

Factors Governing the Vulnerability of Coastal Marsh Platforms to Sea Level Rise



Special Report • Fall 2015



LeeAnn Haaf
lhaaf@delawareestuary.org

Joshua Moody
jmoody@delawareestuary.org

Angela Padeletti
apadeletti@delawareestuary.org

Danielle Kreeger, PhD
dkreeger@delawareestuary.org

Erin Reilly
ereilly@ocean.edu

Martha Maxwell-Doyle
mmdoyle@ocean.edu



Funding was provided by the New Jersey Department of Environmental Protection through the National Fish and Wildlife Foundation for Building Ecological Solutions to Coastal Community Hazards.

The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. government or the National Fish and wildlife Foundation and its funding sources. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government, or the National Fish and Wildlife Foundation or its funding sources.

Suggested citation:

Haaf, L., J. Moody, E. Reilly, A. Padeletti, M. Maxwell-Doyle, D. Kreeger. 2015. Factors Governing the Vulnerability of Coastal Marsh Platforms to Sea Level Rise. PDE Report #15-08. Partnership for the Delaware Estuary and the Barnegat Bay Partnership.

Cover photograph of high water levels observed while performing condition assessment in the Dennis Creek watershed; courtesy of the Partnership for the Delaware Estuary 2014.

Factors Governing the Vulnerability of Coastal Marsh Platforms to Sea Level Rise

INTRODUCTION

Coastal wetlands play a crucial role in the maintenance of clean waters. Across the Mid-Atlantic, coastal wetlands are rapidly declining due to anthropogenic alteration, climate change, and sea level rise.^{1,2} Due to the importance of coastal wetlands, the Partnership for the Delaware Estuary (PDE) and Barnegat Bay Partnership (BBP) consider these habitats a research and conservation priority. To help stem coastal wetland losses in the Delaware and Barnegat Bay Estuaries, PDE and BBP coordinate the Mid-Atlantic Coastal Wetland Assessment (MACWA) with the goal of providing multiple agencies with invaluable monitoring and assessment data on marsh condition, as well as site-specific sources of stress that reduce marsh condition, function and acreage.

The goal of this synopsis is to briefly summarize the scientific knowledge on the factors that contribute to vertical losses in brackish and saline marshes of the Mid-Atlantic. Vertical losses, or those driven by platform elevation declines, can be largely attributed to functional impairment. Horizontal loss, also a large contributor to wetland acreage decline, is governed by factors such as edge erosion. This orientation seeks to aid coastal managers and practitioners in understanding the complex array of factors that affect platform (vertical) vulnerabilities of the coastal wetlands in our region. Although guidance on best management protocols and appropriate restoration tactics is beyond the scope of this document, PDE and BBP have previously released reports³ that examine factors of marsh loss, the associated methods for diagnosing marsh condition, and identifying restoration tactics:

- [Mid-Atlantic Coastal Wetland Assessment \(MACWA\) reports](#)
- [Delaware Estuary Living Shoreline Initiative Reports](#)
- [Marsh Futures Local Restoration Planning Tool](#)
- [Living Shoreline Monitoring Framework](#)

WHAT IS A COASTAL WETLAND?

A coastal wetland is any habitat that is subject to tidal action sufficient to sustain hydric (flooded or saturated) soils and support the growth of water loving vegetation (i.e. hydrophytes).⁴ These include, but are not limited to, salt or brackish marshes, tidal freshwater marshes, bottomland swamps, and sea grass beds. A majority of coastal wetlands within the Mid-Atlantic (particularly NJ, DE, and PA) are coastal marshes.^{2,5} Coastal marshes are dominated by herbaceous, emergent vascular plants⁶ and typically occupy elevations between mean sea level and mean high water.

1 Church, J. A., and N. J. White. 2011. Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics* 32(4-5): 585-602.

2 Miller, D., A. Padeletti, D. Kreeger, A. Homsey, R. Tudor, E. Creveling, M. M. DePhilip, C. Pindar. 2012. Chapter 5 - Aquatic Habitats in the Technical Report for the Delaware Estuary & Basin. Partnership for the Delaware Estuary. PDE Report No. 12-01, pages 119-165.

3 See the Partnership for the Delaware Estuary's website: <http://www.delawareestuary.org/>

4 New Jersey Coastal Wetland Protection Act. N.J. STAT. ANN: 13:18-1 to 13:9A-10; Clean Water Act (33 U.S.C. Section 125)

5 U.S. Fish and Wildlife Service. Accessed October 2015. <<http://www.fws.gov/wetlands/Documents%5CMid-Atlantic-Wetlands-A-Disappearing-Natural-Treasure.pdf>>

6 U.S. Environmental Protection Agency. Accessed October 2015. <<http://water.epa.gov/type/wetlands/marsh.cfm>>

WHAT IS MARSH CONDITION?

