Salt Marsh Advancement Zones

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Background

There is consensus in the scientific community that anthropogenic emissions of greenhouse gases are changing the earth's climate. Global temperature is increasing as more greenhouse gases are trapping the earth's emitted radiation. This increase in temperature may have detrimental effects on much of the world's natural habitat. One of the current effects of increased global temperature is increased global sea level rise (IPCC, 2007).

Increasing rates of global sea level rise have the potential to alter coastal salt marshes (IPCC, 2007). The flora and fauna that inhabit salt marshes are uniquely adapted to tolerate specific salinity ranges, which allow them to thrive in certain zones in the marsh community (Bertness, 1991). Thus, the height of sea level and, therefore, the degree and duration of inundation by salt water is of critical importance to the marsh ecosystem.

Salt marshes have two functional responses to increases in sea level. Historically, salt marshes have accreted inorganic and organic sediment to increase their elevation and keep pace with sea level rise (Titus, 1988; Bricker-Urso *et al.*, 1989; Dreyer and Niering, 1995; Nydick *et al.*, 1995; NECIA, 2007). However, salt marshes may not be able to accrete fast enough to maintain pace with the projected increases in sea level. Salt marshes can also migrate inland, as increased inundation presents new opportunity for marsh expansion. Marshes that are unable to accrete enough sediment and/or expand inland could become permanently inundated leading to further wetland loss (Brinson *et al.*, 1995). Even if marshes are not permanently inundated, increases in sea level could lead to different flooding regimes, which could dramatically alter the ecology of the salt marshes (Warren and Niering, 1993). It is therefore important to assess which marshes could be the most affected by changes in sea level, so that immediate and longer-term adaptation, mitigation and restoration efforts can be planned and implemented.

This project made use of high resolution remote sensing data, along with site specific *in-situ* data, to develop a salt marsh migration tool in ArcGIS that projects future marsh habitat under various sea level rise scenarios. Specifically, the tool uses elevation data derived from LiDAR (Light Detection and Ranging) to simulate inundation using a combination of the 'Map Algebra' tool and 'Cost Distance' tool. Using these simulated inundations, along with aerial photographs of current marsh conditions, and *in-situ* vegetation and accretion data, this tool enables a projection of future marsh conditions, and specifically, suitability of upland areas for future marsh advancement by the year 2080.

Results from the salt marsh migration tool is designed to:

- Predict the change in total marsh habitat in response to sea level rise
- Predict which marshes will experience the most detrimental effects of sea level rise
- Predict which upland areas could be suitable for future salt marsh advancement, for environmental management and land acquisition

METHODS

The model was run to simulate future marsh conditions under the high end A2 sea level rise scenario generated by the Goddard Institute.

Model Inputs

There are six inputs used in the salt marsh migration ArcGIS tool: a high resolution Digital Elevation Model (DEM), a land cover classification, site-specific Mean High Water (MHW), site specific Spring High Water (SPHW), site specific low marsh accretion rate and site specific high marsh accretion rate.

Digital Elevation Models (DEMS). The DEMs for CT were generated from LiDAR point clouds. The points were interpolated using the 'Geostatistical Analyst' in ArcGIS to a 0.61-meter (two-foot) raster. An 'Ordinary Kriging' interpolation method was used with a 'Gaussian' semivariogram, and four neighbor points. The interpolated rasters then had to be mosaicked together in a fashion that reduced edge effect errors. These errors associated with the edge of the raster occur because the interpolation can only use points from one side on the edge of a shapefile. This resulted in overlapping areas between interpolated rasters having different values. To remove these errors the rasters were clipped back 1.52 meter (five feet), by using the 36 sections of each tile created by splitting the tile scheme. However, this time they were buffered to 1.52 meter (five feet) instead of 3.05 meter (ten feet). These sections were then used to extract the interpolated rasters and all the extracted rasters were then mosaicked together. The result was a seamless 0.61-meter (two-foot) DEM for each study site in CT. For NY, the DEMS were already provided in 1.52 meter (five foot) rasters.

