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Nutrient-enhanced decomposition of plant biomass in a freshwater wetland

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ABSTRACT

We studied soil decomposition in a *Panicum hemitomon* (Schultes)-dominated freshwater marsh located in southeastern Louisiana that was unambiguously changed by secondarily-treated municipal wastewater effluent. We used four approaches to evaluate how belowground biomass decomposition rates vary under different nutrient regimes in this marsh. The results of laboratory experiments demonstrated how nutrient enrichment enhanced the loss of soil or plant organic matter by 50%, and increased gas production. An experiment demonstrated that nitrogen, not phosphorus, limited decomposition. Cellulose decomposition at the field site was higher in the flowfield of the introduced secondarily treated sewage water, and the quality of the substrate (% N or % P) was directly related to the decomposition rates. We therefore rejected the null hypothesis that nutrient enrichment had no effect on the decomposition rates of these organic soils. In response to nutrient enrichment, plants respond through biomechanical or structural adaptations that alter the labile characteristics of plant tissue. These adaptations eventually change litter type and quality (where the marsh survives) as the % N content of plant tissue rises and is followed by even higher decomposition rates of the litter produced, creating a positive feedback loop. Marsh fragmentation will increase as a result. The assumptions and conditions underlying the use of unconstrained wastewater flow within natural wetlands, rather than controlled treatment within the confines of constructed wetlands, are revealed in the loss of previously sequestered carbon, habitat, public use, and other societal benefits.

1. Introduction

Plants evolved in a mixed field of opportunities and constraints that gave rise to a nuanced plasticity of form and function. Those features of plants may be seen in the evolving nature of the Anthropocene that is characterized, in part, by large increases in reactive nitrogen (Galloway and Cowling, 2002). Nutrient enrichment, whether from atmospheric deposition, river diversions, sewage, runoff of agricultural fields, or leakage from urban systems, creates new extrinsic conditions that the plant and ecosystem respond to. Compared to low nutrient conditions, for example, plant communities undergoing nutrient enrichment tend to have faster growth rates, weakened cellular structure, expanded aerenchyma, allocate less biomass to roots, have higher nutrient concentrations in their biomass, and have leaky nutrient cycling, while carbon storage in the individual plant is higher (Aerts and Chapin, 2000; Poorter and Nagel, 2000). Vascular terrestrial plant decomposition is almost always faster with nutrient enrichment at levels that are commonly found today (Webster and Benfield, 1986; Enriquéz et al., 1993; Kominoski et al., 2015; Rosemond et al., 2015).

Individual wetland plant communities seem to share many of these traits, and relatively higher degradation of wetland plant or soil organic matter with nutrient enrichment is well known (Harris et al., 1962; Bridgham and Richardson, 1992; Eggelsmann, 1990; Güsewell, 2005; Güsewell and Verhoeven, 2006; Rejmáková and Houdková, 2006; Li et al., 2012). Decomposition rates are directly related to substrate quality (Godshalk and Wetzel, 1978; Chimney and Pietro, 2006). Nutrient enrichment often results in higher con-

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centrations of nutrients in plant tissues (e.g., Rejmáková et al., 2008) and lower carbon sequestration in the soil (Mack et al., 2004; Bubier et al., 2010; Larmola et al., 2013).

Thus the broad outline is that the nutrient enrichment at the community and individual species level may lead to more aboveground biomass, a higher % N or % P in tissues above- and belowground, higher quality litter, perhaps less belowground biomass, increased tissue decomposition rates, and leaky nutrient cycles (i.e., lower re-sorption efficiencies). The response of wetland plants communities and coinciding litter quality to nutrient enrichment, therefore, can have far-reaching consequences to nutrient cycling, carbon storage, habitat quality, etc. The cumulative effects of nutrient enrichment on salt marshes can even culminate in their destabilization (Swarzenski et al., 2008; Turner, 2011; Kearney et al., 2011; Deegan et al., 2012) and an increase in NO_x release (Moseman-Valtierra et al., 2011).

Testing assumptions of carbon assimilation or release during transition from low to high nutrient enrichment of wetland ecosystems can better inform policy options for sustainable outcomes for management if details at the on-the-ground level study are included—not only for generic plant communities, but also (and especially) when focused on dominant species. This study attempted to address these questions by investigating soil decomposition in a *Panicum hemitomon* (Schultes)-dominated freshwater wetland unambiguously compromised when sewage effluent was introduced to the area in November 2006. The results may inform discussions about habitat loss, carbon sequestration, public use, and potential consequences of increased nutrient loading to natural wetlands.

2. Materials and methods

2.1. Panicum hemitomon *freshwater marshes*

P. hemitomon (maidencane) is a clonal C_3 grass found in areas with low wave energy and negligible soil content (Sasser et al., 1995). In the 1970s this plant community covered about 26% of the freshwater marsh area in coastal Louisiana (Chabreck, 1972), equal to about 807 km^2. The area of *P. hemitomon*-dominated communities decreased from 44% to 18% in the Barataria estuarine watershed from 1968 to 1990, and from 67% to 19% in the Terrebonne estuarine watershed for undetermined causes (Visser et al., 1996, 1999).