Marshes provide many services to coastal communities: they support habitat for local fisheries; provide storm and flood protection;⁷ and sequester carbon and nitrogen.⁸ Such services are derived from dynamic, coalescing processes which are the foundation of a functioning marsh. The services provided by marshes scale with marsh functions, which are reduced when condition is reduced. Degradation of condition typically precedes marsh acreage decline. Therefore, it is vital to assess condition and associated functions, not just acreage.

Marsh functionality can be compromised by natural or anthropogenic alterations to the environment. The effects of these alterations are often described by *marsh condition*, *vulnerability*, and *resilience*. To deduce which management or restoration practices are warranted for a site, it is critical to discern the marsh's a) current condition b) underlying causes of impairment, c) future vulnerabilities, and d) the future trajectory of marsh condition or resilience with no intervention.

Condition

Condition is the cumulative effect of multiple impacts or disturbances on marsh health. The interacting physical, chemical and biological factors affecting marsh condition may include nutrient concentrations, competition with invasive plants, or herbivory. Additionally, anthropogenic activities and management practices may alter water levels, sediment supplies, nutrient regimes, and migration potentials. The evaluation of marsh condition requires the assessment of physical and biological indices that describe levels of impairment or gauge performance of ecosystem services and functions. Marsh condition is described as *poor* or *good*; *impaired* or *healthy*.⁹

Vulnerability

Vulnerability is the susceptibility to decreased function driven by a specific impact. It is helpful to understand that vulnerability is stressor-specific and future-focused,¹⁰ whereas condition reflects the integrated effect from all stressors. For example, a marsh in good condition may be vulnerable to future impact from intensifying boat wakes, increasing nutrient loads, insufficient sediment supply, or greater frequency of severe weather events.

Resilience

Resilience is the long term ability of a marsh to sustain or regain performance and functionality in the face of multiple vulnerabilities.^{11,12} Resilience can also be thought of as the expected ability of a marsh to persist with good condition and function over time.

7 Arkema, K. K., G. Guannel, G. Verutes, S. A. Wood, A. Geuray, M. Ruckelshaus, P. Kareiva, M. Lacayo, J. M. Silver. 2013. Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change Letters*, DOI:10.1038/NCLIMATE1944.

8 Costanza, R., R. D'Arge, R. de Groot, S. Farberk, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Suttonkk, M. Van Den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387(6630): 253-260.

9 Turner, R. E., E. M. Swenson, C. S. Milan, J. M. Lee, T. A. Oswald. 2004. Below ground biomass in healthy and impaired salt marshes. *Ecological Research*, 19: 29-35.

10 Cahoon, Donald R., et al. 2006. Coastal wetland vulnerability to relative sea-level rise: wetland elevation trends and process controls. *Wetlands and natural resource management*. Springer Berlin Heidelberg, 271-292.

11 Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecological Systems*, 4: 1-23.

12 D'Alpaos, A., S. M. Mudd, L. Carniello. 2011. Dynamic response of marshes to perturbations in suspended sediment concentrations and rates of relative sea level rise. *Journal of Geophysical Research*, 116: F04020.

INTERACTING FACTORS OF MARSH CONDITION

Coastal marshes are able to maintain elevations relative to sea level as it rises. The two main functions that drive elevation maintenance are: a) sediment capture (organic or inorganic, allochthonous or autochthonous), and b) *in situ* organic matter accumulation via plant production. Several interacting factors contribute to these functions including sediment supply, nutrient loads, hydrology, and geologic activity (Figure 1).¹³ Alterations to these factors will have large effects on the natural feedback mechanisms that allow a marsh to keep pace with sea level rise, potentially imperiling the resilience of the marsh.^{14,15,16,17}

