EFFECTS OF LITTER REMOVAL ON NITROGEN CYCLING IN A TIDAL WETLAND AFTER ERADICATION OF PHRAGMITES AUSTRALIS

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Abstract. Riverine wetlands play an important role in the maintenance of river water quality. Tidal wetlands in particular can exchange large volumes of water with the rivers they border and generally serve as sinks for inorganic nitrogen, helping to mitigate nutrient loading of waterways. Macrophyte litter is often abundant in wetlands, and can have significant effects on nitrogen cycling in these ecosystems. One increasingly common wetland macrophyte, *Phragmites australis* or the common reed, has been aggressively colonizing wetlands since the 1970s, and in many cases wetland managers have actively removed stands of *Phragmites.* In this study, we examined the effect of *Phragmites australis* litter on nitrogen cycling in reed-removal plots in Tivoli North Bay, a tidal freshwater wetland of the Hudson River. Porewater nutrient concentrations and denitrification potentials of *Phragmites* removal sites with litter were compared to those of sites without litter. To determine sediment porewater nutrient concentrations, porewater equilibrators were installed in *Phragmites* removal sites and allowed to remain in place for one week before samples were extracted for analysis. Sediment denitrification potentials were measured by conducting denitrifying enzyme assays on sediment cores retrieved from removal sites. After initial data on porewater nutrient concentrations and sediment denitrification potentials were collected, the litter layer was removed from two of the four plots in a *Phragmites* removal site containing litter, and placed on two of the four plots in a nearby site that lacked litter. The manipulation was left in place for three weeks before additional sediment cores were collected and porewater equilibrators were installed a second time. Denitrification potentials were significantly higher at sites with litter, but the presence or absence of litter did not affect ammonium or nitrate concentrations. The short-term litter manipulations did not affect porewater nutrient concentrations or denitrification potentials. The potential increase in rates of denitrification that could be brought about by retaining reed litter on-site is too slight to warrant concerted efforts by wetland managers maintain reed litter following *Phragmites* treatment.

INTRODUCTION

Wetlands perform a variety of important ecosystem services and can have a considerable effect on the quality of nearby waterways (Johnston et al. 1990, Arrigoni et al., 2008). Tidal wetlands, in particular, may have contact with large volumes of river water and are consequently capable of substantially altering the nutrient content of a river (Arrigoni et al., 2008). In general, tidal wetlands serve as a sink for inorganic nutrients such as nitrate (Childers et al. 2000). This ability of wetlands to mitigate nitrogen loading of rivers is critical, as additions of this nutrient to rivers from anthropogenic activity, especially agriculture, can induce algal blooms and lead to the eutrophication of aquatic systems (e.g. Turner et al. 2008).

Plant litter plays an important role in the cycling of nitrogen through wetlands, serving alternately as a source and a sink for nutrient additions. Microbes degrading litter that is carbon-rich but nutrient-poor must initially take up nutrients from the overlying water or porewater in order to decompose the plant material. Subsequently, as the material breaks down, it becomes a source of nutrients for plants and microbes (Melillo et al. 1984, as cited by Jordan et al. 1989). Moreover, litter may serve as an insulating layer, keeping sediment cooler in summer or slowing the diffusion of oxygen to the sediment surface (Jordan et al. 1989). Both temperature and the availability of dissolved oxygen affect microbial activity (Boon 2006), and thus the presence or absence of a plant litter layer in wetlands has the potential to significantly influence nutrient cycling.

Phragmites australis (hereafter *Phragmites*), known as the common reed, can generate two to three times as much above-ground biomass (and therefore litter) relative to the wetland plants it commonly replaces (Templer et al. 1998, Rooth et al. 2003). Though native to North America, in the last 40 years *Phragmites* has expanded rapidly into freshwater wetlands and salt marshes across the northeast, displacing other macrophytes, most importantly the historically dominant species *Typha angustifolia* in freshwater wetlands and *Spartina patens* in salt marshes (see review by Marks et al. 1994). Expansion of *Phragmites* can have both beneficial and detrimental effects on wetland ecosystem functioning. For example, invasion of Phragmites increases sediment accretion rates (Rooth et al. 2003) and may increase nesting habitat for certain bird species (Parsons 2003), but greatly reduces plant species diversity, potentially threatening the viability of local populations of threatened and endangered wetland plant species (Meyerson et al. 2000, Minchinton et al. 2006).