The DEMs for both CT and NY then had to be processed to remove any artificial impediments to flow. LiDAR is unable to penetrate pavement, thus the data returned on bridges appears as a ground return. This created artificial dams in the DEMs, which created errors in the flooding model to be discussed later. Aerial imagery was used to identify all bridges and overpasses in the eight study sites. To remove the bridges a new polygon shapefile was created in ArcCatalog and edited to outline all bridges and overpasses. Then, the shapefile was exported to a 0.61-meter (two-foot) raster in CT and 1.52 meter (five feet) raster in NY. The raster was then reclassified giving bridges a value of 0 and all other areas a value of 1. The resulting reclassification was then multiplied by the DEM producing a raster that had an elevation of 0 (i.e., sea level) for any bridges or overpasses (Figure1).

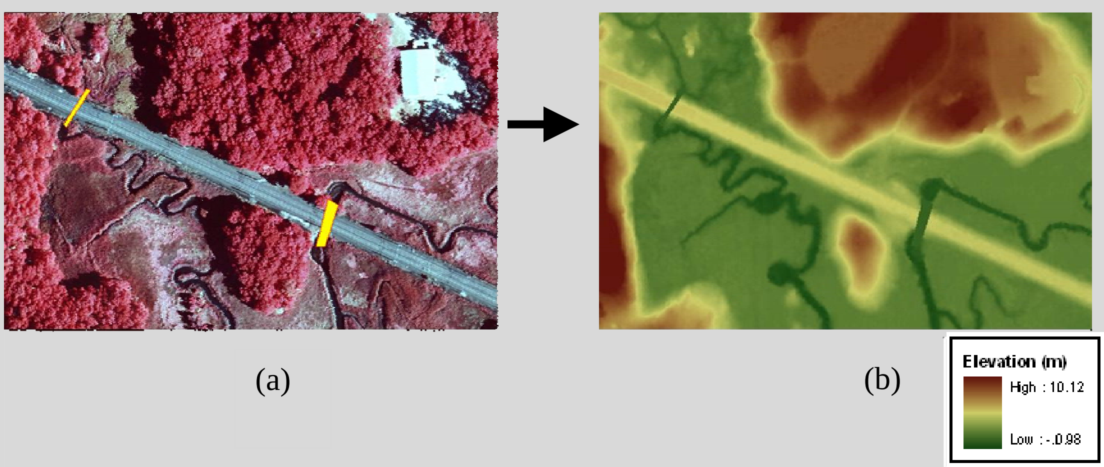

Figure 1: The (a) Creation of Polygons to Cover Bridges and the (b) Subsequent DEM after the Bridges were Removed

Land Cover Classifications. For the land cover classifications an object-oriented approach to image classification was implemented. The classifications were broken into broad upland categories of: 'urban', 'agrigrass' (a combined agricultural and grassland category), and 'forest', and more specific marsh categories: 'low marsh', 'high marsh', 'iva' (*Iva frutescens* L. (marsh elder)), 'phrag' (*Pragmites australia* Cav. (common reed)), 'sand', and 'water'. The classifications were done in eCognition using the DEMs as well as 4-band 1 foot CIR imagery in the segmentation and classification process.

Tide Levels. Simplistically stated, there are two general habitats in salt marshes; low marsh and high marsh (Lefor *et al.*, 1987; Mckee and Patrick Jr., 1988; Bertness, 1991). The distinction between the two is based on the frequency of inundation. Low marsh habitats lie below the MHW line and are flooded semi-diurnally. High marsh habitats are above MHW and are only flooded occasionally by spring high water SPHW and storm events (Lefor *et al.*, 1987; Mckee and Patrick Jr., 1988; Titus, 1988; Bertness, 1991). By modeling these tide levels in addition to increases in sea level, it is possible to project future low marsh and high marsh habitat. NOAA tide gauges in proximity to the study area were used to generate site specific tide values. The MHW and SPHW were calculated for each of the tide gauges using data from the NOAA website*. Tide levels from the year of imagery retrieval (2005 for CT and 2007 for NY) were used. The average Mean Higher High Water (MHHW) for each month was used as the MHW. The SPHW was calculated by taking the average of the highest tide for all twelve months. Once the MHW and SPHW values were calculated from the surrounding NOAA tide gauges, the values were linearly interpolated to generate site-specific tide conditions.

