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# Restoring a degraded marsh using thin layer sediment placement: Short term effects on soil physical and biogeochemical properties

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ABSTRACT

Recent interest has focused on wetland restoration techniques that introduce a thin layer of sediment onto degrading marsh surfaces. A restoration project in Avalon, New Jersey, received 5–19 cm of dredged sediment onto vegetated marsh areas and 32–82 cm of sediment into degraded open water panne features interspersed within the degraded marsh plain. There were significant differences in soil physical properties between the placed dredged sediments and the buried native marsh and panne soils. For example, six months after project implementation, application of dredged sediment increased surface panne bulk density from $0.22 \pm 0.02\ \mathrm{g\ cm^{-3}}$ to $0.83 \pm 0.09\ \mathrm{g\ cm^{-3}}$, surpassing the threshold required for *Spartina alterniflora* Loisel. establishment. Soil nutrient and microbial properties also differed between placed sediments and buried marsh/panne soils. Notably, buried marsh soils remained microbially active demonstrating the capacity for buried soils to provide labile nutrient sources, such as ammonium, during vegetation recruitment. Results suggest that thin layer sediment placement techniques may jump-start marsh recovery by maintaining native vegetation seed sources, rhizomes, and microbes in near-surface soils compared to other restoration approaches. Examining short term changes in soil microbial activity may provide early indicators of restoration outcome, although, additional research is required to more accurately predict changes in soil properties over time.

## 1. Introduction

Healthy marshes maintain elevation through vertical accretion and contain stable vegetated areas interspersed with shallow un-vegetated pannes or deeper, open water areas (Wilson et al., 2009; Friedrichs and Perry, 2001). This mosaic of vegetated and un-vegetated geomorphic features provides varied habitat types within the marsh, supporting a variety of threatened and endangered species (Daniels et al., 1993; Gedan and Bertness, 2009). For example, un-ditched marshes in New England support an average open water feature density of $945\ \mathrm{m^2\ ha^{-1}}$ (13 ± 7 open water features per hectare), providing both vegetated nesting and open water foraging sites for avian species (Adamowicz and Roman, 2005). Formation and infilling of open water features are natural processes that occur within the marsh environment through various erosional and accretionary processes (Wilson et al., 2014). However, several studies link extensive fragmentation and degradation of healthy marshes to expanding un-vegetated shallow pannes and deeper open water pools (La Peyre et al., 2009; Turner, 1997; Day et al., 2000). DeLaune et al. (1994) developed the concept of pond initiation, in which newly formed open water areas promote erosion and soil collapse resulting in further marsh degradation. Others describe the expansion of open water areas as marsh drowning, a process in which sea level rise rates outpace marsh accretion, wave erosion accelerates edge retreat, or marsh collapse occurs within newly formed un-vegetated areas (Mariotti, 2016).

Berkowitz et al. (2018) report several significant differences in soil physicochemical and biogeochemical properties between vegetated areas and panne features within a marsh located near Avalon, New Jersey, USA. For instance, soil physical properties (e.g., bulk density, total C) were significantly higher in vegetated areas than panne features. This is consistent with available physicochemical data demonstrating that degraded panne features displayed decreased structural integrity from loss of vegetation, increased decomposition rates, and lower mineral and organic contributions via sediment entrapment and vegetation productivity (DeLaune et al., 1990; Chambers et al., 2013; Wilson et al., 2014). At the Avalon site, biogeochemical properties also varied between vegetated areas and pannes features. For instance, the potentially mineralizable nitrogen (PMN) rate was significantly lower and extractable $NH_4^+$ significantly higher in the panne features compared to vegetated areas, indicating both lower microbial activity and