In order to control the advancement of *Phragmites* and preserve native species diversity, wetland managers often remove stands of *Phragmites* by treating them with the herbicide glyphosate, also known as Rodeo (Marks et al. 1994). Typically, a thick litter layer remains, but in some cases it may be removed by tides, storms, and ice. While a handful of studies have examined the effect of the presence or absence of *Phragmites* litter on plant re-growth (Minchinton et al. 2006), macroinvertebrate populations, and fish abundance (Fell et al. 2006), to the best of our knowledge none have looked at the consequences of this litter layer for nitrogen cycling in wetlands.

This study aimed to determine what effect, if any, the presence or absence of a *Phragmites* litter layer has on porewater nutrient concentration and denitrification potential in *Phragmites* removal sites. Jordan et al. (1989) studied the effect of *Typha angustifolia* (narrow leaved cattail) litter on sediment ammonium concentrations in a brackish tidal marsh and found that the presence of litter decreased ammonium in the sediment. They concluded that the litter layer served primarily as a physical barrier, and hypothesized that its presence was decreasing rates of mineralization by insulating the sediment and maintaining cooler temperatures. Thus, we hypothesized that the presence of litter in reed-removal sites would decrease porewater ammonium concentrations. We speculated that a litter layer might also inhibit the diffusion of surface water. Reduction in diffusion may have contrasting effects on sediment denitrification. It might slow input of nitrate into the sediment thus reducing denitrification. If litter reduces oxygen diffusion into the sediment, rates of denitrification might be expected to increase.

MATERIALS AND METHODS

Site description

The study was conducted at Tivoli North Bay, a freshwater tidal wetland along the Hudson River and part of the Hudson River National Estuarine Research Reserve (HRNERR) (Fig. 1). Prior to 2006, several stands of *Phragmites* were interspersed throughout the wetland, ranging in area from 640-3800 m^2, with the four largest averaging 2875 m^2. Stands were treated with glyphosate during the summers of 2006 and 2007. In half of these stands a thick litter layer remained, averaging 2.13 kg litter per m^2. Almost no new plants were growing in these sites at the time of study. In the other half, the litter layer and standing *Phragmites* stalks had been almost completely removed, presumably by tides, storms, and winter ice. These sites were nearly bare in early June, but were covered with new plant growth by the end of July.

Porewater

All fieldwork was conducted in June and July 2008. Porewater nutrient concentration of *Phragmites* removal sites was examined by installing porewater equilibrators in each of the six sites. Equilibrators were prepared as described in Findlay et al. (2003), and were then buried in the sediment. One equilibrator was installed in each of three or four 1 x 1 m plots located at each site. Equilibrators were left in place for one week before being removed. Samples were then extracted, acidified in the field, and refrigerated until analysis.

Denitrification potential

Two 10 cm sediment cores were collected from each plot at the time equilibrators were installed and brought to the lab for analysis. Denitrification potential was determined using Denitrifying Enzyme Assays (DEAs), as described in Findlay et al. (2003). Sediment cores were also analyzed for moisture and organic matter content.

Manipulation

In addition to collecting observational data on the porewater nutrient concentrations and denitrification potentials of *Phragmites* sites with and without litter, a manipulation was performed on two adjacent reed-removal sites. The litter layer from two of the four plots in a *Phragmites* site containing litter was removed and placed on two of the four plots in a site that lacked litter. The added litter layer was held in place by a square of coarse nylon mesh. The manipulation remained in place for four weeks; after three weeks, porewater equilibrators were installed a second time and allowed to equilibrate over the final week of the manipulation.

Statistical analyses

Observational data were analyzed with ANOVA comparing depth-averaged ammonium concentrations or plot-averaged denitrifying enzyme activity of plots with or without a litter layer. Post-hoc differences between sites revealed that ammonium concentrations at one no-litter site were substantially higher than at the other two sites without litter. As a result, ammonium concentrations from this site were removed from the analysis of observational data. Experimental data were analyzed with two-sample t tests. All statistical analyses were conducted using SYSTAT software.