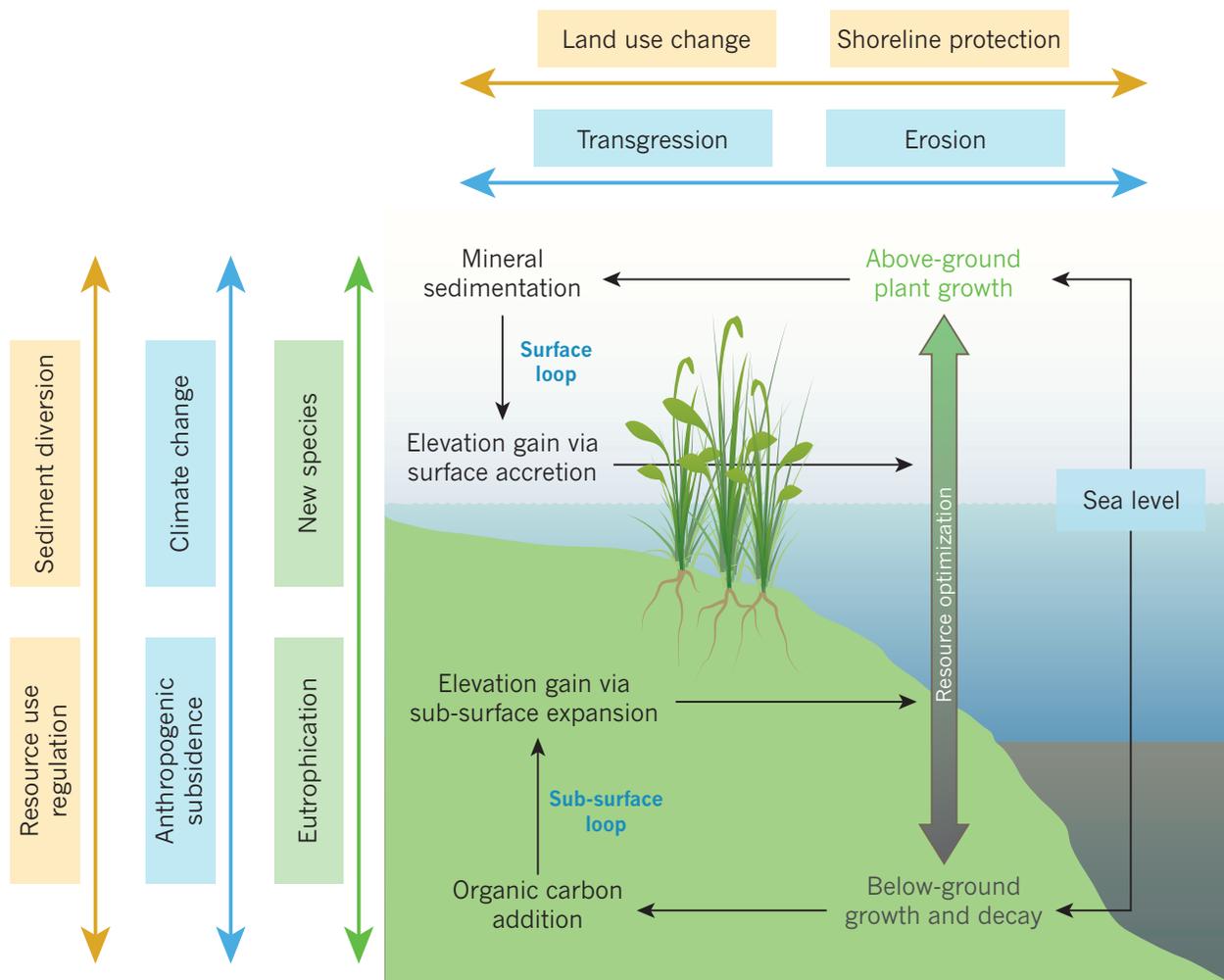


Figure 1. Factors that contribute to the stability of coastal wetlands from Kirwan & Megonigal 2013.¹³ Within the diagram: processes/feedback that contribute to stability; arrows to the left are impacts that affect vertical processes and arrows on the top are impacts affecting horizontal processes.

13 Kirwan, M. K., & J. P. Megonigal. 2013. Tidal wetland stability in the face of human impacts and sea-level rise, review. *Nature*, 504: 53-59.

14 Gleason, Mark L., et al. 1979. Effects of stem density upon sediment retention by salt marsh cord grass, *Spartina alterniflora* Loisel. *Estuaries* 2(4): 271-273.

15 Mudd, Simon Marius, et al. 2004. Flow, sedimentation, and biomass production on a vegetated salt marsh in South Carolina: toward a predictive model of marsh morphologic and ecologic evolution. *The Ecogeomorphology of Tidal Marshes, Coastal Estuarine Stud* 59: 165-187.

16 Butzack, C., et al. 2014. Sediment Deposition and Accretion Rates in Tidal Marshes Are Highly Variable Along Estuarine Salinity and Flooding Gradients. *Estuaries and Coasts* 38(2): 434-450.

17 Morris, J. T., P. V. Sundareshwar, C. T. Nietch, B. Kjerfve, D. R. Cahoon. 2002. Responses of coastal wetlands to rising sea level. *Ecology*, 83(10): 2869-2877.

