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How do management treatments affect invasive cattail (*Typha x glauca*) and pore water nutrient concentrations?

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ABSTRACT Invasive species are problematic for wetland managers, but little is known about how common management treatments influence nutrient cycling or plant responses. This study tested three experimental treatments (mowing, herbiciding, and harvesting (i.e., removal of aboveground biomass)) on several response variables: wetland soil porewater nutrient content (NO_3^-, NH_4^+, PO_4^-), native plant and invasive-*Typha* density, and light attenuation through the plant canopy. Seventeen days post-treatment, herbiciding resulted in higher porewater phosphate concentrations (55.63 µg-P/L) than harvesting (8.95 µg-P/L). After 24 days, herbicide had higher porewater phosphate concentration (72.03 µg-P/L) than all other treatments (control=15.15 µg-P/L, harvest=12.48 µg-P/L, mow=24.75 µg-P/L). After 32 days, harvest treatments promoted higher native density (333.2 stems/m^2) than mowing (29.05 stems/m^2) or herbiciding (31.85 stems/m^2), which may have resulted from the increased light penetration to the soil surface (70%) associated with removing the aboveground biomass. Together, these data suggest that harvesting should be considered by managers aiming to reduce *Typha* density, increase native abundance, and avoid eutrophication downstream.

INTRODUCTION

Wetlands are situated between terrestrial and aquatic systems where they provide important ecosystem services including flood abatement, biological productivity, and improvement of water quality (Zedler and Kercher 2005).

When terrestrial run-off containing pollutants and nutrients (especially nitrogen and phosphorus) enter a wetland, they can be retained, transformed during biogeochemical processes, buried or exported downstream to freshwater aquatic systems. For example, Great Lakes coastal wetlands retain an estimated 53,000 tons of nitrogen per year, providing an important ecosystem service by improving Great Lakes water quality (Sierszen et al., 2012). The usage and storage of nitrogen and phosphorus in wetlands prevents nutrient enrichment and algal blooms that can lead to eutrophication within the

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wetland and in adjacent aquatic systems (Zedler and Kercher, 2005).

Globally, biologically available nitrogen and phosphorus have increased dramatically with the widespread implementation of industrial agriculture. Between 1890 and 1990, the total amount of biologically available nitrogen increased ninefold with most of the growth deriving from increased use of fertilizers in the 1960s and onward (Milleniium Ecosystem Assessment, 2005).

Likewise, phosphorus-based fertilizer use is projected "to increase by 50-100% by 2050" due to dietary changes and food demand (Cordell et al., 2009). While wetlands can transform N and P and reduce their export downstream to aquatic systems, excessive nutrient loading from agricultural and urban runoff tends to promote invasion by dominant macrophytes that can out compete native species and alter the ecosystem services provided by wetlands (Zedler and Kercher, 2004).

Wetlands throughout eastern North America and the Great Lakes region are experiencing an increase in hybrid cattail invasion (*Typha x glauca*) (Galatowitsch et al., 1999), which expands in response to nutrient enrichment (Woo and Zedler 2002) and hydrologic changes (Boers and Zedler 2008, Lishawa et al. 2010). In a Great Lakes coastal wetland, *Typha x glauca* was associated with nutrient-rich soils, low biological diversity, high litter biomass, and high levels of soil organic matter (Tuchmann et al., 2009). Larkin et al. (2012) and Tuchmann et al. (2009) also found that *Typha* enriches its soils with nitrogen, generating plant-soil feedbacks that sustain its dominance. Another mechanism by which *Typha x glauca* further displaces native species is through dense litter accumulation. *Typha* litter accumulates on the wetland surface, creating a thick canopy that does not allow sunlight to penetrate and reduces native seed germination (Vaccaro et al. 2009).

