Functions of wetland plant assemblages on water quality improvement

By

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A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Biological Sciences
in the Department of Biological Sciences

Mississippi State, Mississippi

August 2016

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Studies have shown wetlands act as filters for nutrient rich waters, in part due to macrophyte properties. Differences have been found in nitrogen removal rates among plant species in studies of monocultures grown in mesocosms mimicking wastewater treatment constructed wetlands, but little research has been done on assemblages in natural or restored wetlands. This study aims to identify differences in water quality among plant assemblages in natural and restored wetlands. Thirty natural and restored wetlands in the Mississippi portion of the Mississippi Alluvial Valley were sampled four times. Water quality was measured and plant assemblages identified. Significant differences in pH, conductivity, and turbidity were found among four different plant growth forms, but nutrient concentrations were not significantly different among growth forms. Because nutrient concentrations were low, data collected may not have adequately captured potential differences in nutrient concentrations among plant assemblages.

ACKNOWLEDGEMENTS

I would like to thank all those involved in making this work possible. Dr. Gary Ervin managed to find time to support and guide me even while serving as Interim Department Head. Dr. Lisa Wallace and Dr. Matt Moore provided helpful feedback as my committee members. Cory Shoemaker was an essential part of the experimental design and data collection process and also provided great advice. The Mississippi State University Water Quality Lab allowed me to use their equipment and Derek Faust ran all of the water samples. Kevin Nelms helped me find landowners who allowed us to use their wetlands. Dr. Charles Bryson helped with species identification. Finally, the Mississippi Water Resource Research Institute provided the funding that made this work possible.

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CHAPTER I

INTRODUCTION

Background

Excessive nutrients and sediments entering waterways cause degradation of aquatic ecosystems. As nutrient rich runoff enters a body of water, primary productivity increases (Ribaudo et al. 2001, Mitsch et al. 2001). This increased primary production, driven largely by phytoplankton, results in a hypoxic zone when oxygen is consumed for respiration or decomposition (Carpenter et al. 1998, Ribaudo et al. 2001). Decreased light penetration resulting from suspended solids can cause shifts from communities dominated by submersed macrophytes to emergent species-dominated communities (Egertson et al. 2004). Much of these nutrients come from the application of fertilizers on agricultural lands that are carried into waterways via drainage ditches during runoff events (Taylor et al. 2015). In fact, agriculture contributes 70% of nitrogen and phosphorous delivered to the Gulf of Mexico (Alexander et al. 2008). Nitrogen fertilizer is the largest source of nitrogen to the Mississippi River, representing about 50% of nitrogen loads, followed by nitrogen fixed by crops (Howarth 2008). Nutrients carried via the Mississippi River and its tributaries empty into the Gulf of Mexico and contribute to a yearly hypoxic zone responsible for habitat degradation, alteration of food-web structures, and loss of biodiversity (Howarth 2008, Ribaudo et al. 2001, Mitsch et al. 2001).

Wetlands can act as filters on the landscape by retaining or transforming nutrients. Aquatic macrophytes aid in reduction of nutrients and sediments in these ecosystems (Verhoeven et al. 2006, Srivastava et al. 2008). Macrophytes decrease water velocity, which increases sedimentation of suspended solids and reduces erosion (Bouldin et al. 2004, Brix 1994a). Macrophytes also enhance nutrient removal through uptake and integration into their tissues, as well as providing sources of carbon, oxygen, and surface area for aquatic micro-organism attachment (Srivastava et al. 2008, Brisson and Chazarenc 2009, Deaver et al. 2005). Studies have shown reductions ranging from 3% to 50% of incoming phosphate, 32% to 95% of nitrate, 13% to 47% of ammonium, and 48% to 91% of total suspended solids, in waters that have passed through wetlands (Blahnik and Day 2000).