Elevation is the cumulative result of various interacting processes, but assessing elevation alone does not elucidate underlying problems, which is the basis of understanding marsh condition and resilience. Platform elevation deficits may describe a vulnerability to sea level rise, but not the myriad of other vulnerabilities, such as edge erosion, reductions in belowground plant production due to eutrophication, or inability to migrate inland due to development. These diverse and interdependent processes make assessing marsh condition a difficult but necessary task in understanding how to enhance and maintain important ecosystem services provided by marshes functioning well. The following are brief descriptions of common factors affecting marsh condition in the Mid-Atlantic:

Sediment Supply Deficits

Sediment supply deficits are frequently caused by altered hydrology (damming, dikes, levees, sluices), nearby dredged sediment removals, or changes in upstream land use. Sediment supply is an important part of marsh platform elevation maintenance.¹⁸ Sediments are supplied either through the downstream transport of sediments or from resuspension of eroded marsh materials.^{19,20} Suspended sediments are delivered to tidal marsh platforms and contribute to accretion via tidal exchange, which is also a source of erosion. In a natural and healthy system, erosion and accretion are in balance, so a net positive sediment budget (capturing more than releasing) must be maintained to have sediments contribute positively to elevation accumulation.²¹ Over time, as upstream sediment sources decline, this balance shifts as less allochthonous sediment is available to be added to the marsh platform. Since both the Delaware and Barnegat Bay Estuaries face decreasing sediment budgets²² and high rates of subsequent marsh loss,²³ sediment management should be an important consideration for wetland managers in this region.

Nutrient Loading

Eutrophication in estuarine ecosystems is typically caused by runoff of nitrogen and/or phosphorus from upstream land uses and activities such as agriculture, urbanization, or waste water treatment. Both of these elements are important nutrients for plant production, but are typically limited in estuarine ecosystems.²⁴ Without nutrient limitation, marsh plants experience changes in growth rates and patterns which vary based on nutrient concentration, ratios, and variations in release from its/their source(s). There is a solid base of scientific literature concerning changes to the structure and production of marsh plant communities due to

18 Turner, R. E., E. M. Swenson, and C. S. Milan. 2000. Organic and inorganic contributions to vertical accretion in salt marsh sediments. *Concepts and controversies in tidal marsh ecology*. Springer Netherlands, 583-595.

19 DeLaune, R. D., R. H. Baumann, and J. G. Gosselink. 1983. Relationships among vertical accretion, coastal submergence, and erosion in a Louisiana Gulf Coast marsh. *Journal of Sedimentary Research* 53(1).

20 Reed, Denise J. 1988. Sediment dynamics and deposition in a retreating coastal salt marsh. *Estuarine, Coastal and Shelf Science* 26(1): 67-W

21 Temmerman, Stijn, et al. 2003. Spatial and temporal factors controlling short-term sedimentation in a salt and freshwater tidal marsh, Scheldt estuary, Belgium, SW Netherlands. *Earth Surface Processes and Landforms* 28(7): 739-755.

22 Weston, N. B. 2014. Declining Sediments and Rising Seas: an Unfortunate Convergence for Tidal Wetlands. *Estuaries and Coasts*, 37: 1-23.

23 Stammerman, R., and M. Pasecki. 2012. Influence of sediment availability, vegetation, and sea level rise on the development of tidal marshes in the Delaware Bay: a review. *Journal of Coastal Research*, 28(6): 1536-1549.

24 Valiela, I., and J. M. Teal. 1974. Nutrient limitation in salt marsh vegetation. p. 563-574. In R. J. Reimold and W. H. Queen (eds), *Ecology of Halophytes*. Academic Press, NY.

increased nutrient availability.^{25,26,27,28,29,30,31} The effects of eutrophication are not always consistent and can co-vary with salinity,³² plant or microbial diversity, and factors of hydrology or water chemistry. Generally, marsh plants in nutrient rich environments produce similar or more aboveground vegetation at the expense of belowground biomass (roots and rhizomes). The net result is that nutrient-laden marshes may appear similar or lush aboveground, but belowground components, which are more vital for elevation-building, are reduced.

Although nutrient loading directly impacts plant production, potentially decreasing marsh platform condition, there is no singular diagnostic metric³³ that can deduce this vulnerability. Plant communities undergoing increased inundation are similar in form to those that are affected by high nutrient loads. In either case, a marsh that is vulnerable to drowning or suffering from reduced belowground production may paradoxically look full and healthy above ground. Current favorable diagnostics for eutrophication focus on above to belowground production ratios and include water or soil nutrient monitoring. Wetland ecologists (and water quality specialists) are vital to deciphering the causes and potential solutions for such an impact.

Hydrological Alterations

Hydrological alterations can result from management practices such as Open Marsh Water Management, ditching, or other tidal restrictions. It may also result from natural changes to tidal amplitudes or relative sea level rise, and even changes in meteorology (wind speeds/directions or precipitation). Hydrologic alteration can have large impacts on the biology, structure and condition of coastal marshes. Coastal marsh topographies are shaped by the relative distribution of hydrologic regimes. Very small changes in these regimes, on the scale of millimeters, lead to important shifts in ecological processes. Although changes in sediment supplies and nutrient loads can be local or regional in scale, hydrologic alterations are typically local factors that can interact with or exacerbate regional factors. In addition to the direct effects that hydroperiod has on plants (see *Vegetation Diagnostics* below), there are secondary effects that impact plant productivity such as changes to marsh soil chemistry³⁴ (e.g. redox potential, nutrient delivery) or functionally dominant infauna benefitting plants, such as the ribbed mussel (*Geukensia demissa*).