Because *Typha x glauca* alters biodiversity and ecosystem function, it is a large management concern, though information on how to effectively manage the species is limited. It is unknown which treatments are most effective at managing the regrowth of *Typha* and reducing nutrient levels in wetlands. However, there are studies that have analyzed the effectiveness of mechanical, biological, or chemical treatments on reducing other wetland invaders and their influence on nutrient cycling. Findlay et al. (2003) investigated the effects of removal treatments on nutrient cycling in common reed (*Phragmites australis*) dominated wetlands. One year post herbicide treatment, Findlay et al. (2003) found ammonium concentrations in pore water to be four times higher than reference communities. While herbiciding reeds in the marsh promoted greater plant diversity, it might promote further invasion or export of nitrogen to aquatic systems by increasing pore water concentrations. In the Florida Everglades, Martin et al. (2010) analyzed how the application of biological and herbicidal treatments to an invasive tree (*Melaleuca quinquenervia*) can affect nutrient cycling. They found higher phosphorus levels associated with the herbicide-treated sites, which can lead to unwanted eutrophication of aquatic systems near-by.

Our study tested how experimental harvesting, mowing, and applying herbicide affected *Typha x glauca* and native regrowth, light penetration, and short-term (~3 weeks) pore water nutrient levels. Harvest involves cutting down above-ground biomass and removing the litter, which may lead to increased light penetration and less nitrogen and phosphorus in the soil and water because there is no litter to decompose and release nutrients. Mowing and herbiciding, however, leave cut above-ground biomass either on the marsh surface or as dead plants standing upright, which could reduce light penetration to the soil surface and increase pore water nutrients as the litter decomposes. Thus, I hypothesized that harvesting will result in lower nitrogen and phosphorus levels in the pore water than the mowing and herbicide treatments, and will also increase native regrowth as light will be able to penetrate to the soil surface.

METHODS

Experimental Setup

The experiment was conducted at the University of Michigan Biological Station (Pellston, Michigan, USA) during June-August 2013, using 16 experimental mesocosms that were constructed in 2002. Each mesocosm was a box frame measuring 1-m wide, 2-m long, and 1-m deep. The mesocosms were lined with rubber pond liners that measure 1-mm thick and counter-sunk into the ground. The mesocosms were filled with hydric soils from a nearby wetland and mixed with 20% Rubicon sand. Each were planted with 11 native species from a nearby marsh in year 2003, and subsequently hand planted with *Typha x glauca* at 16 stems/m^2 in 2004. The mesocosms have been subjected to different water levels and *Typha* litter addition in the past decade to investigate the effect these factors have on the vegetation community, *Typha* dominance, and nutrient cycling (Larkin et al. 2011).

Management treatments

Each treatment (herbicide, mow, harvest, control) had four mesocosms as replicates. Treatments were assigned to each mesocosm based on pre-treatment *Typha* density and litter abundance and stratified across historical water level and litter manipulations in order to address initial variability and reduce confounding factors. Water levels were maintained at 5-cm above the soil surface throughout the duration of the experiment (June 20-August 16, 2013).

We implemented the treatments during the week of July 8, 2013. We manually applied a glyphosate-based herbicide (Shore Klear™) to each plant. We used an aquatic weed mower (RedMax® model GZ23N) to cut all vegetation at the soil surface for the mow and harvest treatments. Cut biomass was left on the soil surface for mow treatments, and removed from harvest replicates.

Response Variables

Both pre- and post-treatment, we quantified *Typha* and native species abundance and photosynthetically active radiation (PAR) penetrating through the canopy. For nutrient concentrations, porewater samples were collected biweekly.

Quantification of Vegetation

Before the treatment applications and 32 days post-treatment, we quantified the density of vegetation in each mesocosm by laying out ten 0.1-m wide and 2-m long transects per mesocosm. At every other 0.1-m distance, transects were chosen for quantification of vegetation. The number of stems of each species rooted within each transect was identified and recorded. We added the stems of all native species (*Carex aquatilis*, *C. hystericina*, *C. viridula*, *Eleocharis. erythropoda*, *E. smallii*, *Juncus alpinoarticulatus*, *J. balticus*, *J. nodosus*, *Scirpus acutus*, *Scirpus cyperinus*, *Schoenoplectus pungens*, and *Schoenoplectus tabernaemontani*) together to compare native vs. *Typha* responses. We scaled stem density for native and *Typha* to 1-m^2.