RESULTS

Observation results

Nitrate levels were uniformly low (range 0.018 mg/L – 0.051 mg/L) and did not vary significantly by site type. When porewater ammonium concentrations from all sites were included in analysis, depth-averaged porewater ammonium concentrations of observational plots without litter were significantly higher than those of observational plots with litter ($p=0.027$). However, after examining Post-hoc differences between sites, we determined that one no-litter site was driving the observed pattern. When data collected from this site were removed from the analysis, there was no significant difference in porewater ammonium concentrations at sites with and without litter ($p=0.372$, Fig. 2). Denitrification potentials were significantly higher at sites with litter ($p=0.024$, Fig. 3).

Experiment results

Porewater ammonium concentrations decreased significantly over the course of the summer in the site without litter, in both the control plots and the plots to which litter was added ($p=0.028$ and $p=0.046$ respectively), but did not change significantly in the site with litter, in both the control plots and the plots from which litter was removed ($p>0.05$, Fig. 4). Denitrification potentials did not change significantly over the course of the summer at either site with any treatment ($p>0.05$, Fig. 5).

DISCUSSION

The presence or absence of *Phragmites* litter did not appear to affect porewater nutrient concentrations in either our experimental or observational plots. Porewater nitrate concentrations were uniformly low across all sites, suggesting that the absence of a litter layer did not enhance the ability of surface water to diffuse into the sediment and deliver nitrate. Removing litter did not increase ammonium concentrations, perhaps because it did not increase daytime sediment temperatures, as required by our hypothesized mechanism. Jordan et al. (1989) found that removing a *Typha angustifolia* litter layer increased the concentration of porewater ammonium, perhaps due to the resulting ≈3 ^{o}C increase in sediment temperature and hypothesized consequent increase in rates of mineralization. We had predicted that our reed-removal sites would behave as in Jordan et al., and that removing litter would increase sediment temperature, increasing rates of mineralization and concentrations of ammonium. However, we found no increase in sediment temperature after litter removal, and it follows then that ammonium concentrations also did not increase.

Over the course of the summer, porewater ammonium concentrations decreased significantly in all plots at the site without litter but remained the same in all plots at the site with litter, despite our litter manipulations to half of the plots at each site (Fig. 4). Ammonium concentrations may have decreased in plots at the site without litter because of significant plant growth on the site. In contrast, the site with litter exhibited very little plant growth over the course of the summer. We hypothesize that the lack of plant growth allowed porewater ammonium to remain unchanged throughout the summer.

Denitrifying enzyme activity did not increase with the addition of litter to our short-term manipulation plots (Fig. 5). However, denitrification was significantly higher in sites where litter had been present for a longer period of time. This suggests that litter may slow the diffusion of oxygen into the sediment, decreasing the availability of oxygen to heterotrophic bacteria and increasing denitrification in plots with litter, but only after some period of time greater than our three-week manipulation.

Though the long-term presence of *Phragmites* litter may increase rates of denitrification, the potential increase is too slight to warrant concerted efforts by wetland managers to revise current management practices. However, the effects of a *Phragmites* litter layer on the success of seedling re-growth and the quality and availability of bird and fish habitat may be substantial and should be subjects of future study.