Results from wastewater treatment studies have shown differences in pollutant removal efficiencies among plant species, even among those with similar life forms (Brisson and Chazarenc 2009). Tanner (1996), for example, found a linear correlation between biomass production and total nitrogen removal indicating that species with the most rapid growth are able to accumulate the most nitrogen. Oxygen is another important component in nitrogen removal processes, because nitrifying bacteria require aerobic conditions (Vymazal 2007). Plants that release more oxygen from their roots, such as species with connective through-flow ventilation systems, would allow for greater nitrification to occur. Increased nitrification would provide more nitrate for denitrifying bacteria (Brix 1994a). Deaver et al. (2005) found that *Ludwigia peploides* was capable of greater NH_3 removal than *Leersia oryzoides* or *Juncus effusus,* and they suggested that this may be due to its extensive adventitious root system that provides a source of oxygen for attached microbes within the water column. Other plants exhibiting this same feature may also facilitate greater NH_3 removal efficiency due to increased surface area and direct contact with water. Brisson and Chazarenc (2009) suggested that, because roots and submersed leaves provide surface area for microbial colonization and emergent leaves transport oxygen to the roots, leaf and root surface area might also be possible characteristics related to removal. However, a study of tropical river floodplains found that macrophyte surface area alone was not a good predictor of epiphyte biomass, but that species with more complex structural architecture had more attached algae (Pettit et al. 2016). The results of this study by Pettit et al. (2016) suggest that plants with more complex structural architecture might provide better conditions for nutrient reduction via microbes.

Holmroos et al. (2015) found lower water nutrient concentrations in areas dominated by a submersed species, *Myriophyllum verticillatum*, than areas dominated by a floating leaved species, *Nuphar lutea*. They attributed the difference to differential nutrient uptake methods; rooted, floating-leaved species take nutrients from the soil and submersed macrophytes are capable of uptake from the water column. Other studies have reported lower nutrient concentrations in ruderal species than perennial species, suggesting that ruderal species might be less effective in nutrient reduction. Low nutrient content of ruderals as opposed to perennials may be due to high growth rates that require nutrients to be immediately integrated into new tissue production instead of being stored (McJannet et al. 1995).

Given these inherent differences in plant functional traits, it is likely that assemblages of species exist that may improve water quality significantly, while providing other benefits such as wildlife habitat. However, water quality improvement properties of species assemblages in naturally occurring and restored wetlands that receive non-point source runoff has been largely unexplored. Much of the wastewater treatment research has been in containers, rather than intact wetlands. Small-scale studies are impacted by greater edge effects, such as fewer interactions with neighboring plants, and greater root crowding in pots or mesocosms, that can cause results to be less translatable to full scale wetlands (Tanner 1996, Brisson and Chazarenc 2009). Plants used in these studies are typically restricted to species that are highly tolerant to high nutrient loads, grow and reproduce quickly, and are tolerant to local climates and pests (Tanner 1996). In addition, previous studies have commonly used immature or unhealthy plants, which could cause a species to appear less efficient at removing nutrients (Brisson and Chazarenc 2009). Wastewater treatment studies also apply nutrients at greater concentrations and rates than those observed in natural wetlands receiving agricultural run-off. Some other studies use aspects common to constructed wastewater wetlands, such as gravel substrate, high hydraulic loading rates, and plant monocultures, that are not encountered in natural wetlands (Brisson and Chazarenc 2009, Brix 1994b). These typical experimental designs make direct comparisons with natural and restored wetlands difficult.

This research took place on natural and restored wetlands within the Mississippi portion of the Mississippi Alluvial Valley (referred to as the Mississippi Delta hereafter). Many of these wetlands are part of the Wetlands Reserve Program (WRP), in which marginal farmland is converted back into wetlands via government funded easements. These wetlands have been restored with water quality improvement and other wetland services, such as flood mitigation and wildlife habitat, in mind. The present work used natural or restored wetlands, enabling collection of data from established assemblages in full scale wetlands. This study also improves upon studies of wastewater treatment that focused on monocultures of plants by including assemblages consisting of multiple species and growth forms. Considering these aspects, this study was expected to provide insight on the largely unexplored role of macrophyte species assemblages in water quality improvement in natural and restored wetlands receiving agricultural run-off.

Hypothesis

Water quality parameters (dissolved oxygen, temperature, pH, conductivity, turbidity, and oxidation reduction potential, total suspended solids, phosphate, nitrate, and ammonia) will differ among plant assemblages, with some assemblages being associated with water quality closer to or within accepted ranges of criteria for the support of aquatic life (Table 2). These differences in water quality will be linked to differences in plant characteristics among assemblages.