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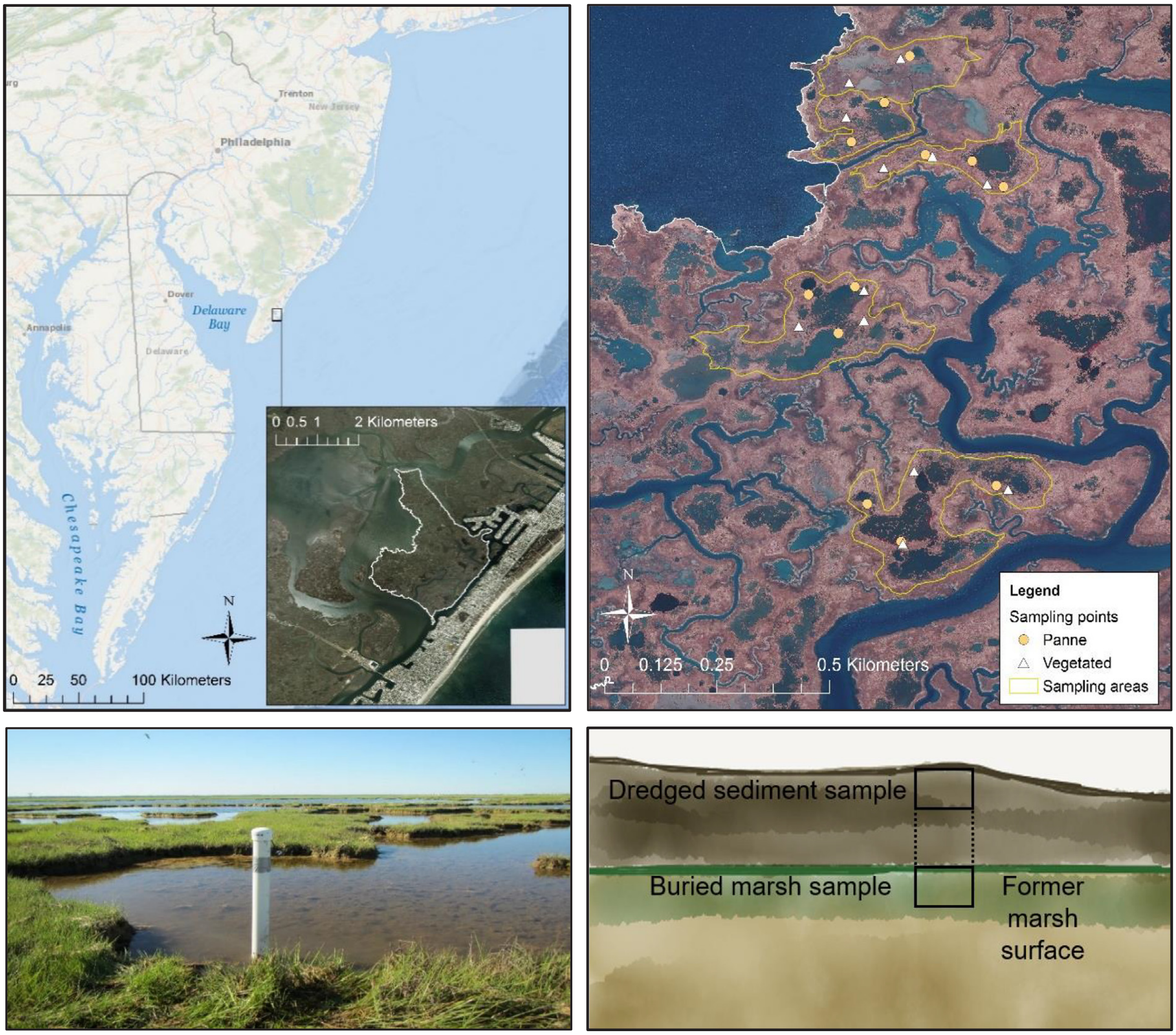

**Fig. 1.** A) Map of Avalon, NJ marsh site; B) Sampling locations on the marsh. The control areas and portions of the marsh that received thin layer sediment application are outlined in yellow; C) Degraded vegetated *Spartina alterniflora* Loisel. marsh interspersed with expanding open water panne features near Avalon, NJ; and D) Marsh and dredged material sampling approach.

lower nutrient uptake in panne features due to the absence of macrophytes (Berkowitz et al., 2018). Microbial biomass C and N were also significantly elevated in vegetated areas compared with panne features. Results from Berkowitz et al. (2018) suggest that microbial communities and pool sizes may differ across marsh features, highlighting the need to evaluate soil physical and biogeochemical properties of different marsh features prior to and following restoration projects in order to assess the response of different marsh features to restoration activities.

Restoration strategies that mitigate marsh degradation while improving marsh structure and function are necessary, and have been implemented over several decades to stabilize, nourish, and enhance marsh ecosystems (La Peyre et al., 2009; Warren et al., 2002). Restoration techniques include erosion control, invasive species removal and establishment of native vegetation, and re-connection of tidal flow to promote sediment deposition (GMCHRS, 2004; Jackson, 2009). These restoration techniques, and others, do not address a critical component of marsh restoration–elevation of the marsh platform in relation to tidal regime (Broome et al., 1988). Thus, there remains a need for restoration strategies that address marsh subsidence, especially as increasing storm frequency and intensity may exacerbate marsh stressors in the future (Hauser et al., 2015). Therefore, resource managers should pursue strategies designed to create optimum conditions (i.e., elevation in the tidal range) to support marsh accretion and stabilize the marsh substrate for healthy vegetation growth and resiliency with expected sea level rise and storm impacts (La Peyre et al., 2009; Baustian and Mendelssohn, 2015). The application of dredged sediments to the marsh surface has the potential to maintain marsh elevation despite current coastal subsidence or accelerating future rates of sea level rise by supporting a stable platform for plant growth, while maintaining natural patterns of hydrology and vegetation (Neubauer, 2008).

Thin layer placement restoration techniques involve the application of sediment, typically dredged from nearby navigation channels, to a depth, thickness, or elevation that does not transform the ecological function of the receiving habitat, while improving environmental outcomes, infrastructure, and resiliency (Wilber, 1992). Typical dredged material or sediment thicknesses range from a few centimeters to a half a meter (Berkowitz et al., 2017). Previous marsh restoration studies utilizing thin layer placement of dredged sediments studies examined response of plant communities (Pezeshki et al., 1992; Ford et al., 1999), invertebrates (Croft et al., 2006), soil organic matter accumulation and bulk density (Slocum et al., 2005), and marsh resilience following a disturbance (Stagg and Mendelssohn, 2011).

Soils provide the physical platform for plant growth and support microbes responsible for nutrient cycling essential to vegetation growth