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Simulated storm surge effects on freshwater coastal wetland soil porewater salinity and extractable ammonium levels: Implications for marsh recovery after storm surge

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ABSTRACT

Coastal wetland systems experience both short-term changes in salinity, such as those caused by wind-driven tides and storm surge, and long-term shifts caused by sea level rise. Salinity increases associated with storm surge are known to have significant effects on soil porewater chemistry, but there is little research on the effect of flooding length on salt penetration depth into coastal marsh soils. A simulated storm surge was imposed on intact soil columns collected from a non-vegetated mudflat and a vegetated marsh site in the Wax Lake Delta, LA. Triplicate intact cores were continuously exposed to a 35 salinity water column (practical salinity scale) for 1, 2, and 4 weeks and destructively sampled in order to measure porewater salinity and extractable NH_4—N at two cm depth intervals. Salinity was significantly higher in the top 8 cm for both the marsh and mudflat cores after one week of flooding. After four weeks of flooding, salinity was significantly higher in marsh and mudflat cores compared to the control (no salinity) cores throughout the profile for both sites. Extractable ammonium levels increased significantly in the marsh cores throughout the experiment, but there was only a marginally ($p < 0.1$) significant increase seen in the mudflat cores. Results indicate that porewater salinity levels can become significantly elevated within a coastal marsh soil in just one week. This vertical intrusion of salt can potentially negatively impact macrophytes and associated microbial communities for significantly longer term post-storm surge.

1. Introduction

Between the years of 1850 and 2008, approximately 106 tropical storm events have made landfall along the Louisiana coast (Stone et al., 1997; Roth, 2010), and winter cold-front passages occur more often and affect larger swathes of coastline (Feng and Li, 2010; Moeller et al., 1993). Both hurricanes and storm fronts can cause major storm surge events that flood low-lying fresh and oligohaline coastal marshes with high salinity water (Moeller et al., 1993; Rego and Li, 2009). Hurricane-derived storm surge can vary significantly based both on the Saffir-Simpson category, the areal extent, and the forward speed of the hurricane (Irish et al., 2008; Rego and Li, 2009). The resulting storm surge does not immediately exit the marshes after the passage of the storm as both high water and salinity levels persist (Li et al., 2010). Consequently, a fresh or oligohaline marsh may be exposed to high salinity conditions for a significant period of time (Li et al., 2010).

The Mississippi River coastal deltaic plain is similar to other deltaic settings globally, which are characteristically low relief and, as a consequence, are highly susceptible to inundation by frontal storm events and hurricanes/cyclones and their associated storm surges. The topographic relief in southeastern coastal Louisiana is as low as 0.2 cm per kilometer (Byrne et al., 1976). Consequently, even small increases in water level from storm surges can flood a considerable area of the coastal zone. Additionally, a large portion of the Mississippi River delta region is subsiding and, in concert with increasing sea level, is particularly vulnerable to storm-derived salinity incursions (DeLaune and White, 2012).

Concern over global sea level rise has triggered a number of investigations on the effects of increased salinity on macrophyte response, wetland soil biogeochemical processes, and associated

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coastal marsh ecosystem functions. Research has shown that plant growth, ability to uptake nutrients, rates of photosynthesis, and ability to store energy are all negatively impacted by an increase in salinity in coastal freshwater and oligohaline marshes (Chaudhuri and Choudhuri, 1997; Parida and Das, 2005; Rysgaard et al., 1999; Wu et al., 1998). Short-term salinity pulses into freshwater wetlands have also been found to increase the rate of C mineralization (Chambers et al., 2011). Increased salinity can reduce the rate of microbial processes in wetland soils, such as denitrification (Marks et al., 2016; Putnam Duhon et al., 2012). The effect of increased salinity on N mineralization is less clear as both no effect and a negative effect on N mineralization with increased salinity have been found (Giblin et al., 2010; Marks et al., 2016; Putnam, 2009). A single salinity pulse was found to increase the microbial biomass pool but did not increase microbial activity (Kiehn et al., 2013). Further, an increase in salinity decreased the activity of wetland soil extracellular enzymes; phosphatase, β-glucosidase, and NAGase (Jackson and Vallaire, 2009). These enzyme activities are related to nutrient turnover, regulating ecosystem primary productivity. Field measurements from an estuarine system experiencing seasonal fluctuations in salinity have shown increases in salinity are related to lower availability of extractable ammonium (Weston et al., 2010).

Ammonium (NH_4) plays various roles in coastal wetland ecosystems and can serve as a macronutrient for macrophytes, algae and can be considered a source of pollution at high concentrations. Ammonium is known to be toxic to fish and can lead to algal blooms (Bargu et al., 2011; Eddy, 2005). Algal blooms can subsequently lead to hypoxia or cause direct harm as some algal species produce and release toxins (Roy et al., 2016; Smith et al., 1999). Salinity can have a substantial impact on the movement of NH_4 in coastal systems as it influences the sorption of NH_4 to soils as well as the ability of microbes to process NH_4 (Rysgaard et al., 1999; Putnam Duhon et al., 2012).

