Modeling the Fate of New Jersey's Salt Marshes Under Future Sea Level Rise

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July 3, 2014

Background

With nearly 214,000 acres, tidal salt marshes are a characteristic landscape feature of New Jersey's coastal bays, fringing both the back side of the barrier islands, as well as the mainland. Salt marsh ecosystems are a critical feeding ground and nursery for dozens of commercially important aquatic species. The grasses and related biological processes provide a vast amount of nutrients and food needed to sustain the aquatic food web. Salt marshes help filter out pollutants from the water and the marsh peat helps sequester carbon dioxide. During flooding events, the salt marshes act as a sponge helping to absorb the floodwaters. Several recent reviews (Gedan et al., 2011; Shepard et al., 2011; Spalding et al., 2013) have found that salt marshes have a moderating influence on attenuating storm surge and waves and a moderately positive role in shoreline stabilization.

Through the process of vertical accretion of sediment and organic matter, the tidal salt marsh surface will rise in relation to sea level, i.e., the marsh can continue to grow 'up' into a rising sea (McKee and Patrick, Jr. 1988; Titus, 1988; Cahoon 2010). When sea level rises faster than marsh accretion, tidal marshes are drowned and replaced by unconsolidated shore (i.e., mud or sand flat) and eventually open water (Cahoon and Guntenspergen, 2010). In addition to accreting vertically, salt marshes can also retreat landward through a process of 'creative destruction' (Titus et al., 2009). If there is only a gradual rise in elevation, the adjacent uplands will be periodically flooded by rising tidal inundation. The more sensitive upland vegetation will be stressed by the flooding and higher salinity and be replaced by emergent marsh vegetation. However, in some areas, the slope above the coastal marsh is steeper than the marsh surface itself restricting the landward migration process. Development or other 'hard' obstructions (i.e. levees or bulkheads, roadways, causeways, fill) in the upland fringe adjacent to coastal wetlands will also impinge on the landward retreat process, effectively squeezing out the marshes.

Sea level rise in New Jersey and elsewhere may substantially affect coastal wetlands. A panel of sea level rise experts predict that the sea level in New Jersey could rise between 1.0 feet and 2.5 feet by 2050 (Lathrop et al., 2014). A recent assessment of the sensitivity of the Mid-

Atlantic region to sea level rise reported a large amount of variability in wetland responses to sea-level rise, highlighting both the influence of local processes on wetland elevation and the difficulty of generalizing from regional scale to the local scale in the absence of local accretionary data (Cahoon et al., 2009). To better model projected wetland susceptibility to sea-level rise, more detailed information on a local scale is needed on maximum sustainable vertical accretion rates; complex interactions between sediment elevation, flooding, and biotic organic matter accretion; and factors that affect spatial variability in sediment accretion dynamics (Cahoon and Guntenspergen, 2010; Cahoon et al., 2009; Nicholls et al., 2007). As the effects of sea level rise continue to impact coastal systems, effective management of coastal wetland habitats and resources requires in-depth assessments of the effects of accelerated sea-level rise on wetland vertical accretion and the expected changes in plant and animal communities (Nicholls et al., 2007).

To provide these locally scaled, site specific data, federal, state and academic institutions have partnered to develop and implement a four-tiered Mid-Atlantic Coastal Wetlands Assessment (MACWA) program to monitor sediment accretion rates and track change in acreage, health and function of tidally-influenced wetlands across the state of New Jersey. In the meantime, while these site intensive studies are being initiated, we have undertaken a preliminary geospatial modeling to better understand the scope of the problem of how sea level rise may potentially affect salt marsh across the state and to identify which areas may be most vulnerable to permanent inundation. We were also interested in identifying marsh retreat zones to inform land use and conservation planning efforts.

We undertook to model those areas of New Jersey's coastal marsh (as mapped in 2007) that were vulnerable for conversion to either mud/peat/sand flats (unconsolidated shore) or open water under 1 to 3 feet of sea level rise (i.e., brackets the range of the expected rates of sea level rise expected by 2050). The NOAA Coastal Services Center (CSC) provided a potential marsh change GIS map based on SLAMM (Sea Level Affecting Marsh Model; Ehman, 2012; USFWS, 2011) using a 'moderate' level of vertical accretion (4 mm/yr over a 50 yr time frame). Using geospatial analysis software, we also modeled future marsh retreat zones for these same sea level rise scenarios (for more information, see Appendix A). Those portions of New Jersey's coastal zone adjacent to coastal marsh that will be inundated under sea level rise and expected to convert to emergent marsh over time as part of the natural landward migration process were mapped and labeled as **unimpeded marsh retreat zones**. Areas where future tidal marsh retreat are blocked by developed uplands, other coastal protection structures or roads were mapped and labeled as **impeded marsh retreat zones**. Tidal marsh areas that are vulnerable to submergence and conversion to unconsolidated shore (i.e., mud/peat/sand flat) or open water under rising sea levels were also included as **marsh conversion: unconsolidated shore** and **marsh conversion: open water**, respectively. The projected future marsh maps were incorporated into the NJFloodMapper.org WEBGIS tool.