Accretion Rates. Site-specific accretion rates were another input that had to be calculated. In general, areas with greater tidal amplitude have higher accretion rates. Also, areas of low marsh accrete more since their increased frequency of inundation leads to increased access to sediment (Harrison and Bloom, 1977). Accretion data available for the study sites was limited to a few sites. Again, to generate site specific rates, linear interpolation was used between known values.

Tool Process

Predicting Future Marsh Habitat

The tool begins by generating data layers that will be used in processes down the line. The first step is the creation of a 'Source' layer which will be used in the 'Cost Distance' tool to simulate flooding. The 'Source' layer is the raster from which the flood will originate from and therefore represents the ocean. It is created by using 'Map Algebra' to select all elevations under 0m in the DEM.

After the base layers are created, the accretion rates for the first time step of 14 years from 2006 to 2020 are generated. Using the classification shapefile, developed earlier, a new field named "Accretion" is added to the attribute table. Then the low marsh areas are selected, and given the low marsh accretion rates in the "Accretion" field. The areas classified as 'high marsh', 'iva', or 'phrag' are similarly given the high marsh accretion rates. The classification is then converted to a raster (either 0.61-meter (two-foot) raster for CT or a 1.52 meter (five feet) raster in NY) with the 'Polygon to Raster' tool with "Accretion" as the value field. This raster is then multiplied by the first time step of 14 years, and added to the DEM.

This new DEM, adjusted to account for accretion, is the projected elevation for the year 2020, and is used to model the sea level rise scenarios of 2020. The flooding is simulated using two processes: level slicing and the 'Cost Distance' tool from ArcGIS. The first step is level slicing. The projected height of sea level by 2020 is used to calculate all the areas in the 2020 DEM under that height (Figure 2). This is done by using the Raster Calculator and the simple algorithm:

If 2040 DEM<=2020 Sea Level Height, then 1, else 0

* National Oceanic and Atmospheric Administration http://tidesandcurrents.noaa.gov/

The algorithm output is a raster with a value of 1 (true) for areas under the flood height and a value of 0 (false) for areas above the flood height. The output is then reclassified so that areas under the flood height are reclassified to 0 and the areas above the flood height reclassified to 1. Once the reclassification is complete, the 'Cost Distance' tool is used. For this tool the 'Cost Raster' is the reclassified level slice, the 'Source Data' is the 'Source' layer created earlier, and the 'Maximum Threshold' is set to 0.5. The 'Cost Distance' tool 'grows' from the ocean and sums the values of the pixels encompasses. Since the maximum threshold is 0.5 it does not include any pixels that have a value of 1. In this way the 'Cost Distance' tool generates one connected flooded region (Figure 3). The 'Cost Distance' output raster is then converted to a polygon.

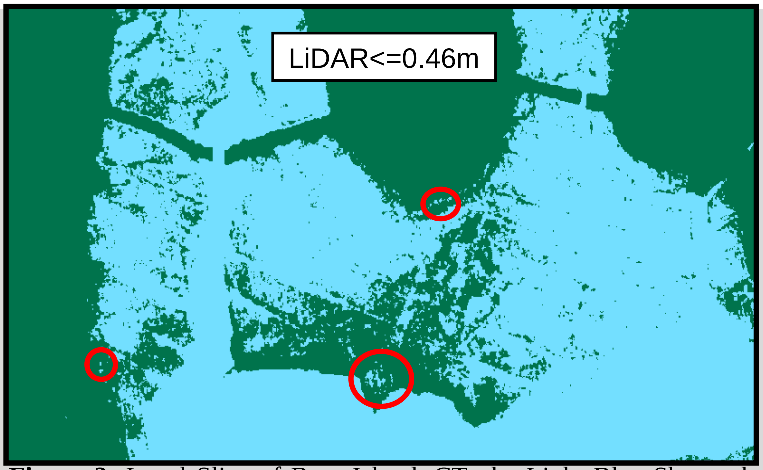

Figure 2: Level Slice of Barn Island, CT, the Light Blue Shows the Area Under 0.46m. Notice the Unconnected Blue Areas in the Red Circles