CHAPTER II

METHODS

Effects of plant assemblages on water quality were assessed in 24 WRP wetlands and six naturally occurring wetlands within the Mississippi Delta (Table 5). Wetlands were chosen from 12 Delta watersheds grouped into low (≤17.9 kg/ha), medium (17.9 - 39 kg/ha), and high (≥39kg/ha) nitrogen load categories. Loads were estimated based on land use and typical fertilization practices. This categorization yielded four watersheds per nitrogen load group. Two wetlands were chosen randomly per watershed for each nitrogen loading category, given landowner willingness. This allowed us to examine wetlands experiencing a range of nitrogen loads. Additionally, two naturally occurring wetlands were selected from two watersheds in each loading category (Ervin 2016). These wetlands were sampled four times from March to October, 2015.

The number of points from which samples were taken was determined by size of the inundated area of each wetland at the time of sampling. If the length of the inundated area was less than 50 m on its longest side, then four points were taken. If the length of the inundated area was 50 m or greater on its longest side, then six points were taken.

Sample points within each wetland were taken where distinct plant species assemblages existed. Plant species assemblages were determined using interpolation of past data, as well as identification of present plants, depending on the state of vegetation when samples were taken. Since identification of plant assemblages was difficult in March, due to ice and lack of leaves or inflorescences, maps of probable plant assemblages were interpolated using Thiessien polygons of dominant species from August 2014 surveys (Figure 1).

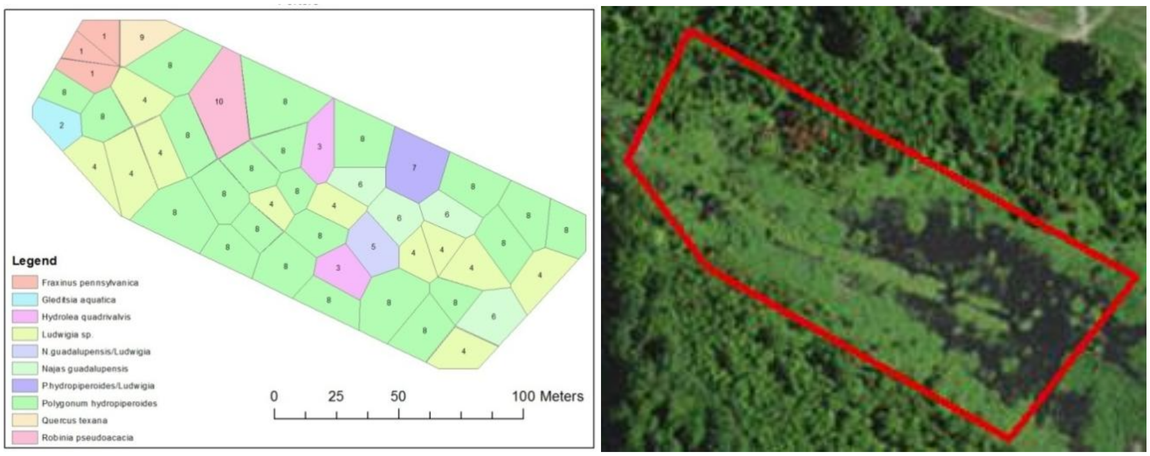

Figure 1 Site maps

Left: Probable plant assemblage map. Right: Satellite imagery of the same site at 1 m resolution.

In May and August, water samples were taken immediately after plant surveys were conducted. Fifty circular plots (0.5 m²) were spaced evenly through each wetland and species and percent cover were recorded. Vouchers were taken of species that could not be identified in the field for later identification in the lab using Manual of the Vascular Flora of the Carolinas (Radford et al. 1968), Aquatic and Wetland Plants of Southeastern United States: Dicotyledons (Godfrey and Wooten 1981), and Aquatic and Wetland Plants of Southeastern United States: Monocotyledons (Godfrey and Wooten

1979) (Table 3, Table 4). A maximum of four nearest plant survey plots that shared a dominant species with the nearest plot were used to characterize assemblages where water samples were taken. Any water samples that shared those nearest plots were considered part of the same assemblage and water quality measurements were averaged (Figure 2).