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APPENDIX

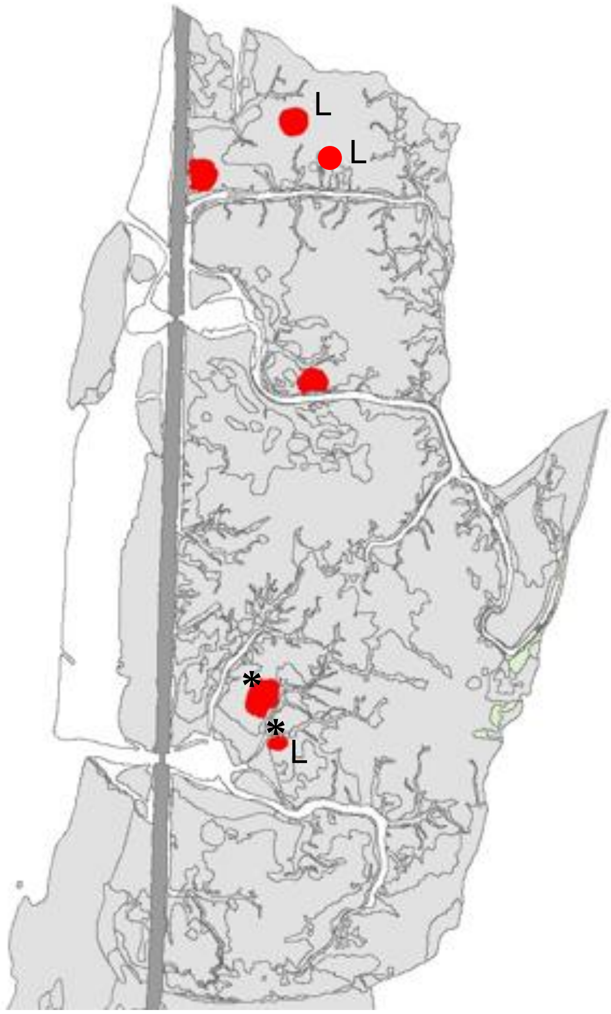

FIGURE 1. *Phragmites* stands in the Tivoli Bays Management Area treated in 2006-2007, as of July 2008. A thick litter layer was present at sites labeled "L" and absent at sites with no label. Observational data was collected from all sites; an experimental manipulation was also performed on the two stands marked with an asterisk.

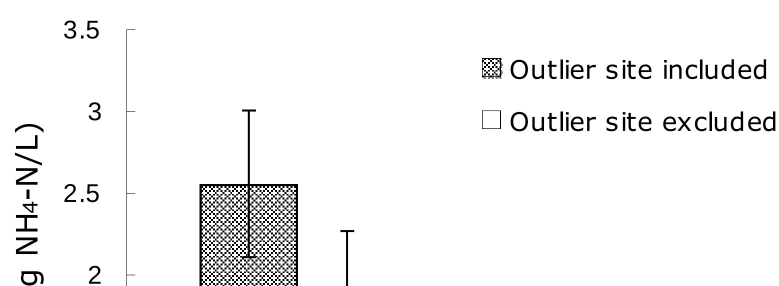

FIGURE 2. Porewater ammonium concentration in reed-removal sites with and without a litter layer. Litter layers had either been in place since reed removal or had been removed by tides, ice, and storms. Values are means of depth-averaged ammonium concentrations. Open bars did not differ significantly (p = 0.372).

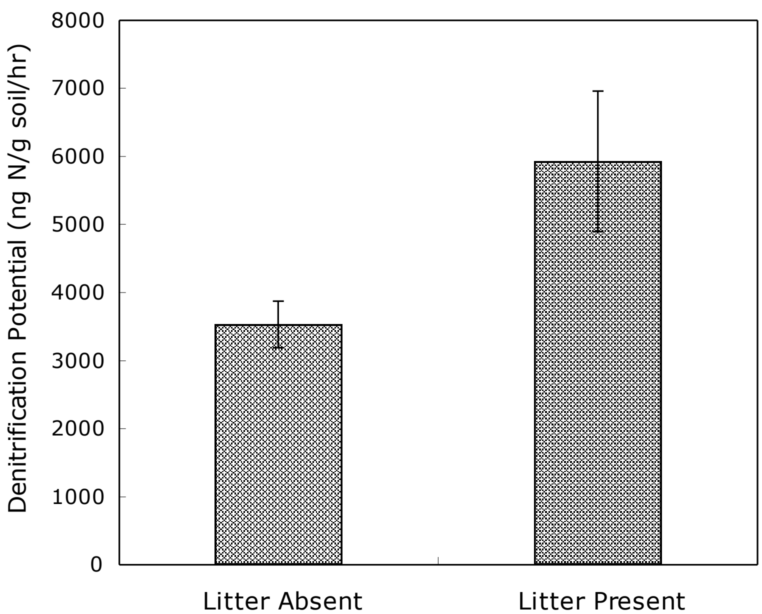

FIGURE 3. Denitrification enzyme activity in sediment cores taken from reed-removal sites with and without a litter layer. Litter layers had either been in place since reed removal or had been removed by tides, ice, and storms. Values are means of 2 cores taken from each of 3-4 plots located within each site. Rates differed significantly (p= 0.024).