Photosynthetically Active Radiation (PAR)

We used a LI-COR model LI-189 photometer to determine the amount of PAR penetrating to different depths within the canopy of each mesocosm pre- and post-treatment. We collected PAR data on overcast days with constant diffuse light and used the percent reduction in PAR at 1-m, 0.5-m, and the soil surface relative to 2-m (above the plant canopy) to compare light attenuation pre- and post-treatment. PAR estimates were collected prior to the treatment implementations and 26 days afterwards.

Porewater nutrient concentration

Two porewater samplers constructed of PVC pipe (2-cm diameter) were installed to 10-cm depth in the soil of each mesocosm. Each sampler had four holes drilled 1.5-cm from the bottom to allow water infiltration and were covered with fiberglass mesh to limit sediment contamination of samples. The porewater located within the samplers was pumped using a hand-held air pump that collected the water into acid-washed 50-mL centrifuge tubes. The tubes were stored in the dark until further processed. The samples were centrifuged and filtered within 24 hours of sample collection. Porewater samples were collected prior to the application of the treatments, and 10, 17, and 24 days after the treatments took place. The analytical laboratory of University of Michigan Biological Station analyzed the porewater samples for the concentrations of NO_3^-, NH_4^+, and PO_4^{-3} through the use of a UV/Vis spectrophotometer (SEAL AutoAnalyzer 3). The station used methods from

Kerouel and Aminot (1997) for ammonium, Armstrong et al. (1967) and Grasshoff (1983) for nitrate, and Murphy and Riley (1962) for orthophosphate.

Statistical Analyses

Average nutrient concentrations were compared across the four treatments (herbicide, mow, harvest, control) for each sample date (pre-treatment, post-10, post-17, post-24). Treatment differences among nutrient concentrations, % PAR, *Typha* and native density were tested using ANOVA analyses if the data passed normality and equal variance tests. If the data did not pass, data were subjected to Kruskal-Wallis non-parametric rank tests. Post-hoc multiple comparisons among the treatments were conducted using Tukey Kramer tests. All statistical analyses were conducted using StatPlus®.

RESULTS

Density of Vegetation

Prior to management treatments, *Typha* density did not differ among the mesocosms ($p>0.05$; Fig. 1A). Management treatments significantly reduced *Typha* density (Fig. 1B), with harvest, herbicide, and mow treatments having 4.75, 0.25, and 6 (#stem/m^2), respectively, compared to an average of 55 stems/m^2 in the control. Pre-treatment, all of the 16 mescosms had a mean native density ranged between 300-450 stems/m^2 and no significant difference existed among the assigned treatments ($p>0.05$; Fig. 1A). Post-treatment, mean native density differed among the treated mesocosms ($F_{3,12}=220.00$, $p=0.04$; Fig. 1B). The controls averaged 265.3 stems/m^2, and the harvest, herbicide, and mow treatments averaged 333.2, 31.85, 29.05 stems/m^2, respectively (Fig. 1B).