25 Wigand, C., R. A. McKinney, M. A. Charpentier, M. M. Chintala, G. B. Thursby. 2003. Relationships of nitrogen loading, residential development, and physical characteristics with plant structure in New England salt marshes. *Estuaries*, 26(6): p 1494-1504.

26 Bertness, Mark D., et al. 2008. Eutrophication and consumer control of New England salt marsh primary productivity. *Conservation Biology* 22(1): 131-139.

27 Deegan, L. A., et al. 2012. Coastal eutrophication as a driver of salt marsh loss. *Nature* 490.7420: 388-392.

28 Turner, R. E., et al. 2009. Salt marshes and eutrophication: An unsustainable outcome. *Limnology and Oceanography* 54(5): 1634-1642.

29 Watson, E. B., A. J. Oczkowski, C. Wigand, A. R. Hanson, E. W. Davey, S. C. Crosby, R. L. Johnson, H. M. Andrews. 2014. Nutrient enrichment and precipitation changes do not enhance resiliency of salt marshes to sea level rise in the Northeastern U.S. *Climate Change*, 125: p 501-509.

30 Turner, R. E. 2010. Beneath the salt marsh canopy: loss of soil strength with increasing nutrient loads. *Estuaries and Coasts*, 34(5): 1084-1093.

31 Morris, J. T. 1982. A model of growth responses by *Spartina alterniflora* to nitrogen limitation. *Journal of Ecology*, 70: 25-42.

32 Crain, Caitlin Mullan. 2007. Shifting nutrient limitation and eutrophication effects in marsh vegetation across estuarine salinity gradients. *Estuaries and Coasts* 30(1): 26-34.

33 For information on various vegetation metrics see [Mid-Atlantic Coastal Wetland Assessment \(MACWA\) reports](#) and the [Living Shoreline Monitoring Framework](#).

34 Warren, R. S., W. A. Niering. 1993. Vegetation change on a Northeast tidal marsh: interaction of sea level rise and marsh accretion. *Ecology*, 74(1): 96-103.

Subsurface processes

Geological processes, such as compaction and subsidence, are important components of marsh elevation and platform vulnerability. These processes can vary at local and regional scales both naturally and associated with anthropogenic activities. The cumulative effects of compaction, decay, and other subsurface processes result in shallow subsidence.^{35,36} Accretion rates (via sedimentation and production) must equal shallow subsidence for a marsh to maintain elevation or surpass it to build elevation. The subsurface, however, may also undergo expansion from abiotic changes, like infiltration of water, yielding negative rates of shallow subsidence and gains in elevation not driven by accretion. Deep subsidence is a geological phenomena controlled by the movement of the earth's surface, including isostasy or tectonic movement. Rates of deep subsidence are substantial in the Mid-Atlantic from continued post-glacial isostatic adjustment (an elevation loss of ~1.4 mm/yr in New Jersey)³⁷ and contributes to current rates of sea level rise (which is 3-4 mm/yr).^{38,39}

VEGETATION DIAGNOSTICS

Absolute elevation (e.g. LiDAR) provides a useful starting point for identifying low-sitting marshes that may be vulnerable to drowning due to sea level rise. On-the-ground assessments of physical, biological and possibly chemical conditions are also needed to augment these data and assess whether marsh health is being compromised and to determine any appropriate interventions. Since marsh plants have optimal growth parameters, their above and below ground morphology can be diagnostic of different impacts. Documenting prevailing conditions, plant community structures and overall plant morphologies is an effective tool to obtain a preliminary understanding of the current health of the marsh. No single metric (e.g. elevation, plant morphology), however, should be used to diagnose marsh condition or make restoration/intervention decisions, since there are a variety of interacting factors that contribute to localized vulnerabilities and conditions.

What dictates marsh plant growth?

Water Levels

Each species of marsh plant has an optimal growth range in the local tidal prism.^{40,41} Marsh zonation and plant distributions are driven in part by hydroperiods, or how frequently a particular elevation is inundated by tidal flow. Hydroperiods are affected by elevation, marsh platform topography, local tidal range, and local

35 Cahoon, DR, JC Lynch, PF Hensel, RM Boumans, BC Perez, B Segura, and JW Day, Jr. 2002a. High precision measurement of wetland sediment elevation: I. recent improvements to the sedimentation-erosion table. *Journal of Sedimentary Research* 72(5):730-733. abstract

36 Cahoon, DR, JC Lynch, BC Perez, B Segura, R Holland, C Stelly, G Stephenson, and PF Hensel 2002b. High precision measurement of wetland sediment elevation: II. the rod surface elevation table. *Journal of Sedimentary Research* 72(5):734-739.

