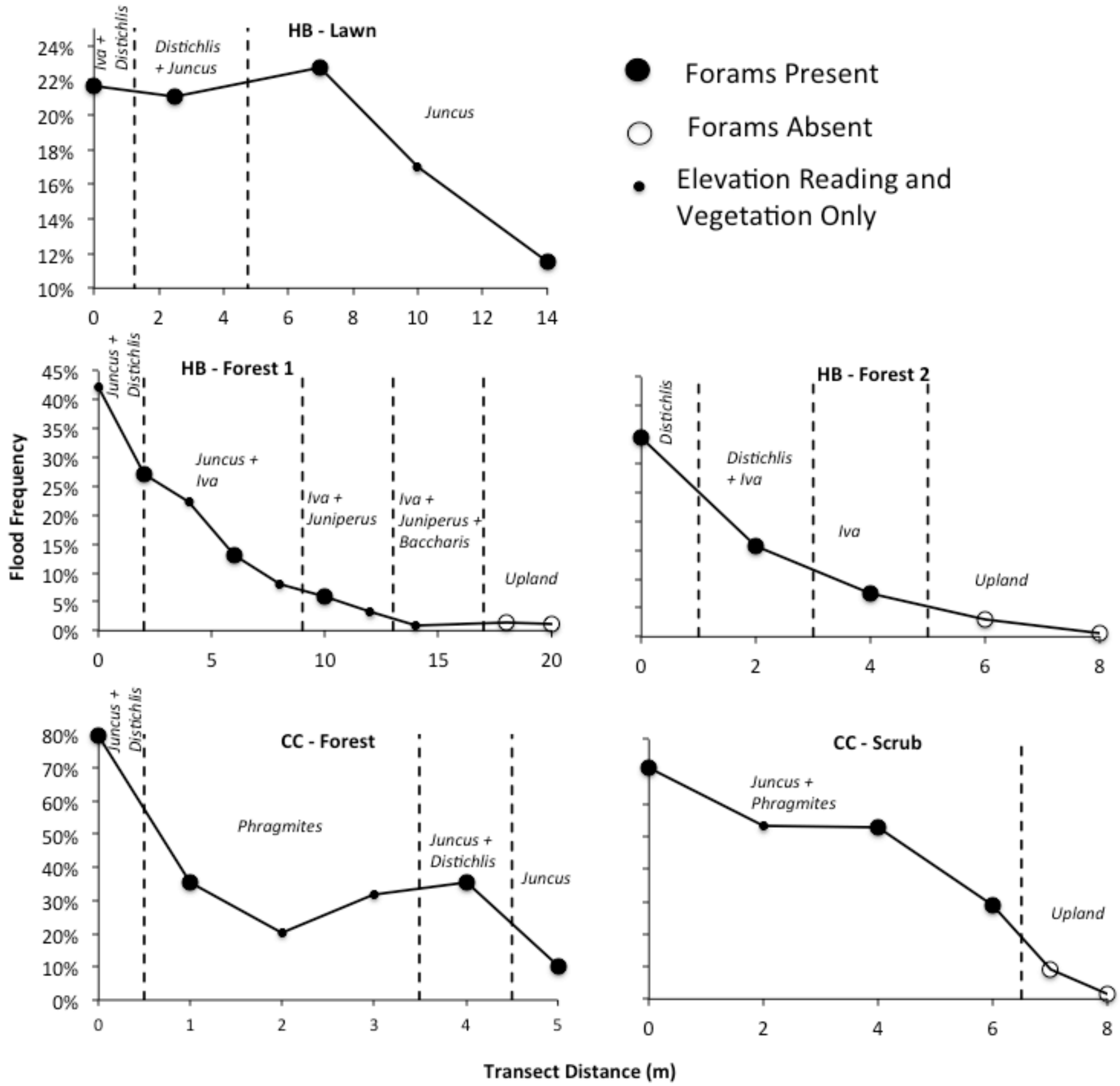

Figure 5. Transect flood frequency, surface foram presence, and surface vegetation community. Vegetation community is approximate, as vegetation type was only recorded at discrete points along the transects where soil cores were extracted and/or surface elevation was measured. Large, closed circles indicate that forams were present (>24/dry g) in the surface sediment. Open circles indicate forams absence (<25 / dry g). Small closed circles indicate a transect point where elevation and vegetative community were measured but no soil core was extracted.