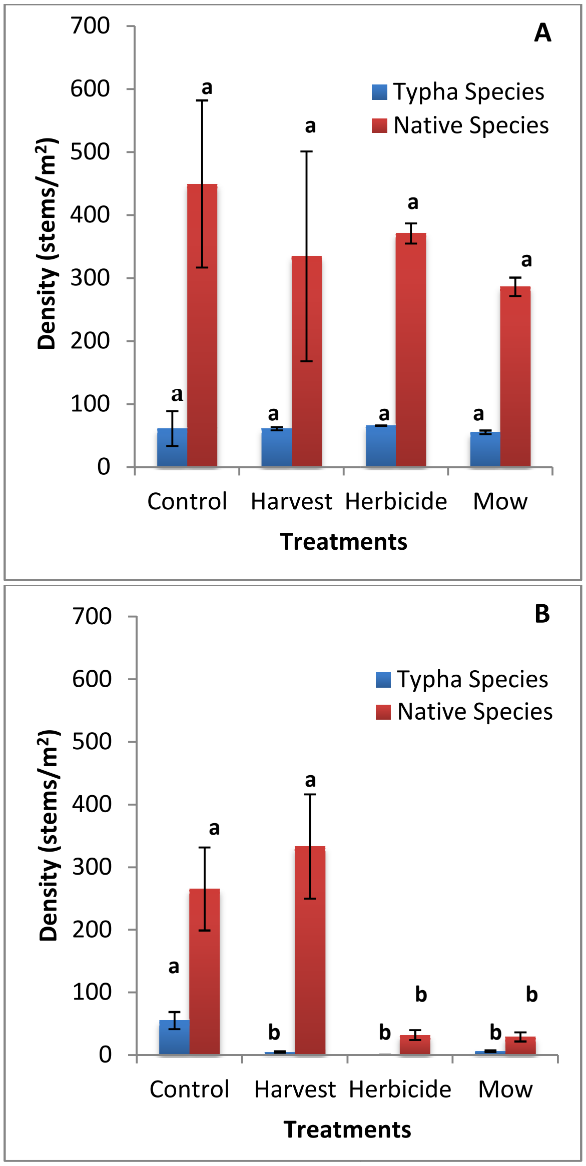

Figure 1. A) Pretreatment, there were no significant differences among treatments in average *Typha* or native species densities (error bars ± 1SE). B) Post-treatment, there were significantly fewer *Typha* stems in the harvest, herbicide, and mow treatments compared to controls. For native species, average density was significantly higher in the control and harvest than in the mow and herbicide treatments. For each response variable, treatments that do not share a common letter differed significantly after Tukey Kramer multiple comparisons.

Photosynthetically Active Radiation (PAR)

Pre-treatment, %PAR did not differ significantly among the replicates at any height ($p>0.05$; Fig.

2A). Post-treatment, %PAR penetration for harvest treatments was significantly higher than control treatments at 1m ($p=0.043$; Fig. 2B). At 0.5m, %PAR penetration was significantly different among treatments ($F_{3,11}=7.11$, $p=0.006$), with harvest treatments having greater PAR penetration than herbiciding (Fig. 2B). At the soil surface, control, mow, and herbicide had significantly lower %PAR penetrating than the harvest treatment ($F_{3,11}=10.79$, $p=0.001$).