37 Kemp, A. C., B. P. Horton, C. H. Vane, C. E. Bernhardt, D. R. Corbett, S. E. Engelhart, S. C. Anisfield, A. C. Parnell, N. Cahill. 2013. Sea-level change during the last 2500 years in New Jersey, USA. *Quat. Sci. Rev.*, 81: 90-104.

38 Engelhart, S.E., and B. P. Horton. 2012. Holocene sea level database for the Atlantic coast of the United States. *Quat. Sci. Rev.*, 54: 12-25.

39 NOAA Tides & Currents Sea Level Trends (for Cape May 8536110 and Atlantic City 8534720, NJ and Reedy Point 8551910, DE). Accessed October 2015 <<http://tidesandcurrents.noaa.gov/sltrends/sltrends.html>>

40 McKee, Karen L., and W. H. Patrick. 1988. The relationship of smooth cordgrass (*Spartina alterniflora*) to tidal datums: a review. *Estuaries* 11(3): 143-151.

41 Morris, J. T., P. V. Sundareshwar, C. T. Nietch, B. Kjerfve, D. R. Cahoon. 2002. Responses of coastal wetlands to rising sea level. *Ecology*, 83(10): 2869-2877.

currents. An understanding of how water may be distributed across the marsh platform over time is key for identifying plant responses to hydroperiod changes. Optimal growth zones, when considering both hydroperiod and elevation, overlap for many marsh species. Plant distributions are often also controlled by other variables, such as soil toxicity or plant competition.

Marsh Plant Zonation

The most common plant found in Mid-Atlantic salt marshes is smooth cordgrass (*Spartina alterniflora*). This grass has tall and short forms. Frequently inundated areas along rivers or creeks, or low marshes, are dominated by tall form smooth cordgrass.⁴² In the less inundated areas of the high marsh, smooth cordgrass assumes its short form. High marsh soils typically have greater toxic stress than low marshes as the longer times between inundation periods increase the amount of water evaporated from the marsh surface, leaving salt and sulfuric compounds behind. Smooth cordgrass is unique in that it adapts to this stress through morphological change, growing shorter so energy can be concentrated on belowground structures to better manage chemistry and scavenge for nutrients, which decrease with increasing distance to tidal creeks. The average height of smooth cordgrass, regardless of form, is proportionate to local tidal ranges. So, smooth cordgrass is shorter on average in Barnegat Bay, where tidal ranges are ~0.7⁴³ m, than in the Delaware Estuary, where tidal ranges are ~1.8 m.

Despite greater toxic stress, high marshes are a mosaic of different species, including salt hay (*Spartina patens*)⁴⁴ and salt marsh spike grass (*Distichlis spicata*).⁴⁵ These plants are physiologically adapted to function in high marshes and may out compete smooth cordgrass under certain conditions. Although it is generally true that high marshes have higher elevations than low marshes, this is not always the case, and it is truly inundation frequency that has the greatest influence on plant species distributions. Furthermore, as inundation patterns become altered with sea level rise, species distributions and morphological changes are expected. These changes are an important part of a functioning marsh's response to climate change. Without considering other vulnerabilities, such changes are not diagnostic of marsh platform condition or resilience.

Another feature of the high marsh is the presence of salt pannes. Salt pannes are areas where surface toxicity is great enough to reduce the production of smooth cordgrass despite its morphological adaptations. So, salt pannes are mostly devoid of vegetation except for sparse smooth cordgrass and glass wort (*Salicornia* sp.). The reduction of plant production, specifically below ground biomass, can lead to decreased elevation profiles within the panne, and potentially, conversion to pools. Pools are depressions consistently filled with water and not directly affected by tidal flow. This is not necessarily a sign of degradation or an indication of marsh-wide elevation deficits. Assessments of marsh condition based on salt panne or pool acreage should be conducted using historical data to ascertain changes in panne or pool coverage over time.

42 Gleason, Mark L., and Joseph C. Zieman. 1981. Influence of tidal inundation on internal oxygen supply of *Spartina alterniflora* and *Spartina patens*. *Estuarine, Coastal and Shelf Science* 13(1): 47-57.