P. hemitomon forms an extensive assemblage of roots and rhizomes that may be part of an attached or floating vegetative mat. There is concern that the anchored *P. hemitomon* mat converts to a detached thick- and then thin-floating mat if sediment (Mayence and Hester, 2010) or nutrient loading increases (Swarzenski et al., 2008; Mayence and Hester, 2010). It is unlikely that increased inundation is the primary cause of these changes because aerenchyma development, root elongation and root volume increase are common responses in wetland plants (Reddy and Delaune, 2008), and for this plant specifically (Willis and Hester, 2004; Mayence and Hester, 2010). Greenhouse experiments, for example, document how flooding is required for vigorous root and rhizome production in *P. hemitomon* (Mayence and Hester, 2010). The results from these same greenhouse experiments also suggest that the % N and % P in plant tissue increases with higher nutrient loading, which, however, also leads to insignificant or negative effects on root diameter, specific gravity or volume after 3 months (Mayence and Hester, 2010).

2.2. *Study area*

We sampled marshes located 11 km south of Hammond, LA, and 60 km north-northwest of New Orleans, LA (Fig. 1). They are at the seaward edge of a Pleistocene terrace and overlie the mineral remnants of a former embayment of the Gulf of Mexico that was created by various east and west movements of the main channel of the Mississippi river over 8000 years. The regional vegetation is a cypress-tupelo swamp canopy (*Taxodium distichum* and *Nyssa aquatica*), and surrounding pockets of marshes dominated by *P. hemitomon* with *Sagittaria lancifolia* (broadleaf arrowhead). Water levels can rise to >1 m above the marsh during hurricanes. The organic layer of the undisturbed emergent marsh is 50–150 cm thick and is anchored to the bottom, i.e., it is not a floating marsh. The age of the basal peat is about 1200 yBP (Turner, unpublished).

The City of Hammond's south sewage treatment plant discharges secondarily treated municipal wastewater effluent (hereafter called 'wastewater effluent' or 'effluent') into what was (before 2006) a *P. hemitomon*-dominated marsh located 5 km to the south. The receiving marsh is bordered to the south by the 10,521 ha Joyce Wildlife Management Area (JWMA) and to the west by an interstate highway and a railroad/levee (Fig. 1A). The effluent is discharged and distributed along the northern edge from a 1.2 km overhead trunk line fitted with 900 uniformly distributed manually controlled outlets along its entire length (Fig. 1B and G). The fully-implemented wastewater effluent discharge program began in November 2006, and went into a 53 ha portion of the former marsh presently owned by the City of Hammond. Monitoring reports from 2006 to 2008 estimate that the average discharge into the area was 14,498 $m^3\ d^{-1}$, and that the average total nitrogen (TN) and total phosphorous (TP) concentrations were 16.90 and 3.23 $mg\ L^{-1}$, respectively. The reference marshes to the north of the discharge area are isolated from the wastewater effluent by the spoil banks built by dredging the South Slough (~1955), a levee road beneath the delivery pipe (Fig. 1A). South Slough parallels the road and drains east-to-west. Additional reference marshes that are isolated from the wastewater effluent discharge are located to the west, south, and east (Fig. 1A).

The marsh was uniformly covered with vegetation and had no open water areas before wastewater effluent was introduced to the marsh (Fig. 1A). The area of the marsh closest to the wastewater effluent entry points began converting to open ponds and mud flats within the first year after receiving this effluent. The open pond and mud flats subsequently expanded outside the City of Hammond property and into the JWMA to cover about 150 ha by 2010 and reaching the southern edge of the marsh (Fig. 1B–G). This newly disturbed area quickly became colonized by floating aquatics and shallow rooted annuals (Fig. 1C–F). There were five notable plants whose distribution or cover changed dramatically:

a Remnant patches of *S. lancifolia* expanded in the area and grew to an exaggerated size during 2007 and then gradually diminished and have been supplanted to a large extent by the more dominant floating and annual species.
b *Zizaniopsis miliacea* (*giant cutgrass*) and *Typha domingensis* (cattail) are found in patches within the degraded area.
c *Ludwigia leptocarpa* (willow primrose), an invasive annual, grows hardily on the floating mud flats in the wastewater effluent area during summer and early fall, but does not compete well in with well-established perennials. The *L. leptocarpa* in the areas receiving wastewater effluent are often found on their side with the roots exposed at the end of summer (i.e., they are lodged).
d *Hydrocotyle ranunculoides* (marsh pennywort) is the dominant early spring floating aquatic in the open water of the former marsh. This succulent plant covers what we estimate to be about one-third of the impacted area each spring, but dies back during the summer.
e *Salvinia molesta* (giant salvinia) is an invasive floating annual that grows rapidly during summer in the open waters of the wastewater effluent area and covers about one-third of the plant cover