A number of recently published modeling efforts have attempted to describe or predict the effects of short-term salinity fluctuations, which can accompany tropical and winter storm surges on coastal systems (Hubbert and McInnes, 1999; Temmerman et al., 2012). Teh et al. (2008) constructed a predictive model on how coastal vegetation changes with changing salinity, however this model was limited in that it only considered surface water salinity and not porewater changes. Another modeling effort focused on coastal storm surge hazards in coastal Mississippi (Niedoroda et al., 2010) and calculated storm frequency and associated storm surge depth, but did not account for changes in salinity. These modeling studies provide excellent predictors of storm surge and resulting water level or surface water salinity changes but they do not address the vertical migration of salinity into the coastal marsh soil. This missing component is likely due to the lack of detailed vertical and temporal measurements in coastal freshwater and oligohaline marsh soil present in the literature.

Detailed information of the vertical movement of salt from the surface water into the subsurface is critical for both understanding and modeling the extent to which storm-driven short-term salinity increases can affect important wetland soil functions and ecosystem productivity. As the salinity of the porewater increases, the plant rhizosphere and associated microbial communities can be negatively affected, leading to a loss in important ecosystem functions. Therefore, the goal of this study was to: 1) measure changes in the spatial (vertical) and temporal porewater salinity and extractable ammonium as a result of imposing 35 salinity water over coastal freshwater marsh soils collected from the Wax Lake Delta, LA in a laboratory setting and 2) produce detailed vertical distributions porewater salinity and extractable ammonium that could prove useful in future ecological and storm surge modeling studies.

2. Methods and materials

2.1. Study site

The study area is located at the southern terminus of the Atchafalaya Basin which receives approximately 30% of the combined flow of Mississippi River and the Red River. The Atchafalaya Basin has two primary outlets where active delta formation is currently underway with associated establishment of coastal freshwater marshes, the Atchafalaya and Wax Lake Deltas (Fig. 1). The Wax Lake Delta wetlands are dominated by fresh marsh species as a consequence of continuous river flow, despite the location within the Gulf of Mexico, as this progradational delta protrudes into the coastal, saline environment. The Wax Lake Delta often experiences short-term changes in salinity due to the physical presence in the marine environment. Newly accreting areas are a mixture of non-vegetated mudflats and early successional macrophyte species. Vegetation cover over the entire Wax Lake Delta is approximately 12%, and is dominated by *Sagittaria latifolia, Salix nigra,* and *Colocasia esculenta.* (Carle et al., 2015; Evers et al., 1998; Holm and Sasser, 2001; Johnson et al., 1985). The marsh sites are more established, and are dominated by *Eleocharis* sp., *Panicum hemitomon*, and *Typha*, but also contain a much more diverse group of species than the mudflats (DeLaune et al., 2016).

2.2. Field collection

Twelve intact soil cores were collected at each of two sites within the Wax Lake Delta, LA in mid-October 2012 (Fig. 1). The first site, referred to as “mudflat” was located at one of the barren, non-vegetated, mudflat islands, which comprise much of the active land building regions in the delta (Roberts et al., 2015). The site was inundated to a depth of ~50 cm at the time of sampling where the 12 cores were all taken within an approximately 2 m^2 area. The second site, referred to as “marsh” was located along Hogs Bayou and was not flooded at the time of sampling. At the marsh site, all of the aboveground biomass was removed by cutting the stems at the soil surface before the 12 cores were collected within a 2 m^2 area. All cores were collected using 7 cm diameter pushcores to collect the top 16+ cm of soil/sediment.

2.3. Experimental setup

Cores were capped on both ends with rubber stoppers and transported to the laboratory where they were placed in a polypropylene tank. Any surface water that remained was removed and triplicate cores from each site were randomly assigned to one of the four treatments: control, 1 week, 2 weeks, and 4 weeks of inundation with salt water. A hole was drilled through the side of the core, 10 cm above the sediment surface, to allow water to flow out of the core and maintain a water column depth of 10 cm. Artificial seawater at 35 was continually supplied to each core by peristaltic pumps and timers, which allowed turnover of the water column four times per day. The cores were shielded from light by covering the tank sides and top with aluminum foil. Triplicate cores were destructively sampled sectioning into 2-cm increments down to a maximum depth of 16 cm. All depth intervals were homogenized, transferred to polypropylene containers, and stored at 4 °C until analyzed. Each time interval had triplicate cores from each of the two sites with a minimum of seven sections, for a total of approximately 190 samples. The triplicate control cores were sectioned immediately upon retrieval from the field.