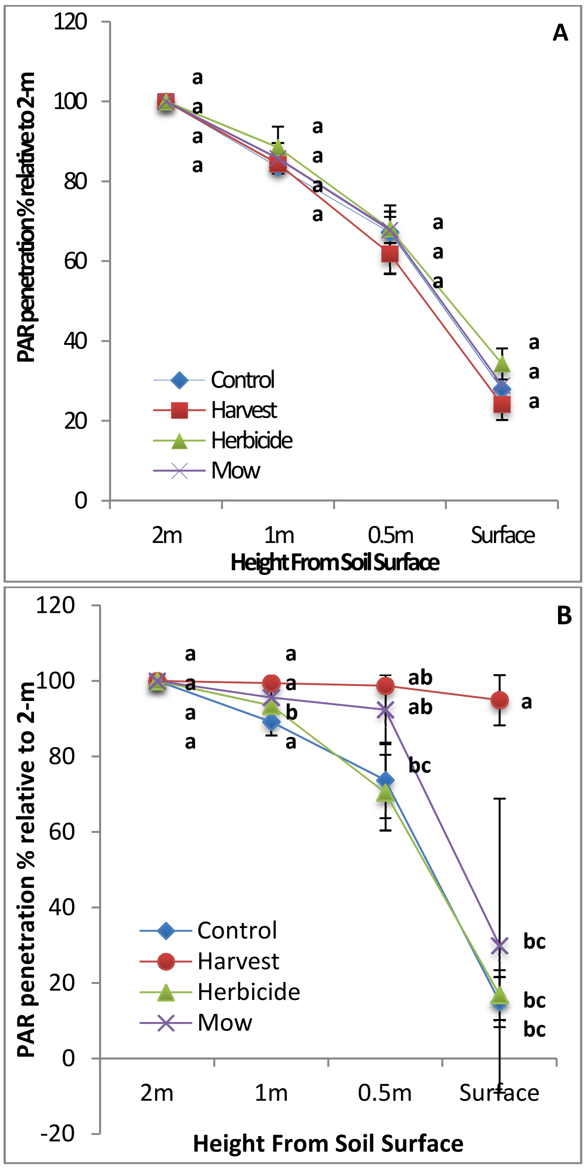

Figure 2. PAR was relativized by 2-m readings to estimate the percent reduction in PAR at 1-m, 0.5-m, and the soil surface. Treatment averages ± 1 SE are presented. A) Pre-treatment, there were no significant differences in PAR penetration among the assigned groups. B) Post-treatment, there were significant differences among treatments at 0.5m above the soil surface ($p=0.010$). Within each sampling height, treatments that do not share a common letter differed significantly after Tukey Kramer multiple comparisons.

Porewater nutrient concentration

Pre-treatment ammonium-N concentrations averaged about 500 µg-N/L and did not differ among assigned treatment replicates ($p>0.05$, Fig. 3). Ten days post- treatment, harvest and mow treatments averaged ~1300 µg-N/L, while control and herbicide treatments ranged between 500-550 µg-N/L. The mow treatment tended to have higher ammonium-N concentrations (991.8 µg-N/L) 17 days after treatment, but there were no statistical differences ($p=0.42$). At 17 and 24 days post-treatment, the harvest treatment tended to have lower concentrations (43.0 and 40.7 µg-N/L) than the other treatments. After 24 days of treatment, herbicide had an ammonium-N concentration of 1825.4 µg-N/L that tended to be higher than the other treatments, but was not statistically different ($p=0.32$).

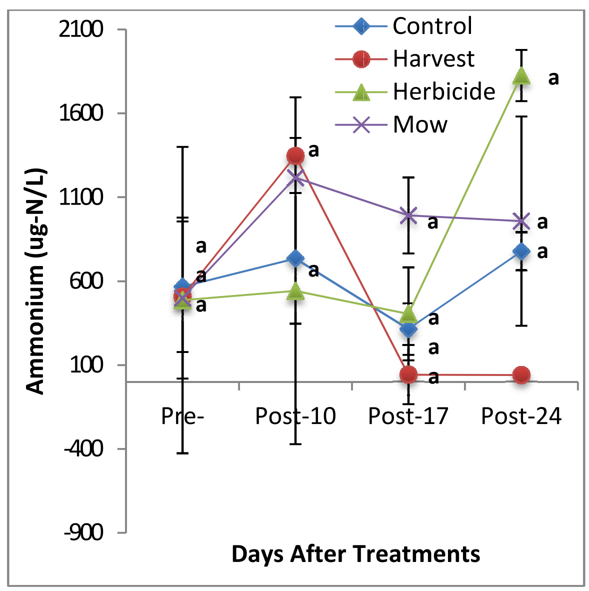

Figure 3. Mean ammonium concentrations (± 1 SE) did not differ significantly among treatments on any of the dates tested. Pre-, Post-10, Post-17, and Post-24 refer to sampling periods before and 10, 17, and 24 days after management applications.

Pre-treatment nitrate concentrations did not differ among treatments (p>0.05). Post-treatment, nitrate concentrations also did not differ 10, 17, or 24 days after treatment implementation (p>0.05), averaging between 2-16 µg-N/L. Total nitrogen concentrations among the management treatments were not significantly different during the pre-, post-10, post-17, and post-24 sampling periods (p>0.05).

