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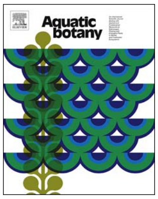

The tensile root strength of five emergent coastal macrophytes

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ABSTRACT

The root biomass of emergent macrophytes in coastal wetlands is essential for anchorage and erosion protection. The tensile root strength of these plants is an important component in determining the strength of coastal wetland soils. We made 1449 tensile strength measurements of roots < 1.5 mm in diameter for five species of emergent wetland macrophytes (*Spartina alterniflora*, *S.patens*, *Panicum hemitomon*, *Schoenoplectus americanus*, and *Sagittaria lancifolia*) collected from six sites in three coastal estuaries. An analysis of variance revealed that the tensile root strength of dead and live roots for all species decreased with depth and that dead roots were stronger than live roots of the same diameter ($p < 0.05$). There was low variation in the mean tensile root strength among all sites. The *S. alterniflora* dead roots from the Barataria Basin site, however, were stronger than those from the Lake Pontchartrain site and the *S. patens* live and dead roots collected from Breton Sound were stronger than those from a nearby site in the same watershed. Wetland root samples exposed to partially-treated sewage effluent were considerably smaller than roots collected from the nearby reference wetland. Further investigation is warranted to ascertain the nature of the factors that causing these variations in tensile root strength with depth, between live and dead roots and with nutrient exposure

1. Introduction

A plant's ability to resist the erosive forces of waves, wind, grazing herbivores, gravity, and storm surge may be diminished by factors weakening the belowground biomass to exert uprooting forces on plants. Higher nutrient loading in coastal wetland plants, for example, has been associated with lower live root and rhizome biomass (Darby and Turner, 2008), faster organic matter decomposition (Wigand et al., 2009), and decreased soil shear strength (Turner, 2010). Wetland erosion can occur if erosive forces exceed the ability of the belowground biomass to resist tensional and compressional loading, which may lead to pond expansion, altered drainage patterns, dislodged or destroyed vegetation, shoreline erosion and marsh displacement. The magnitude of these destructive erosional forces is probably affected by the type, distribution, and health of wetland vegetation. The fibrous architecture of emergent macrophyte roots may function in a manner analogous to concrete reinforcement bars to contribute to coastal marsh stability. Three examples from the agricultural literature are: 1) Fan and Su (2008) demonstrated how the roots of the annual legume, *Sesbania bispinosa* (Prickly Sesban), increased shear strength by 39–42% within soils in Kaohsiung City, Taiwan, 2) Ennos (1989) explored the mechanics of uprooting forces on seedlings of *Helianthus annuus* L. (Sunflower). He found that seedlings with longer roots (50–60 cm) required more force to extract them than those with shorter roots (10 cm), and 3) Comino and Druetta (2010) reported increases in soil shear strength and root displacement exceeding 100% in Italian alpine soils that were reinforced by three grass species in the family *Poaceae*. The traits of individual roots, e.g., length, diameter, cross-sectional area, volume, sinuosity, age, and decomposition stage can affect the moisture content, bulk density, soil texture, shear strength, and organic matter content of soils. In addition, the morphological configuration of the belowground biomass of roots and rhizomes contribute to the magnitude of soil reinforcement (diameter class distribution and depth distribution, as well as the mechanical properties such as tensile root strength, tortuosity, elastic modulus, and root-soil friction) (De Baets et al., 2008).

A soil's shear strength, a measure integrating some of these factors, can be calculated by measuring tensile strength, which is defined as the resistance of a material in tension to an external load (Niklas, 1992; Wu et al., 1979). Tensile root strength data can be used to populate models and provide predictions of soil shear strength (Nyambane and Mwea, 2011; De Baets et al., 2008; Wu et al., 1979). For example, Wu et al. (1979) devised a model of a soil-root system in which roots were placed in tension as a shearing force was applied to the soil:

$$s_r = t_r\ (\cos\theta \tan\Phi' + \sin\theta) \tag{1}$$

where $\mathbf{s_r}$ is the shear strength of the soil due to roots (kPa), $\mathbf{t_r}$ is the total tensile strength of the roots per unit area of the soil (expressed as tensile stress in MPa m^{-2}). Theta (**θ**) is the angle of shear distortion in the

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shear zone, and Φ′ is the soil friction angle. For a range of θ from 48 to 72°, the increase in soil shear strength (s_r) is:

$$s_r = 1.2t_r 1.2t_r \qquad (2)$$

The shear strength of the soil-root system (s*) can be estimated by:

$$s^* = s + s_r \qquad (3)$$

where **s** is the soil shear strength.

Quantifying tensile root strength can also estimate the resilience and resistance of individual root masses to various erosive forces. These measurements, if sufficiently repeated, can be scaled up to provide a more accurate measurement of the strength of the soil-plant matrix. Both tensile and soil shear strength may be useful to determine the impact of different potential stressors on the health of a wetland plant's belowground biomass and to predict areas that may be vulnerable to erosion and wetland loss. Many studies have investigated tensile root strength in regard to soil shear strength (Nyambane and Mwea, 2011; Muntohar, 2012; Jain, 2013), cotton fiber decomposition (Maltby, 1988; Slocum et al., 2009; Baustian et al., 2010), soil stabilization (Wu et al., 1979; Genet et al., 2007; Pollen, 2007), plant uprooting resistance (Easson et al., 1995; Mickovski et al., 2007; Crouzy et al., 2014), submerged aquatic plants (Puijalon et al., 2007; Puijalon et al., 2008; Lamberti-Raverot and Puijalon, 2012), and seagrasses (Martin et al., 2015). Therefore, determining the tensile root strength of emergent wetland plants in the Mississippi River Delta (MRD) may assist researchers with curtailing Louisiana coastal land loss and guide current and future coastal restoration efforts in this and other regions.