The previous flooding methodology is then repeated for two more floods in the 2040 time step. The two floods are the projected increase in sea level by 2020 plus the current MHW and the projected increase in sea level by 2020 plus the current SPHW. The resulting three flooded areas all overlap, so, to generate unique areas for low marsh and high marsh, the 'Erase' tool is used. First, the 2020 sea level plus MHW is erased from the 2020 sea level plus SPHW. This generates a polygon that represents the area between MHW and SPHW for 2020 - predicted area of high marsh habitat. Next, the 2020 sea level polygon is erased from the 2020 sea level + MHW polygon generating the area between sea level and MHW - predicted area of low marsh habitat.

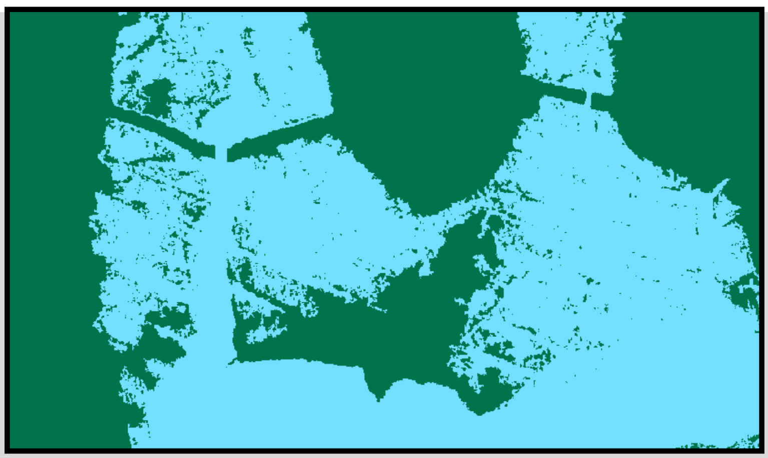

Figure 3: The output from the Cost Distance Tool.

For the 2050 time step, the low marsh and high marsh accretion rates were entered into the "Accretion" field of the 2050 low marsh and high marsh polygons, respectively. These two polygons are converted to raster, multiplied by 30 to generate the 2050 accretion, and added to the 2020 DEM to generate the 2050 DEM.

The 2050 elevation and the respective increases in sea level by 2050 are used to simulate 2050 conditions. The projected areas of low marsh and high marsh for 2050 are used to simulate accretion rates for 2080, and the process is repeated to create the final two polygons: one that represents predicted areas of low marsh for 2050, and one that represented predicted areas of high marsh for 2080.

Creating Advancement Zones

Once the shapefiles projecting low marsh habitat and high marsh habitat for the time steps of 2020, 2050 and 2080 were generated they were merged to create three shapfiles representing total marsh habitat for each time step. These shapfiles were then clipped to upland land cover types to create 'advancement zones'. 'Advancement Zones' project which upland habitat are suitable for future marsh habitat. It takes the shapefiles generated by the model which represent areas that will be hyrdologically suitable for future marsh habitat and overlays them with current land cover to analyze where marshes could reasonably occur.

The projected marsh habitats are clipped to upland land cover types to generate shapefiles which represent suitability of marsh advancement. First, the projected marsh habitats are clipped to suitable land cover types of ‘forest’ and ‘agrigrass’. These habitats will convert relatively easy to marsh habitat when the correct hydrological conditions are generated. On the other hand, current urbanized land will not convert to marsh habitat even when the hydrologic conditions are met. To simulate this, the projected marsh habitats are clipped to the unsuitable land cover type of ‘urban’ to generate an unsuitable for marsh advancement layer. These layers are then merged together to form an ‘advancement zone’ shapefile (Figure 4).