Pre-treatment phosphate concentrations did not significantly differ (p>0.05) among assigned treatments, but tended to be higher in the herbicide replicates (127.8 vs. 25-50 µg-P/L). Ten days post-treatment, the control treatment had significantly higher phosphate levels ($F_{3,12}$=3.49, p=0.046) than harvest treatment. Seventeen days post-treatment, the herbicide treatment had significantly higher levels of phosphate concentrations ($F_{3,12}$=7.51, p=0.004) than mow and harvest treatments (Fig. 4). Twenty-four days post-treatment, herbiciding resulted in significantly higher phosphate concentrations ($F_{3,12}$=4.97, p=0.018) than the other treatments.

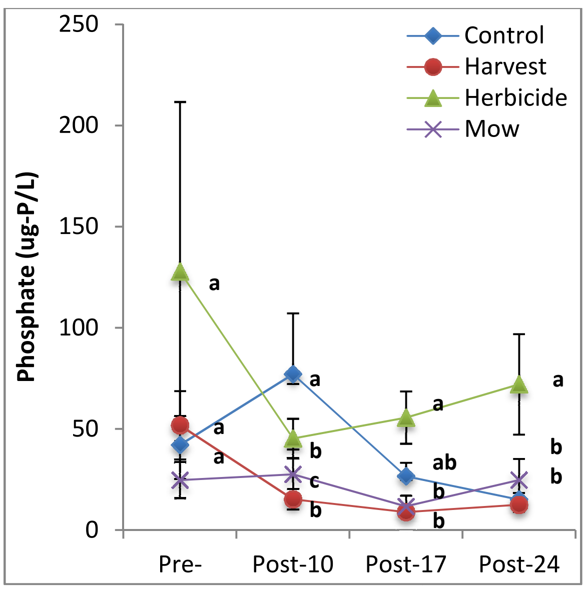

Figure 4. Mean phosphate concentrations (± 1 SE) among management treatments. Herbicide had higher phosphate concentrations after 10, 17 and 24 days of applying the treatments. Pre-, Post-10, Post-17, and Post-24 refer to sampling periods before and 10, 17, and 24 days after management applications. Within each sampling period, treatments that do not share a common letter differed significantly after Tukey Kramer multiple comparisons.

DISCUSSION

Herbiciding, mowing, and harvesting are commonly used management techniques that aim to control invasive plant species in wetlands. However, little is known about how these management techniques can affect wetland nutrient cycling. We initially hypothesized that 1) harvest would reduce N and P concentrations in pore water compared to herbiciding and mowing, and 2) that harvest would reduce the regrowth of *Typha* while increasing native density. The rationale behind these hypotheses was that both herbiciding and mowing leave behind litter at the soil surface that eventually decomposes in the water, which can result in an increase of *Typha* density as well as N and P concentrations (Larkin et al., 2011).

Although the duration of our study was short, our preliminary data support these hypotheses, as harvesting above-ground biomass resulted in significantly higher native species density than herbiciding and mowing treatments. Compared to harvesting, herbiciding had significantly less sunlight penetrating through the plant canopy and reaching the soil surface, which might inhibit native species re-sprouting or germinating. Post-treatment, herbiciding resulted in higher phosphate in the pore water than the other treatments, possibly due to the release of phosphate as dead biomass began decomposing or as a result of the residuals of the glyphosphate herbicide used in this study. Future tests of *Typha* management techniques will use greater replication to address the variability found in our porewater nutrient concentrations such as nitrate.

All three management treatments significantly reduced *Typha* density. However, the removal of dead plant material in the harvest treatment significantly increased native density compared to herbiciding and mowing. Our results suggest that herbicide application can increase phosphorus concentrations, which could promote re-introduction of *Typha* as well as eutrophication downstream. Harvesting *Typha* appears to be the most effective technique at increasing native density and does not elevate nitrogen or phosphorous in the pore water. Based on our preliminary results, we recommend large scale testing of *Typha* harvesting in the field under different hydrologic conditions to control this aggressive invader. Harvested *Typha* biomass could also be potentially used as a biofuel, which would be an additional benefit of this management strategy.

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