43 See Tidal Datums for stations in each estuary as maintained by NOAA Tides & Currents. Tidal ranges are the distance between mean higher high water and mean lower low water. < <https://tidesandcurrents.noaa.gov/stations.html?type=Datums>>

44 Naidoo, G., K. L. McKee, I. A. Mendelssohn. 1992. Anatomical and metabolic responses to waterlogging and salinity in *Spartina alterniflora* and *Spartina patens*. *American Journal of Botany*: 79(7). p 765-770.

45 Emery, N. C., P. J. Ewanchuk, M. D. Bertness. 2001. Competition and salt marsh plant zonation: stress tolerators may be dominant competitors. *Ecology*, 82(9), 2471-2485.

Understanding marsh zonation can aid marsh condition diagnoses. For example, smooth cordgrass grows taller when inundated frequently, which is a healthy condition if the plants are near drainages or along creeks and rivers. The same species would grow shorter, appearing stunted, on a less regularly inundated high marsh. The presence of short form smooth cordgrass is rarely a sign of impairment, and may be regarded as a sign of good marsh health. In contrast, marshes with elevation deficits may have tall form across the marsh platform with little or no short form, suggesting the whole platform is regularly inundated and high marsh stressors do not exist. Over time, such a marsh may lose plant productive capacity⁴⁶ and, as taller forms of smooth cordgrass encroach into higher areas, plant diversity may be lost.⁴⁷

CONCLUDING REMARKS

We support the efforts to help stem continued losses and degradation of our region's vital coastal wetlands. With limited resources and capacity, the intent of PDE and BBP is to help ensure that any investments in coastal marshes are strategic, focused on primary site-specific issues, and that the projects yield the greatest possible ecological outcomes.

It is not the purpose of this synopsis to summarize appropriate actions that could be taken to address marsh platform vulnerability. But, as discussed in other MACWA and PDE related reports, there are numerous tactics that exist and continue to be developed to address coastal marsh stressors and to directly restore these vital habitats such as various types living shorelines or breakwaters, thin-layer sediment application, and removal of restrictions to tidal flow or sediment supply. To boost success of any of these marsh enhancement projects, we suggest that the local, site-specific conditions be assessed and put into an appropriate ecological context:

- **Verify that the marsh does in fact need enhancement.** Consult existing datasets and perform at least rapid assessments (e.g. Mid-TRAM)⁴⁸ to measure its condition: is it reduced relative to representative marshes in vicinity?
- **If a marsh is degraded, identify the root cause of the impairment.** Interpret the condition assessment data and perform additional intensive studies to pinpoint the main stressors.
- **Choose an appropriate intervention tactic matched to the main stressors and vulnerabilities for the location.** Often, a tactic is selected for a location without regard for the actual sources of stress. Some tactics can easily harm a wetland if not matched to the stressor, or if not correctly adjusted to local physical and biological targets. For example, thin-layer sediment application has the potential to compress or smother a marsh if the wrong amount or grain size is used.
- **Use scientifically based methods to track project performance when possible.** With

46 Voss, C. M. R. R. Christian, J. T. Morris. 2013. Marsh macrophyte responses to inundation anticipate impacts of sea level rise and indicate ongoing drowning of North Carolina marshes. *Marine Biology*, 160: 181-194.

47 Donnelly, J. P., and M. D. Bertness. 2001. Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea level rise. *PNAS*, 98(25): 14218-14223.

48 Mid-Atlantic Tidal Rapid Assessment Method, v 3.0. 2010. < <http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Documents/Tidal%20Rapid%20Protocol%203.0%20Jun10.pdf>>

all marsh enhancement tactics, assessing specific project performance metrics is crucial to understanding not only the success of the project but expanding our knowledge base to improve methods and outcomes regionally. Monitoring frameworks and methods are available to encourage consistent and sharable performance data outcomes.

As our coastal wetlands continue to come under increasing pressures for their future survival, understanding coastal wetlands processes is critical if we are to make sound management decisions that will help ensure their future. Without that understanding our best efforts to save this precious resource could have a deleterious effect.

APPENDIX

Diagram of Typical Salt Marsh Zonation



Figure 2. This diagram is a representation (not necessarily to scale) of plant community structure along a hydrologic gradient. See table below for common names. The low marsh (left) is frequently inundated by tides. Towards the right, the communities experience less regular inundation. The numbers above right-pointing arrows are zonations based on elevation and distance from the tidal water source.

Table 1. Common names for plant species referenced in Figure 1.