The objective of this study was to determine the variability in tensile root strength for several coastal wetland plants with soil depth, site, age, and species. We hypothesized that tensile root strength decreases with depth and differs between sites, whether live or dead, and among species.

2. Materials and methods

We measured the tensile root strength of five wetland species collected from three estuaries in a total of ten vegetation samples using commercially available equipment that normally measures the tensile strength of cloth fibers.

2.1. Study sites

The vegetation samples were obtained from three estuaries in southeastern Louisiana (Fig. 1). The Breton Sound Estuary (Sites 1 and 2, Fig. 1) located approximately 20 km south of New Orleans, LA is comprised of a matrix of fresh, intermediate, brackish, and saline wetlands (CWPPRA, 2017). The dominant vegetation is *Spartina patens* in the lower salinity marshes and *Spartina alterniflora* in the higher salinity areas. Anthropogenic impacts include the dredging of oil and gas canals, the construction of flood protection levees, and the creation of the Mississippi River Gulf Outlet (MRGO) shipping channel changed the hydrologic and ecological dynamics within the estuary (LPBF, 2006). These disturbances resulted in an increase in salinity in the upper estuary, causing a shift in plant communities and conversion of fresh and intermediate marshes to brackish and salt marshes. Dunbar et al. (1992) estimated that 19,035 ha (ha) of wetlands converted to open water from 1932 to 1990. Also, nutrients introduced by the Caernarvon Mississippi diversion caused a chronic weakening of soils, which converted to open water during Hurricane Katrina (Howes et al., 2010) resulting in the loss of 527 km^2 of wetlands (Kearney et al., 2011).

The second sampling site was located in salt marshes near Port Sulphur, LA in the 633,333 ha Barataria Bay Estuary (Site 3, Fig. 1). The dominant vegetation is *Panicum hemitomon* in freshwater areas, *Spartina patens* in the lower salinity marshes, and *Spartina alterniflora* in the higher salinity areas (Chabreck, 1972). The construction of flood protection levees along the Mississippi River and the closure of Bayou Lafourche distributary reduced the input of freshwater and sediment to the Barataria Basin (CWPPRA, 2017). The hydrological dynamics of the basin have been disrupted by the dredging of oil and gas canals. Municipal, industrial, and agricultural sources of non-point pollution have degraded the water quality in the basin (LDWQ, 2004). Agricultural areas at the head of the estuary are a significant source of nutrients and herbicides that enter basin via overland runoff. The Barataria Basin lost wetlands at a rate of 2310 ha yr^{-1} between 1974 and 1990 (CWPPRA, 2017).

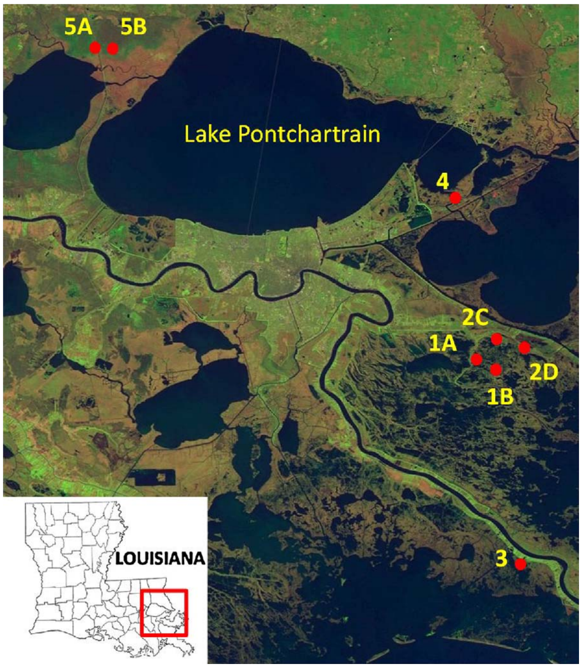

Fig. 1. The locations of field sampling sites in the Breton Sound, Barataria, and Lake Pontchartrain basins in southeastern Louisiana.

The third sampling site was a freshwater marsh located 11 km south of Hammond, LA, which is on the northern border of the Joyce Wildlife Management Area (Joyce WMA; Sites 5A and 5B, Fig. 1). The City of Hammond, LA began a wastewater discharge of partially-treated wastewater effluent (hereafter, effluent) into it in 2006 (Bodker et al., 2015). Before wastewater discharge, the vegetation community of the emergent marsh was co-dominated by *Panicum hemitomon* (Maidencane) and *Sagittaria lancifolia,* which were interspersed among tracts of cypress-tupelo swamp (*Taxodium distichum* and *Nyssa aquatica,* respectively). By 2010, however, 150 ha of the marsh converted to open water and the plant community cover shifted to annual and floating species, two of which were the invasive species *Salvinia molesta* (giant salvinia) and *Ludwigia leptocarpa* (Willow Primrose) (Bodker et al., 2015).

The fourth sampling location, Bayou Sauvage National Wildlife Refuge (Bayou Sauvage NWR; Site 4, Fig. 1) in the Lake Pontchartrain basin, is mostly comprised of salt, brackish, intermediate, and fresh marshes dominated by *Spartina alterniflora* and *Spartina patens*. Sixty percent of the Bayou Sauvage NWR is located within the hurricane protection levee system and as a result, water levels within the levee system are managed by the U.S. Army Corps of Engineers (USFWS, 2009). Anthropogenic alterations, such as large excavated fill pits, canals, spoil banks and urban runoff, can affect the natural hydrologic regime and nutrient chemistry of the area (CWPPRA, 2017). In addition, overland flow during precipitation events entrains numerous toxicants from the City of New Orleans and the large Resource 1 sanitary landfill adjacent to the refuge, which creates a large source of

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