Identification of Marsh Migration Wedge

Foram enumeration within soil cores confirmed the hypothesis of a marsh migration wedge (Figure 6). While the number of forams / g of dry sediment was highly variable between core segments, high flood frequency cores (34 % and higher) contained forams at all depths, implying that these cores consist entirely of marsh soil. Cores collected from lower flood frequencies (higher elevations) only contained forams in their upper segments, indicating that new marsh peat had developed over upland soil. Cores collected from uplands, as defined by surface vegetation, did not contain forams at any depth.

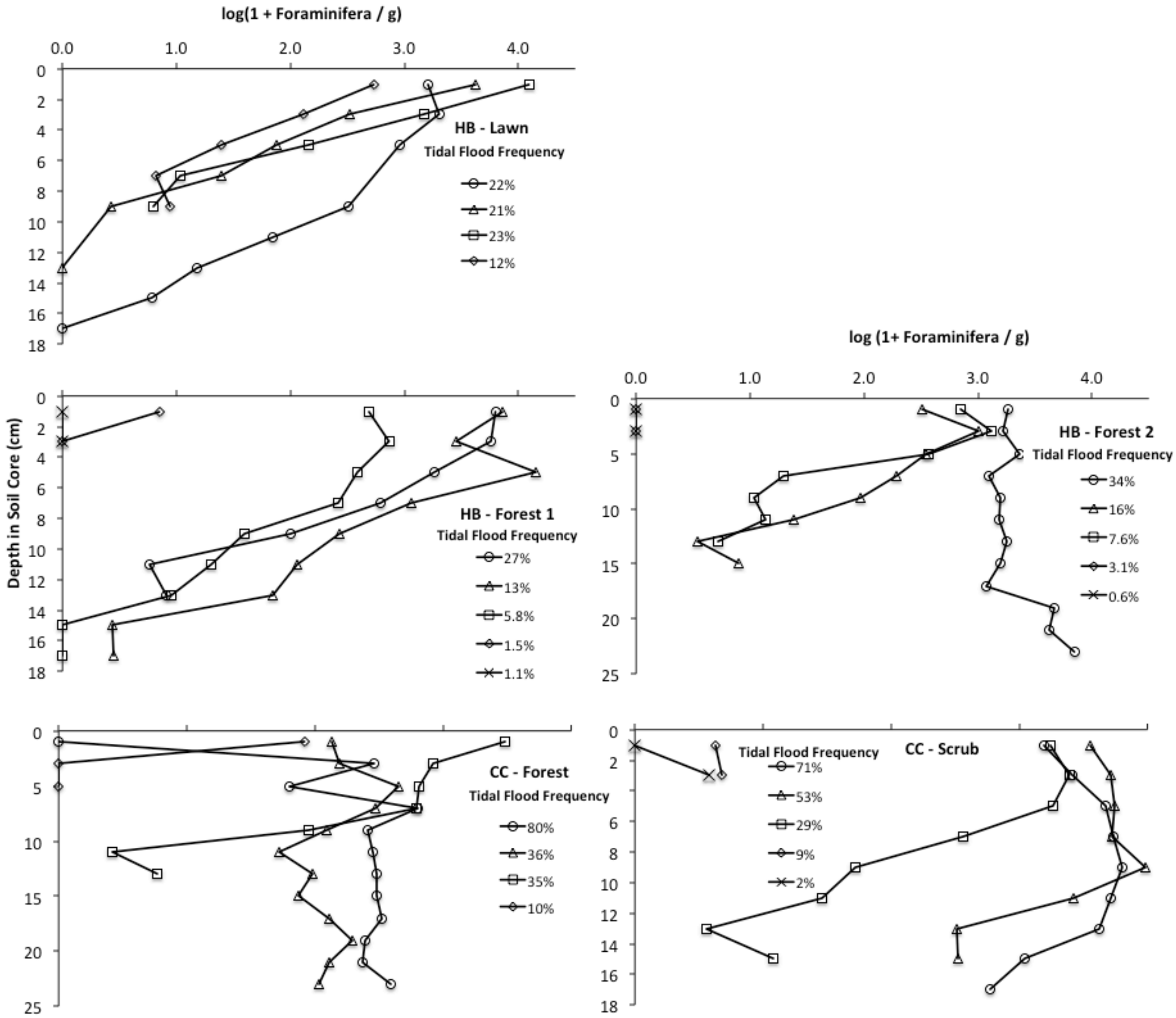

Figure 6. Abundance and depth of foraminifera in soil cores collected at different tidal flood frequencies. The number of foraminifera per dry g of sediment are presented for soil cores collected along five transects. Tidal flood frequency is specific to each soil core, and represents the percentage of high tides that exceed the surface elevation of the soil core.