Results

Our modeling results suggests that if sea level rise is between 1 to 2 feet by 2050, existing tidal salt marsh could decline by approximately 5%, being replaced by open water and unconsolidated shore (Table 1; Figure 1). However, if sea level rise accelerates (on the order of 3 feet or more of rise), then salt marshes will not be able to vertically accrete at a rate fast enough to keep up and the loss and conversion of salt marsh will increase (i.e., 3 feet of rise will result in a loss of marsh on the order of 14%; Table 1).

While the predicted loss may be balanced by 'new' marsh (i.e., unimpeded marsh retreat zone) it is unclear whether this 'new' marsh will have the same ecological value in the short-term (i.e. over decadal time scale) as the established tidal salt marshes that may be lost. Smith (2013) found that there was lag between coastal forest retreat and the rate of salt marsh migration landwards across the Delaware Bayshore region. The lag between the amount of forest retreat and salt marsh migration was accounted for by the presence of *Phragmites australis* which often occupies the forest and salt marsh ecotone. *Phragmites* expands from this edge into forest dieback areas, and the ability of salt marsh to move inland and displace *Phragmites* is likely influenced by salinity at both an estuary-wide scale and at the scale of local sub-watersheds.

Table 1. Projected change in salt marsh area under different 2050 sea level rise scenarios. Note the baseline year is 2007; % change calculated vs. baseline year tidal salt marsh area.

DESCRIPTION	**Baseline**	**1 ft SLR**		**2 ft SLR**		**3 ft SLR**	
	acres	acres	**% change**	acres	**% change**	acres	**% change**
Tidal salt marsh	213,977	204,340	-4.5%	204,195	-4.6%	184,295	13.9%
Unimpeded marsh retreat		16,631	NA	28,220	NA	39,072	NA
Impeded marsh retreat		1,955	NA	2,980	NA	4,764	NA
Marsh conversion: uncon. shore		320	+0.1%	326	+0.1%	19,276	+9.0%
Marsh conversion: open water		9,316	+4.4%	9,455	+4.5%	10,406	+4.9%

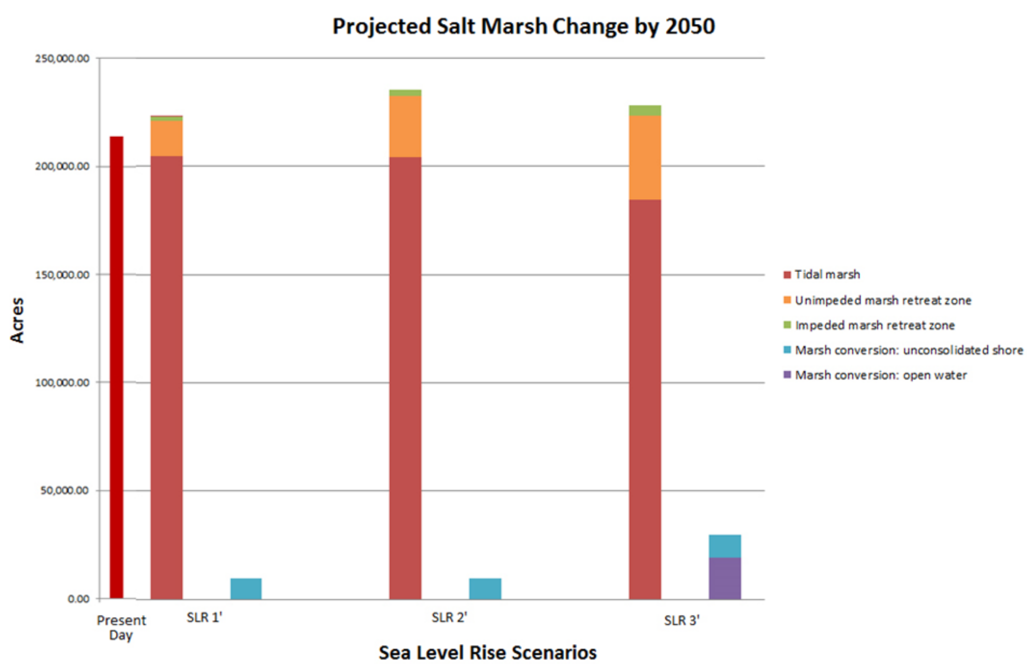

Figure 1. Projected statewide salt marsh by 2050 for 1', 2' and 3' foot sea level rise scenarios.

