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Will hydrologic restoration of Mississippi River riparian wetlands improve their critical biogeochemical functions?

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ABSTRACT

Riparian wetlands are essential components of the landscape, providing critical functions including buffers for floodwaters, wildlife habitat and improvement of surface water quality. Many riparian wetlands have been hydrologically disconnected from the Mississippi River by a vast system of levees, altering the ecosystem services provided by these riparian zones. Efforts are underway to restore these ecosystem services, however previous research demonstrated that the statutory requirements guiding wetland restoration do not adequately consider soil biogeochemical cycling. We examined soil properties and biogeochemical indicators of nitrogen cycling to assess soil recovery in a recently hydrologically restored riparian wetland. This restored wetland, reconnected with the river for approximately two years, was compared to a nearby reference wetland where the river connection has been constant. Seasonal measurements included bulk density, total carbon, nitrogen and phosphorus, microbial biomass nitrogen, potentially mineralizable nitrogen (PMN) and potential denitrification. There were significant differences found for nearly all measured soil properties with higher bulk density and lower total C, total N, microbial biomass, PMN and potential denitrification at the restored compared to the reference site. The PMN and potential denitrification at the restored site plots were 27–46% and 2% (respectively) of the values measured at the reference site. This clearly demonstrates that while the regulatory indicators of success are improving, some critical biogeochemical functions of the restored sites are significantly lower than the reference site two years after hydrologic restoration.

1. Introduction

Historically, wetlands were drained for agriculture to take advantage of their nutrient rich soil for plant growth. This, as well as other factors, resulted in the loss of greater than 50% of all wetlands in the contiguous U.S. between 1780 and 1980 (Dahl, 1990). Wetland loss results in decreased surface water quality and increased flooding frequency (Reddy and DeLaune, 2008).

Along the Mississippi River, which drains 40% of the continental U.S., urban development, agriculture and channelization projects have hydrologically isolated many riparian wetlands from the main river channel (Schilling et al., 2012). The Mississippi River watershed includes some of the most productive agricultural lands on the continent, where biologically available fertilizers are heavily used (Broussard and Turner, 2009; Schilling et al., 2012). The combination of wetland loss and increasing agricultural nutrient runoff, in particular nitrate (Broussard and Turner, 2009) are major drivers of poor water quality within the river and the hypoxic zone in the Gulf of Mexico (Dagg et al., 2005).

Riparian wetland soils in the Mississippi River Valley sequester phosphorus and nitrogen as organic matter, and perhaps more importantly, they promote denitrification in the flooded soils (Reddy and DeLaune, 2008). Under natural conditions, floodwaters flow over the natural riverbank and into the riparian wetland fringe where denitrification, an anoxic, microbial-mediated process, reduces nitrate to nitrogen gas (Yoshinari et al., 1977). However, denitrification can be reduced due to the construction of levees, which decrease flooding frequency and decrease the prevalence of anaerobic soils (White and Reddy, 2003). In addition to nutrient reduction, riparian wetlands can also remove other contaminants (White et al., 2006; Conkle et al., 2010) and provide many other important ecosystem services including

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storage of floodwaters, wildlife habitat, carbon sequestration and stabilization of riverbanks (Mitsch and Gosselink, 2000).

Knowledge of the functions and ecosystem services provided by riparian wetlands and the impacts of their loss (Costanza et al., 1997; Mitsch and Gosselink, 2000) is fueling riverbank restoration. Along the Mississippi River, projects focus on reestablishing the hydrologic connection the river channel and riparian systems (DeLaune et al., 2013; Roy et al., 2013). However, many of these projects also have specific guidelines to determine restoration success within the regulatory framework (Berkowitz and White, 2013).

"Regulatory success" of a restoration project is generally determined by hydrology and the presence of similar phenotypic vegetation between a reference and restored wetland site (Kentula, 2000). While communities rapidly re-colonize wetlands once hydrology is restored (Zedler and Kercher, 2004; Matthews and Endress, 2008; Benjankar et al., 2012), soil properties and microbial activity are much slower to recover (Bruland et al., 2003; Ballantine and Schneider, 2009). Therefore, regulatory success can be easily achieved, while vital soil biogeochemical functions are ignored. These "restored" wetlands may not be as efficient at improving water quality or supporting plant growth compared to natural wetlands, despite their obvious visual similarities (Zhang et al., 2012a,b). In order to fully restore a wetland and its ecosystem services, soil biogeochemical cycling must be reestablished (Reddy and DeLaune, 2008; Vitt et al., 2011). Here we examine the short-term changes to soil biogeochemical processes, specifically nitrogen cycling, at a recently restored Mississippi River riparian wetland. The expectation, due to the ~50 years of hydrologic disruption, was that the restored wetland soils would have lower nutrient concentrations and a diminished ability to utilize bioavailable nutrients, specifically nitrate, when concentrations increase compared to the reference wetland. Wetland soils were sampled seasonally during the second year of the restoration at three Mississippi River secondary channel wetland sites to assess temporal and spatial changes in various soil parameters indicative of biogeochemical health. While this data was used to assess the current state of the restoration, future monitoring will provide data to assess the long-term wetland restoration trajectory (Ballantine and Schneider, 2009).