The organic content of soil core segments was also considered as a possible indicator for differentiating between marsh and upland soil to define a marsh migration wedge. Marsh peat tends to be high in organic matter, so a drop in organic content could signify a switch from marsh to upland soil within a core. Organic matter in duplicate soil cores collected along three of the study transects did decrease with depth (Figure 7). However, it was unclear whether the decrease represented a switch between marsh and upland soil, or if it simply indicated older soil where more of the organic matter had decayed. The presence of forams was a much clearer indicator of saltwater influence, and was therefore used as the marsh indicator for this study.

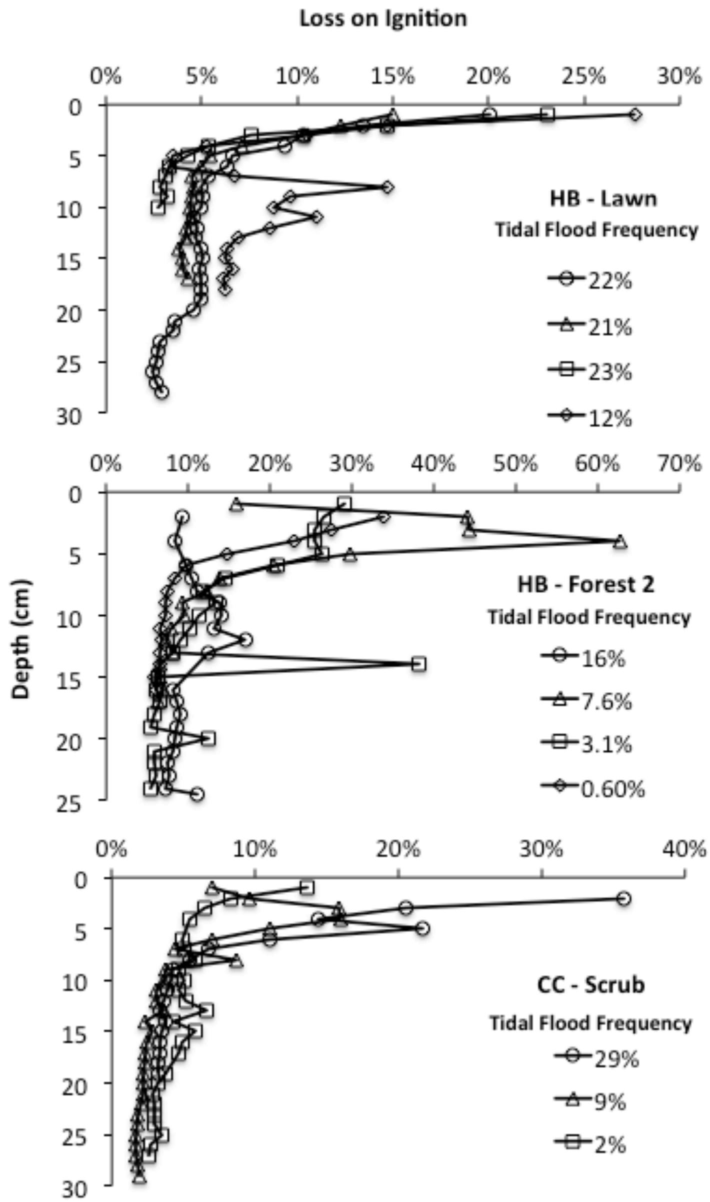

Figure 7. Organic content of soil cores collected along three transects: HB - Lawn, HB - Forest 2, and CC - Scrub. Tidal flood frequency is core specific and refers to the percentage of high tides exceeding the suface elevation of the soil core. Organic content for the lowest elevation core of the HB - Forest 2 transect (34 % flood frequency) and the lowest two cores of the CC - Scrub transect (71 % and 53 % flood frequency) was not measured.