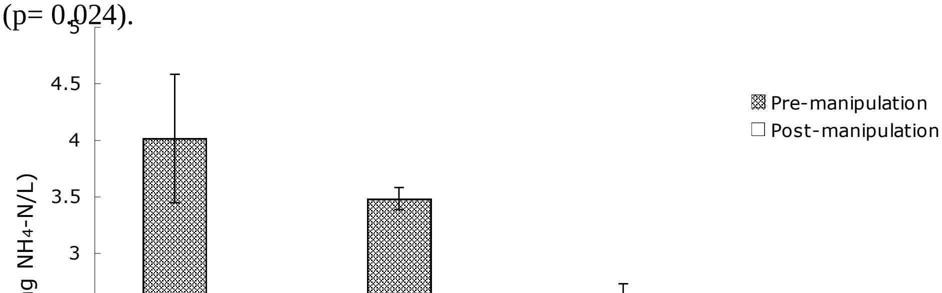

FIGURE 4. Porewater ammonium concentrations in reed-removal sites with and without a litter layer, pre- and post-manipulation. Values are means of depth-averaged ammonium concentrations collected from two equilibrators. The similar decline over time in sites where litter was added (two left-hand pairs of bars) suggests litter addition had no effect on porewater ammonium. For the plots where litter was originally present and then removed (two right-hand pairs of bars) showed no difference over time or in response to litter removal.

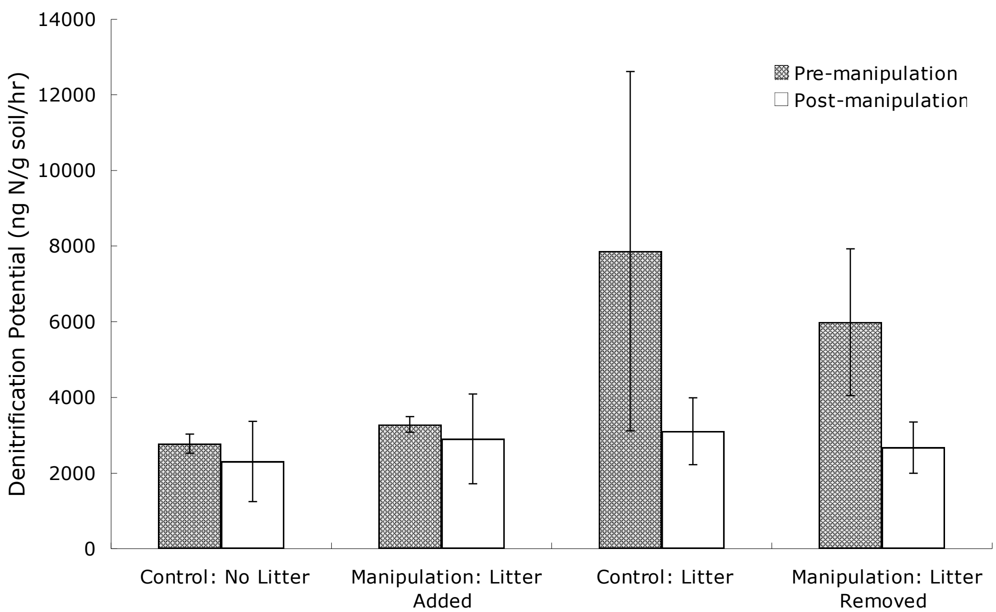

FIGURE 5. Denitrification enzyme activity in sediment cores from reed-removal stands with and without a litter layer, pre- and post-manipulation. Values are means of enzyme activity measured on four cores collected from two plots. There were no significant differences after litter manipulation suggesting no influence of litter on denitrification potential.