2. Materials and methods

2.1. Study area

The Loosahatchie Bar and associated secondary river channel are lined by a stretch of riparian wetlands on the west bank (Arkansas side) of the Mississippi River, between river miles 736.5 and 742.8, slightly north of Memphis, TN. In the 1960s, stone dikes were constructed by the United States Army Corps of Engineers to divert flow away from the Redman Point Loosahatchie Bar secondary channel complex and into the main river navigation channel (Fig. 1). These dikes maximized water levels in the main river channel during low flow events and ensured safer navigation. Beginning in the summer of 2008, 12 notches (only 10 are visible in Fig. 1) were excavated in nine existing dikes by the United States Army Corps of Engineers. The goal of the notches was to re-establish hydrologic connectivity between the Mississippi River and ~11 miles of secondary channel in the bar (Fig. 1). The notches are 0.9–3.3 m in the vertical direction depending on surface elevation and height of the dike, while the length of the notches are 20–64 m in length. Fig. 2 presents Google Earth images of the dikes pre-restoration (a), during flooding (b) and post-restoration with notch locations (c).

2.2. Sampling sites

Three sites along the secondary river channel were selected to examine changes in soil characteristics and nitrogen biogeochemistry along the water flow path as well as temporally with the restoration efforts (Fig. 1). One site was on the northern tip of Mud Island (Near: 35°12′00.04″N, 90°04′34.55″W; elevation: 202.604′) and the other two are on the western bank of the channel (Mid: 35°11′05.04″N, 90°05′14.56″W; elevation: 202.898′; Far: 35°09′57.44″N, 90°04′42.58″W; elevation: 206.482′) A nearby reference riparian wetland site (35°15′14.26″N, 90°06′51.23″W; elevation: 205.526′) was selected as a baseline to determine restoration progress. The reference site is similar in elevation and vegetation (*Saliz nigra* dominated) to the restored sites, but had not been hydrologically altered. The physical and spatial similarities between the restored sites allowed for their comparisons individually and as a whole. Data on site elevation was obtained from the U.S. Army Corp of Engineers GIS elevation maps and river stage data (National Weather Service Gauge, MS 126 at Memphis, TN) was utilized to further explore the results (Fig. 3).

2.3. Soil sampling and analyses

The hydrologic connection was restored in the summer of 2008 and four seasonal (December, March, June, August/September) soil collections occurred from the winter to fall of 2009. At each site, three 25 m × 25 m plots were established. One randomly placed soil sample was collected from each of the three plots during each sampling event (except the near site where a quadruplicate sample was taken from one plot each event). Therefore, a triplicate sample was collected at the reference, mid and far site, while 6 samples were collected at the near site, for a total of 18 during each of the four sampling events. Pushcores (10 cm diameter and 15 cm length) were used to collect the top 20 cm of soil. Samples were analyzed for bulk density, which was calculated on a dry weight basis (Blake and Hartge, 1986). Total carbon (TC) and nitrogen (TN) were measured on dried, ground samples using a Carlo-Erba NA-1500 CNS Analyzer (Haak-Buchler Instruments, Saddlebrook, NJ). Total phosphorus (TP) was calculated using the ashing method by Andersen (1976). Dried, ground sediment was combusted in a muffle furnace (Barnstead Thermodyne 62700 Furnace) at 550 °C for 4 h followed by digestion with 20 mL of 6 M HCl on a hot plate and analyzed for SRP using a SEAL AQ2 Automated Discrete Analyzer (SEAL Analytical, West Sussex, England; Method 365.1 (USEPA, 1993)). Microbial biomass N (MBN) was determined using the fumigation extraction technique (Vance et al., 1987) with modifications by Malecki-Brown et al. (2007). The potentially mineralizable nitrogen (PMN) rate was determined by anaerobic incubations of soil at 40 °C as described in White and Reddy (2000). Potential denitrification rates were assessed in anaerobic incubations under acetylene inhibition (White and Reddy, 2003). Each sample was injected with 10 mg-N from a KNO_3 solution to create non-limiting nitrogen conditions and increase microbial activity. All headspace gas concentrations were analyzed using a Shimadzu GC-8A equipped with an ECD (Shimadzu Scientific Instruments, Columbia, MD).

Spatial and temporal statistical relationships were examined between the reference and restored sites, individually and as a whole. Additionally, the relationships between individual restored sites at each sampling interval and for each restored site across the monitoring period were explored. These relationships were examined using an one-way ANOVA and Pearson Product Moment correlations. When necessary, data was log transformed to meet ANOVA assumptions. All statistical analysis was performed using R (v 2.14.1, The R Foundation) and Microsoft Excel.