The presence of a migration wedge is easily visualized by plotting the surface elevation of each core and the depth at which forams disappear along each transect (<25 forams / dry g) (Figure 8). The foram depth decreased as elevation increased, suggesting that marsh habitat close to the upland border developed more recently than marsh habitat at the lower transect elevations where forams are present throughout the entire soil core. While most transects took a "wedge" form, with the depth of the marsh peat decreasing as elevation increased, the HB – Lawn transect looked more akin to two layers of sediment - one with forams and one without. This is likely due to the fact that the transect did not extend into the upland. The difference between the land surface and foram depth would likely begin to decrease and form a wedge shape if the transect were extended into higher elevations.

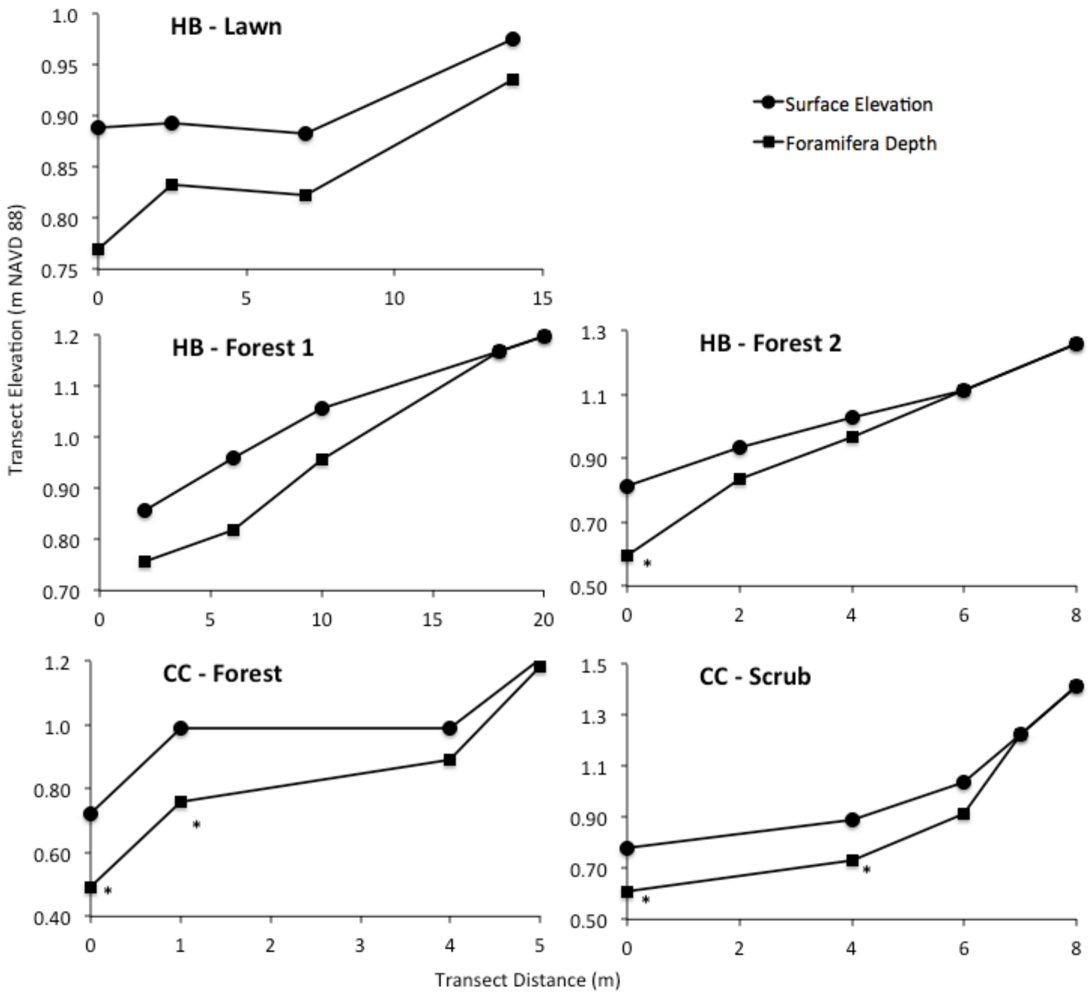

Figure 8. Foram depth (>24 forams / dry g) relative to soil core surface elevation along five transects. The depth to which forams were present (>24 forams / dry g) was plotted relative to the surface elevation of each soil core. Soil cores with forams present at all depths are marked with an asterisk, indicating that forams are likely still present deeper in the soil profile. All transects show the development of a "migration wedge," with the foram depth decreasing as elevation increases until upland is reached and forams are absent. Cores with greater foram depths indicate older marsh sections. Cores with shallow foram depths indicate new marsh development resulting from marsh migration.

Changing the criteria for foram absence from < 25 forams / dry g to < 10 forams /dry gram produces a similar migration wedge (Figure 9). This more stringent definition of foram absence had no impact on the depth of defined marsh peat at the CC transects. It did, however, result in a deeper layer of marsh peat in all cores along the HB – Lawn transect as well as the cores collected at 2m and 4m on the HB – Forest 2 transect. It also resulted in a deeper transition point along the 10m core on the HB – Forest 1 transect.