More detailed case studies were undertaken to assess several sub-areas, notably the Delaware Bayshore in Cumberland County and Barnegat Bay-Little Egg Harbor. Cumberland County has nearly 47,000 acres of salt marsh, which is among the largest expanse in the state. While the county has a low population density, there are several bayshore communities along the edge of the marsh. Our analysis found that, with one foot of sea level rise, more than 3,800 acres of marsh might degrade into open water or mudflats and more than 4,000 acres may migrate toward higher ground, while about 160 acres could be impeded from retreat (Figure 2a). With three feet of sea level rise, more than 5,300 acres could become open water or mudflats, with more than 10,000 acres migrating to higher ground. Nearly 600 acres could be impeded from retreat due to existing roads, houses or other obstructions. More than 22,000 acres of salt marsh in Ocean County ring Barnegat Bay; while the northern shores fronting the bay's salt marshes are densely developed, the southern shores have only a few pockets of dense development. The CRSSA analysis found that, with one foot of sea level rise by 2050, about 700 acres of marsh may convert to open water or mud flats, about 1,300 acres of marsh may migrate and about 20 acres may be impeded from retreat. With three feet of sea level rise by 2050, more than 4,500 acres could become open water or mudflats, nearly 4,000 acres may retreat landward and about 200 acres could be impeded by existing development (Figure 2b).

Our existing analysis was restricted to a 2050 projection; additional modeling needs to be undertaken to predict further into the future towards 2100. These 2050 projection maps serve to present a detailed visualization of the scope of the problem of how sea level rise may potentially affect salt marsh across the state and to identify which areas may be most vulnerable to conversion and loss. For New Jersey to proactively sustain its coastal salt marshes in the face of sea level rise, the preservation of future marsh landward retreat zones is critical. Additional research and field testing is needed to assess the efficacy of ecological restoration techniques to enhance vertical accretion rates and slow marsh shoreline erosion.

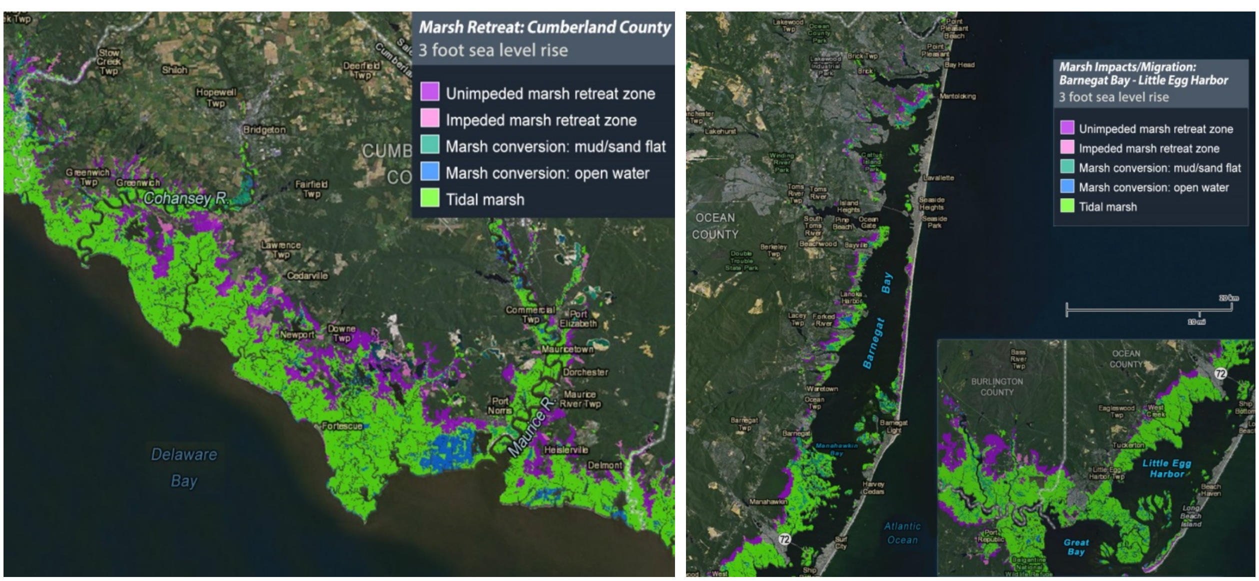

Figure 2a and 2b. Modeled marsh change and retreat under 3 feet of sea level rise for 2a Cumberland County and 2b Barnegat Bay-Little Egg Harbor.

