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Evaluation of coastal wetland soil properties in a degrading marsh

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ABSTRACT

Coastal salt marshes consist of a mosaic of vegetated and open water features, which naturally evolve and change over time. However, the rapid expansion of open water areas has been associated with marsh degradation and there is a growing need for detailed studies as coastal wetlands continue to degrade under increasing rates of sea level rise and related stressors. Yet, few studies investigate soil physicochemical and biogeochemical properties within different marsh landscape features, which could provide insight into mechanisms of the formation and expansion of open water areas. The current study compared wetland soil physical and microbial properties observed in vegetated areas with shallow open water areas called pannes, identifying a number of significant differences. Panne soils possessed lower bulk density, total C, N, P, SOC, DOC, and SRP compared with vegetated marsh areas, suggesting a shift in nutrient pools as vegetated areas transition into shallow open water features. Panne features also displayed significantly lower microbial pool sizes and processing rates than vegetated marsh soils, suggesting reduced capacity for nutrient processing in open water areas. Further, extractable NH_4-N was highest in the panne soils suggesting that the absence of macrophytes decreased N uptake in open water areas. Also related to the lack of vascular plants, extractable DOC in pannes averaged less than half the concentration found in vegetated marsh areas, despite a smaller difference in soil total C. Results underscore the importance of incorporating heterogeneous landscape soil conditions when evaluating marsh degradation and considering potential restoration activities.

1. Introduction

Healthy, stable marshes contain a mosaic of vegetated areas interspersed with shallow un-vegetated pannes and deeper open water pools (Wilson et al., 2009; Friedrichs and Perry, 2001). The combination of geomorphic features supports a variety of habitat types/niches, with open water areas occurring at a frequency of 13 ± 7 features per hectare in a healthy New England marsh (Adamowicz and Roman, 2005). Early work suggested that un-vegetated areas result from rafted debris smothering vegetation, resulting in die-off and subsequent collapse of the marsh platform (Harshberger, 1916). More recent research links conversion of vegetated marsh to open water areas with decreases in living vegetation and soil organic matter, salt water intrusion, soil waterlogging (Wilson et al., 2014), damage from storms or ice/vegetation rafting (Argow et al., 2011; Pethick, 1974), collapse of soil pore space (DeLaune et al., 1994; Nyman, 1993), reduced sedimentation (Roman et al., 2000; Redfield, 1972), and anthropogenic alterations of the marsh surface (Wilson et al., 2009). Based upon the amount of recent and ongoing research, many questions remain regarding the distribution, trajectory and fate of marsh morphologic features.

Formation and subsequent infilling of panne and pool features result from natural cyclical process within the marsh environment (Wilson et al., 2014), yet the associated mechanisms and timescales remain unclear especially in areas displaying disturbance (e.g., marsh ditching). Notably, several studies document fragmentation and subsequent degradation of the marsh platform occurring via increasing conversion of vegetated areas to un-vegetated pannes and pool areas (Turner, 1997; Day et al., 2000). DeLaune et al. (1994) described this process as pond initiation, in which newly formed open water areas allow for further marsh degradation via erosion, collapse, and other mechanisms. The Louisiana Wetland Value Assessment Methodology describes the development and expansion of pools and pannes as a high degree of interspersion and associates the phenomenon with marsh degradation (CWPPRA, 2002). Other research links disturbances of marsh vegetation with the formation of open water features, which subsequently exacerbates marsh fragmentation via erosion and widening of tidal channels (Kirwan et al., 2008; Temmerman et al., 2012). The continued expansion or eventual recovery of marsh pools and pannes is a function of local hydrodynamics, mineral sediment loading, and marsh topography (Mariotti, 2016). Despite the work

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completed to date (Wilson et al., 2010), limited research investigates soil properties in different marsh morphologic components (i.e., vegetated areas and pannes), which may provide insight into the formation, expansion, and degradation process and aid in successful marsh restoration design. In particular, few studies examine soil and biogeochemical conditions within shallow pannes and open water areas occurring within the marsh platform (Spivak et al., 2017).

Understanding soil processes in coastal wetlands remains an important factor in addressing marsh degradation, which occurs in response to a variety of factors including development, erosion, salinization, and a lack of sediment input (Barras et al., 2003; Baumann et al., 1984). Recent studies identify challenges in coastal wetland management posed by increasing sea level rise as well as increasing storm frequency and intensity that exacerbate marsh stressors (Hauser et al., 2015). In response, wetland restoration projects have been implemented over the past three decades to stabilize and enhance marsh ecosystems (Warren et al., 2002; Broome et al., 1988; Neubauer, 2008) and the role of soil properties in restoration has been recognized (Craft, 2007; Zedler, 2000). For example, Edwards and Proffitt (2003) investigated differences in bulk density and soil organic matter content between natural and restored marshes and DeLaune et al. (1979) identified positive responses of marsh stability and plant communities resulting from the influx of mineral sediments. Despite numerous studies examining marsh characteristics, few studies have examined differences in soil properties within marsh morphologic components showing signs of degradation. As a result, the current study investigates soil physical, nutrient, and biogeochemical properties in vegetated and un-vegetated areas of a degrading coastal marsh to evaluate the hypothesis that soil conditions will differ between vegetated marsh and shallow open water panne morphologic components. Several hypothesis are evaluated including 1) whether the development of open water landscape features alters soil microbial/nutrient properties and 2) if the reduction in vascular vegetation in open water areas results in decreased nutrient processing. An example of the implications of incorporating landscape morphologic components into interpretations of marsh nutrient (e.g., carbon) cycling dynamics is also included.