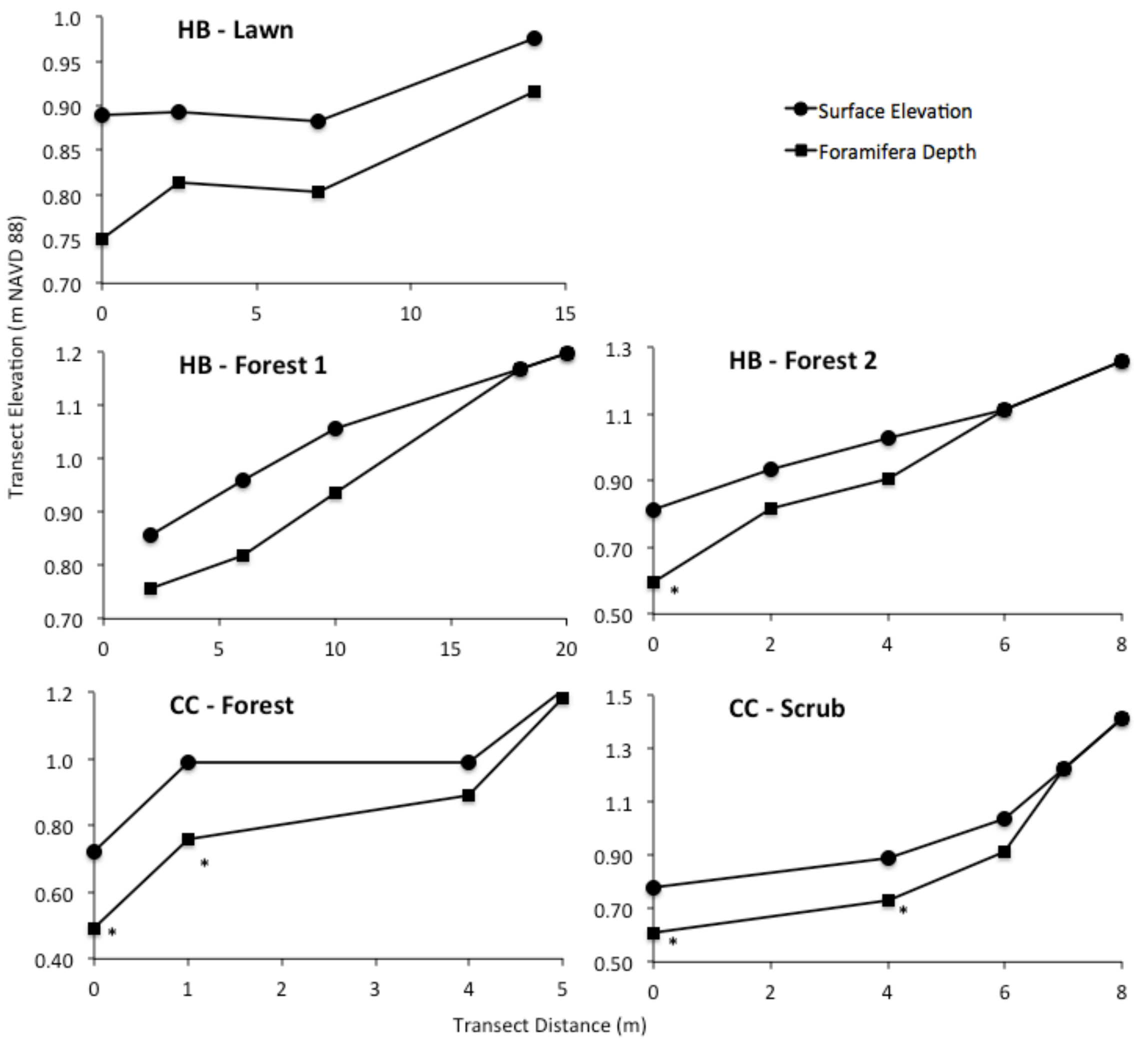

Figure 9. Foram depth (>9 forams / dry g) relative to soil core surface elevation along five transects. The depth to which forams were present (>9 forams / dry g) was plotted relative to the surface elevation of each soil core. Soil cores with forams present at all depths are marked with an asterisk, indicating that forams are likely still present deeper in the soil profile. All transects show the development of a "migration wedge," with the foram depth decreasing as elevation increases until upland is reached and forams are absent. Cores with greater foram depths indicate older marsh sections. Cores with shallow foram depths indicate new marsh development resulting from marsh migration.

Discussion

Analysis of foram presence/absence indicates that marsh migration into upland habitats has occurred at all sites and transects. This agrees with recent studies such as those by Smith (2013) and Wasson (2013), which found that salt marshes are migrating into upland habitat in New Jersey and California.

No standard methodology currently exists to quantify migration into upland habitats. Smith (2013) relied on the use of aerial photographs to document changes in vegetation over time, whereas Wasson established long-term monitoring transects. While both approaches have their merits, neither approach was appropriate for this project. Aerial photographs from 1974 and 2010 were available for the two research sites, but it was not possible to discern changes in the marsh/upland border since tree canopy shadows and growth obscured the camera view of the marsh edge. Aerial photographs also present a challenge when quantifying marsh migration into lawn uplands, since mowing practices make it difficult to differentiate between marsh grasses and turf grasses. While long-term *in situ* vegetation studies such as that conducted by Wasson (2013) are ideal for tracking migration, many projects, such as this one, take place on shorter timeframes. Using the presence/absence of forams to differentiate between marsh and upland soil may be an important methodology to quantify recent patterns in marsh migration.