Latin Binomial (scientific name)	Common Name
<i>Spartina alterniflora</i> (Loisel.)	Smooth cordgrass
<i>Spartina patens</i> (Aiton) Muhl.	Salt hay or salt meadow cordgrass
<i>Distichlis spicata</i> (L.) Greene	Spike grass or seashore salt grass
<i>Spartina cynosuroides</i> (L.) Roth	Big cordgrass
<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	Common reed or Phragmites (invasive)
<i>Salicornia virginica</i> (L.) or <i>Salicornia europaea</i> (L.)	Glasswort or pickleweed
<i>Juncus gerardii</i> (Loisel.)	Saltmarsh rush or black needle rush
<i>Iva frutescens</i> (L.)	Marsh elder or high tide bush

Photographs of Plant Morphologies in the Delaware and Barnegat Bay Estuaries



Figure 3. Delaware Estuary: Tall form smooth cordgrass in the high marsh showcasing evidence of increased inundation (left); tall form smooth cordgrass along a ditch with healthy short form in the foreground exemplifying a healthy the high marsh (right)

Photographs of Plant Morphologies in the Delaware and Barnegat Bay Estuaries (con't)

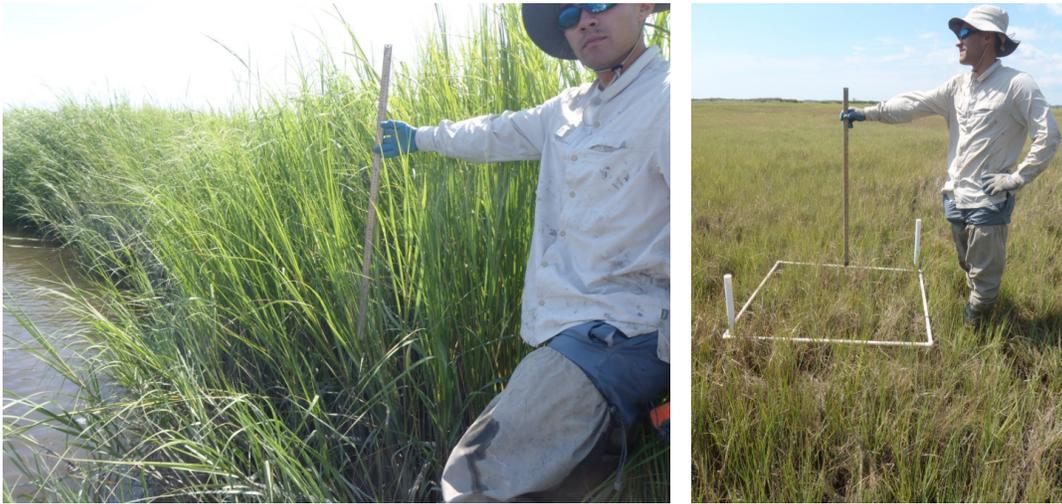


Figure 4. Delaware Estuary: Typical tall form smooth cordgrass along river's edge (left); healthy short form in the high marsh at same location (right).

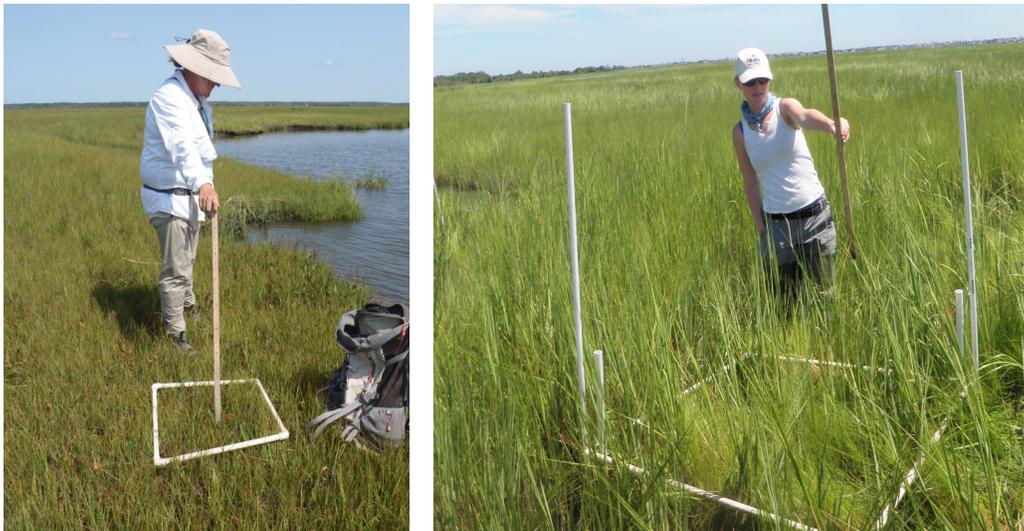


Figure 5. Barnegat Bay Estuary: Short form smooth cordgrass at high elevations along creek edge (left); tall form smooth cordgrass with salt hay (*Spartina patens*) in the high marsh showcasing evidence of increased inundation levels (right)



Figure 6. Delaware Estuary: Tall form smooth cordgrass in the high marsh showcasing effects of higher than average nutrient loads (left); sparse tall form in the high marsh with very high inundation levels (right)