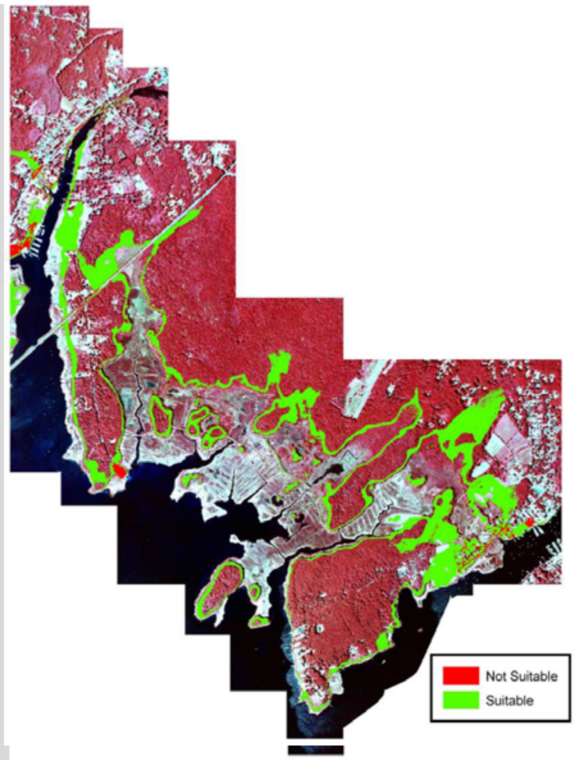

Figure 4: An example of a finished ‘advancement zone’.

Purpose

The purpose of generating marsh ‘advancement zones’ is to aid in future land management and decision making to preserve critical marsh ecosystems. Sea level rise is an impending threat and only by initiating mitigation strategies now can we hope to curtail some of the projected marsh losses. ‘Advancement zones’ offer a realistic look at where future marsh habitat can be propagated. By preserving the ‘suitable’ areas now, one can hope to preserve marsh habitat in the future.

REFERENCES

Bertness, Mark D., 1991. Zonation of *Spartina patens* and *Spartina alterniflora* in a New England salt marsh, *Ecology*, 72(1):138-148.

Bricker-Urso, S.; Nixon, S.W.; Cochran, J.K.; Hirschber, D.J.; Hunt, C., 1989. Accretion rates and sediment accumulation in Rhode Island salt marshes, *Estuaries*, 12(4):300-317.

Brinson, Mark M.; Christian, Robert R.; Blum, Linda K., 1995. Multiple states in the sea-level induced transition from terrestrial forest to estuary, *Estuaries*, 18(4):648-659.

Dreyer, Glenn D.; Niering, William A. (editors), 1995. Tidal marshes of Long Island Sound, The Connecticut College Arboretum: New London, Connecticut.

Intergovernmental Panel on Climate Change (IPCC), 2007. *Climate change 2007: A synthesis report*, Intergovernmental Panel on Climate Change: Valencia, Spain,104p.

Lefor, Michael Wm.; Kennard, William C.; Civco, Daniel L., 1987. Relationships of salt-marsh plant distributions to tidal levels in Connecticut, USA, *Environmental Management*, 11(1):61-68.

Mckee, Karen L.; Patrick Jr.,W.H., 1988. The relationship of smooth cordgrass (*Spartina alterniflora)* to tidal datums: A review, *Estuaries*, 11(3): 143-151.

Northeast Climate Impact Assessment (NECIA), 2007. *Confronting climate change in the U.S. Northeast: science, impacts, and solutions*, Northeast Climate Impact Assessment: Cambridge, MA, 160p.

Nydick, Koren R.; Bidwell, Allison B.; Thomas, Ellen; Varekamp, Johan C., 1995. A sea-level rise curve from Guilford, Connecticut, USA, *Marine Geology*, 124: 137-159.

Rahmstorf, Stefan, 2007. A semi-empirical approach to projecting future sea level rise, *Science*, 135: 368-370.

Titus, James G., 1988. Sea level rise and wetland loss: An overview, U.S. Environmental Protection Agency Report 203-05-8b-013: Washington, D.C, 35p.

Titus, James G., 1998. Rising seas, coastal erosion, and the takings clause: How to save wetlands and beaches without hurting property owners, Maryland Law Review,57(4): 1281-1399.

Warren, R. Scott; Niering, William A., 1993. Vegetation change on a northeast tidal marsh: interaction of sea-level rise and marsh accretion, *Ecology*, 74(1):96-103.