The next phase of this project is to estimate the age of marsh sediment in the migration wedge to determine a migration rate, the rate at which new marsh peat develops over upland soil. Radiometric dating of a subset of soil cores from the HB – Forest 2 and CC – Scrub transects is currently underway. This analysis will allow estimation of migration rates that can be compared to findings from Smith (2013) and Wasson (2013). Understanding the rate salt marsh migration into upland habitat will be essential for resource managers seeking to minimize marsh habitat loss due to sea level rise. Selecting an appropriate threshold for defining foram presence/absence may be important in order to accurately calculate the migration rate.

More research is needed further quantify marsh migration rates into upland habitat. In addition, future research should investigate whether migration happens faster into different upland types such as lawns or forests. This information could help resource managers prioritize upland habitat for conservation.

Conclusions

Salt marshes at HB and CC are migrating into upland habitat. This migration was observed by delineating a marsh migration “wedge” based on the depth of foram presence in soil cores collected along the elevation gradient of five transects. The use of forams to differentiate marsh from upland soil may be an important technique, combined with radiometric dating, to quantify rates of marsh migration into upland habitat. Knowing how quickly marshes can migrate into upland habitat will be essential for resource managers working to minimize marsh loss due to sea level rise. Future research on marsh migration should investigate whether upland type affects the rate of migration into upland habitat.