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Appendix A. Mapping/Modeling Process

The 2007 New Jersey Land Use/Land Cover maps (NJDEP, 2007; http://www.state.nj.us/dep/gis/lulc07cshp.html) provided the baseline 'Present Day' base layer for the coastal tidally-influenced marsh maps. The following LU/LC categories were included: 6111 (Saline marsh: low), 6112 (Saline marsh: high), 6120 (Freshwater Marsh: tidal) and 6141 (Phragmites: coastal). A visual assessment was undertaken and specific polygons of the following LU/LC categories were included if they were geographically situated in the coastal tidal salt marsh complex: 6233 (scrub/shrub wetlands), 6241 (Phragmites: interior), 7430 (disturbed wetlands). A GIS layer of tidally-influenced water was created from the NJ LU/LC GIS by selecting the following categories: 5410 (Tidal Rivers, Inland Bays and other Tidal Waters), 5411 (Open Tidal Bays), 5420 (Dredged Lagoon) and 5430 (Atlantic Ocean). Bridges were extracted from the NJ LU/LC GIS layer and merged into the tidal water coverage (described above). These polygonal GIS coverages (ArcGIS.shp) were rasterized to an ArcGRID format at a 10 foot grid cell size resolution.

Using the ERDAS Imagine software, coastal marsh areas were spatially buffered in a distance of 5000 feet (well beyond the expected marsh retreat distance for a 3 foot sea level rise). A similar buffering was undertaken for tidally-influenced water. The two buffered maps were overlaid and areas closer in distance to marsh were labeled as potential marsh retreat zones. Existing Urban land use (from NJ LU/LC GIS map), roads (as determined from NJ Department of Transportation GIS map) and armored shorelines (as mapped in NOAA's Environmental Sensitivity Index GIS map) were overlaid into the marsh retreat zone map to serve as obstructions to future marsh retreat. The coastal marsh, obstructed marsh retreat zone, tidal water GIS layers were combined into one GIS coverage and then clumped using a 4 neighbor decision rule. This clump coverage was visually inspected and recoded to determine those clumps that were spatially contiguous from tidal water. Marsh and water was then masked leaving only the marsh retreat zones that were labeled as either 1) unimpeded; or, 2) impeded. The resulting potential marsh retreat zone map was then masked with the 1-3 foot sea level rise water surface GIS layers to map out the unimpeded vs. impeded marsh retreat zones under the different sea level rise scenarios.

Additional steps were undertaken to predict those areas of coastal marsh that were vulnerable for conversion to either mud/peat/sand flats (unconsolidated shore) or open water under the different sea level rise scenarios. The NOAA Coastal Services Center (CSC) provided a potential marsh change GIS map (in December 2012) through what they describe as a SLAMM-type model (i.e., a stripped down version of the basic SLAMM). SLAMM stands for Sea Level Affecting Marsh Model. This model is used to predict changes in marsh vegetation under different sea level as well marsh accretion scenarios. We employed a 'moderate' level of vertical accretion of salt marshes (4 mm/yr over a 50 yr time frame) scenario. This 'moderate' level was chosen based on best available literature values for the region (Titus et al. 2009) and discussion with NOAA CSC (Douglass Marcy , Personal Communication). We extracted out areas that converted from coastal marsh to either unconsolidated shore or open water for each of the 1 to 3 foot sea level rise scenarios from the NOAA CSC SLAMM-type mapping. The marsh to unconsolidated shore or open water transitions were incorporated into the NJFloodMapper Marsh Retreat Zone maps as appropriate for the different sea level rise scenarios.

Caveats

Our SLAMM modeling assumed a 'moderate' level of vertical accretion (4 mm/yr over a 50 yr time frame). In the future data collected through the MACWA monitoring program will provide the research and management community a better understanding of the spatial and temporal variability of salt marsh vertical accretion rates across the state's coastal zone to better inform our modeling efforts. Our marsh modeling did not consider other natural processes such as erosion or the impacts of coastal storms that can have significant impacts on future shoreline location and sediment dynamics. A change in vegetation community composition (i.e., between low vs. high salt marsh) was not incorporated into the mapping process. The data do not take into account the amount of freshwater or sediment inputs, or how such upstream flows might be affected in the future.

The data in this map may not completely capture the area's hydrology, such as canals, ditches, storm water infrastructure, hardened shoreline, or dikes. There is some level of error in the elevation data, as well as in the tidal correction and mapping processes. It is important not to focus on the exact location of transitions, but rather to use these areas as a guide to help understand when and where impacts have the potential to occur, and as a gauge as to how severe they may be. Uncertainty associated with the exact amount of sea level rise, or the timing associated with each scenario, is not considered. It is up to the user to select the sea level rise scenario with which they feel most comfortable and evaluate how they will treat the predicted impacts and timing associated with each.