2. Materials and methods

The study area is located within a 1700-ha tidal marsh complex located near Avalon, New Jersey, USA (Fig. 1) with a semidiurnal tidal range of 1.39 m. The salt marsh complex contains a mosaic of morphologic features including tidal creeks, mud flats, vegetated marsh platforms, and unvegetated, open water areas consisting of shallow pannes and deeper pools (NOAA, 2017; Wilson et al., 2010). Marsh degradation within the study area has been identified via the increasing presence of impounded water, the expansion of un-vegetated pannes, erosion, vegetation stress, and loss of herbaceous marsh species (Kirwan et al., 2008; Schepers et al., 2017). Recently field practitioners working within the study area observed the rapid transition of vegetated marsh platforms to un-vegetated shallow pannes and suggested that formation of shallow pannes features may instigate degradation via conversion of emergent vegetated marsh to shallow open water features (VanZomeren et al., 2018, Fig. 2). As a result, the current study area focuses on soil properties in vegetated areas and shallow un-vegetated panne features; it does not include data regarding soil properties or the landscape evolution associated with adjacent tidal creeks, mud flats, or deeper marsh pools.

Vegetated areas examined in the study are characterized by nearly monotypic bands of clonal turf, dominated by *Spartina alterniflora* occupying > 90% absolute aerial cover of the soil surface, with small amounts of *Distichlis spicata* and other trace species (e.g., *Salicornia Sp.*) occupying < 5% of the soil surface (Fig. 2; Ewanchuck and Bertness, 2004a). Vegetated areas within the marsh occur at a median elevation of 0.61 m (NAVD88) with a standard deviation of 0.20 m and are typically tidally inundated once daily. The salinity in the channel

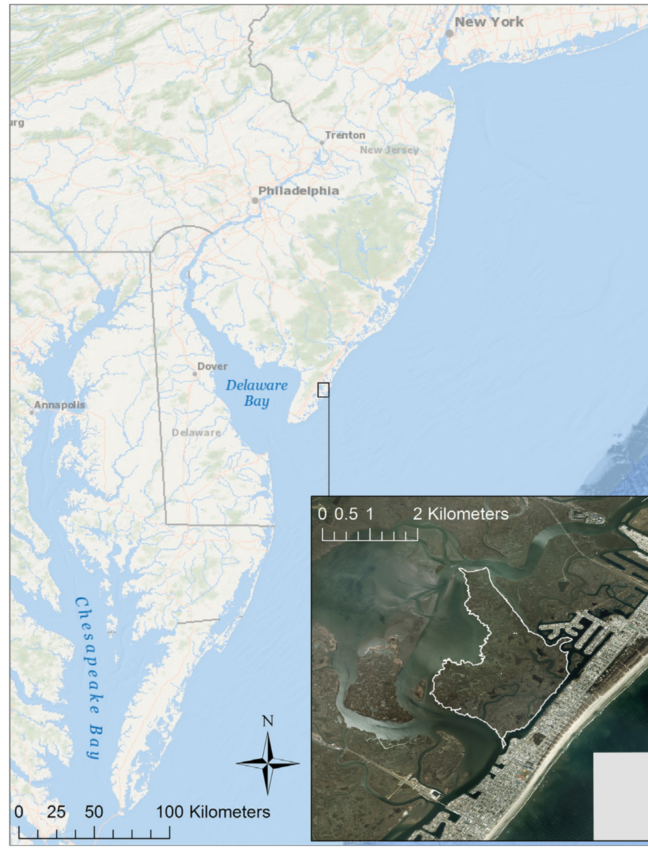

Fig. 1. Location of the tidal marsh in coastal New Jersey, USA. The white outline highlights the study area.

adjacent to the marsh had an average salinity of 32 ppt during the sample period (June–September 2017; http://www.state.nj.us/dep/bmw/capemay3.htm). The salinity range observed in vegetated marsh features ranged from 25 to 35 ppt with an average salinity of 27 ppt based upon data collected during the sampling period.

Panne features occur at lower elevation and experience increased waterlogging, salinity, and more anoxic conditions than the surrounding turfed marsh (Ewanchuck and Bertness, 2004b). While pannes may dry out for portions of the growing season, Adamowicz and Roman (2005) reported that pannes averaged 20–30 cm of surface water, occupying largely un-vegetated portions of the marsh. Within the study area, pannes displayed inundation depths of 5–30 cm and median elevation of 0.26 m (NAVD88) with a standard deviation of 0.13 m and typically remained inundated although the elevations were above local mean sea level. Although not directly connected via surface channels, some tidal forcing was observed within panne features. The salinity range observed in pannes ranged from 29 to 33 ppt with an average salinity of 30 ppt during the same period of observation. As a result of their location within the marsh platform, pannes are distinct from mudflats and tidal creeks. Further, shallow water pannes are dynamic features with irregular elongated shapes characterized by highly complex boundaries. These pannes remain dissimilar from marsh pools which are deep (> 1 m), often rounded features that may persist on the marsh for decades (Wilson et al., 2009, 2014). Additionally, many pannes in the study area exhibit signs of recent marsh platform collapse as indicated by the presence of recently eroded marsh materials at the panne edge and in small (< 1 m^2) isolated “islands” of marsh material degrading within the panne interior (Kirwan et al., 2008, Fig. 2).

In order to investigate soil conditions in vegetated marsh and in un-vegetated shallow water pannes, triplicate soil cores (collected from a 1 m^2 area) were collected and homogenized at 12 vegetated areas consisting of *Spartina alterniflora* and 12 open water pannes (Wilson