Appendix I: GIS Analysis of Salt Marsh Upland Types

Future research on salt marsh migration should compare the rate of migration into different types of upland habitats. A GIS analysis was conducted using ArcGIS version 2.0 to identify marshes bordered by both lawn and forest. This will allow for a random selection of marsh sites that border both upland types, enabling a research design with paired transects to compare the rate of migration into lawn and forested uplands. The steps for this GIS analysis were as follows:

1. Convert land cover data from raster to polygons. Land cover data were accessed in raster format from the University of Connecticut Center for Land Use Education and Research (CLEAR)'s land cover raster dataset for the year 2010, which categorized land cover into the following classes:

- Developed
- Turf & Grass
- Other Grasses
- Agricultural Field
- Deciduous Forest
- Coniferous Forest
- Water
- Non-Forested Wetland
- Forested Wetland
- Tidal Wetland
- Barren
- Utility Rights- of -Way (Forest)

This dataset was converted from raster to shapefile format using the Raster to Polygon tool in the Conversion Toolbox. The "Turf grass" and "Other Grass" polygons were combined into one layer to represent all lawn-covered uplands, and the "Deciduous" and "Coniferous" forest classes were combined to form a layer representing forested uplands. All "Tidal Wetlands" were considered salt marshes for the purposes of project, though the category likely contains both salt marsh and brackish marshes. A new layer was created containing only the "Tidal Wetlands" polygons.

2. Aggregate marsh polygons within 100 m. I assumed that salt marsh polygons within 100 m of one another are part of the same salt marsh system. I aggregated all marsh polygons within 100m of one another in the Tidal Wetlands layer using the Aggregate Polygons tool. I did not use any of the optional features of the Aggregate Polygons tool, such as the Barrier Features option, which would have prevented marshes from aggregating across specified barriers such as roads or rivers.

3. Limit brackish marshes. To minimize the number of brackish marshes in the dataset, I created a new layer of marshes by selecting only those aggregated marshes within 1000 m of the Connecticut coastline. The marsh, lawn, and forest layers were then clipped to a shapefile of Connecticut coastal towns to remove any marshes within 1000 m of the coastline but outside the state of Connecticut, such as in New York or Rhode Island.

4. Select marshes bordered by both lawn and forested uplands. I then used the "Select by Location" feature to select all marshes bordered by lawn or forested upland. I first created a layer using the "Select by Location" menu to select all marshes that touch the boundary of the forested uplands layer, and created a new layer from this selection. I then used that new marsh layer with the "Select by Location" tool to select the marsh polygons also bordered by lawn uplands. The final layer created from these selections contained all aggregated marsh polygons within 1000 m of the coastline bordered by both lawn and forested polygons. This layer contained 153 polygons, or marshes bordered by both lawn and forested uplands.

5. Calculate length of shared borders. I used the Polygon Neighbors tool in the Analysis toolbox to calculate the length of the shared perimeter between the marsh polygons and the lawn and forest polygons. To use the Polygon Neighbors tool, I first created a single layer combining the marsh, forest, and lawn polygons with the Merge tool from the Data Management toolbox. I added a new field in the attribute table to indicate the polygon type (marsh, lawn, or forest). This new layer served as the input feature in the Polygon Neighbors tool, and used the "ObjectID and Poly_Type" attributes as the reporting fields. I left the "Include area overlaps" and "Include both sides of neighbor relationship" boxes unchecked.

The Polygon Neighbor tool determines the neighbor type of each polygon to a source polygon – if a polygon is an edge neighbor (shares a border), then it calculates the length of the shared edge, and records a zero for the node count (node neighbor is when the source and neighbor polygons touch at a point or intersection). If there is no shared edge, then the tool calculates the number of nodes where two polygons touch. The Polygon Neighbors tool produces an output table with a list of all polygons from the input layer (marsh, lawn, and forest), along with the length of all edges shared with a "neighbor" polygon. The first 153 Source ObjectIDs (field name SRC_ObjectID) in the output table correspond to the 153 marsh polygons from the input layer. I then copied the output data associated with the SRC_ObjectID numbers 1 through 153 into excel, and calculated the total lawn and forest borders associated with each marsh polygon.

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