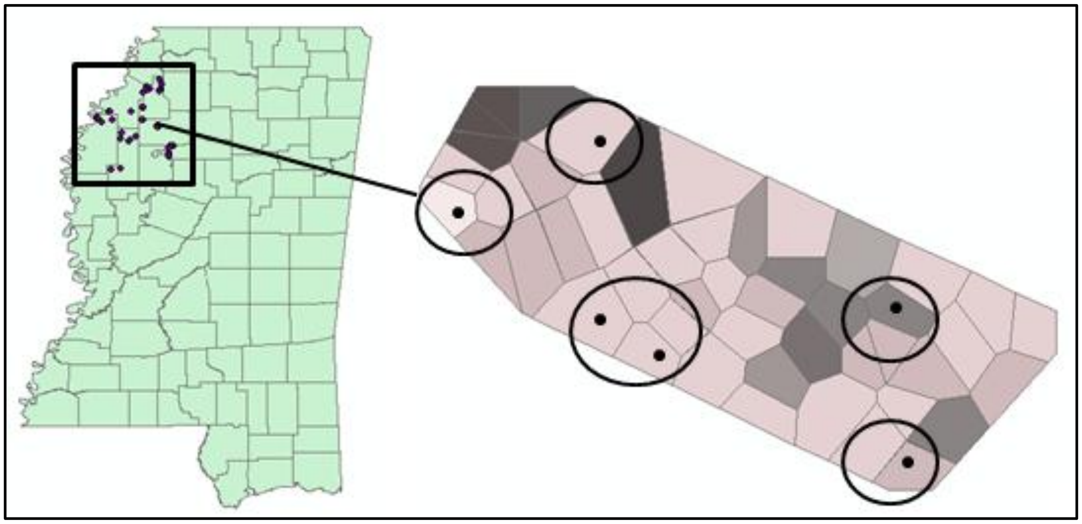

Figure 2 Wetland surveys

Small dots on the map of Mississippi represent individual wetland sites. A single wetland has been magnified to the right. The dots on this wetland represent individual water sample locations and the circles represent assemblages. In the case where two dots are in one circle, the two water samples have been averaged together because they share nearest plant sample plots.

Plant surveys took approximately two hours to complete and water sampling started near the first vegetation sample points to allow disturbed areas to resettle. Low turbidity and total suspended solid values indicate that disturbance during vegetation surveys had little effect on water sampling (Table 2). Sample points were chosen based on observations of plant assemblages made during these surveys. October sample locations were based on a quick visual assessment of the vegetation in each wetland. Number of samples collected and location of samples varied on each trip due to seasonal fluctuations in water level and inundated area (Table 1).

Table 1 Distribution of sample points per trip

Sampling trip	**Number of wetlands where samples were collected**	**Number of water samples collected**	**Number of assemblages sampled**	**Number of water samples per wetland**
March	24	118	97	4-6
May	23	121	91	4-6
August	9	45	33	6
October	2	11	6	6

A Hach Hydrolab DS5 sonde (Loveland, CO) was used to measure dissolved oxygen, temperature, pH, conductivity, turbidity, and oxidation reduction potential. At each point, a 45 ml water sample was taken, preserved with 1.5 ml of sulfuric acid, and transported on ice to the Mississippi State University Water Quality lab for analysis of total suspended solids, phosphate, nitrate, and ammonia.

Nonmetric multidimensional scaling (NMDS) ordinations, conducted using the vegan package (Oksanen et al. 2016) in R (Version 3.1.2; R Core Team 2014), were used to visualize the relationship between plant species and water quality parameters for March, May, and August sampling trips. October data were not used because too few samples were collected. NMDS ordinations attempt to construct a unitless distance matrix that reflects the relationships within the original data. If the original relationships can't be reached within a certain tolerance threshold, the model fails to converge. No groupings emerged from these ordinations that would indicate any relationships between plant species present and water quality at any sample point for models that reached convergence.

This led to reorganization of the data into plant growth form categories (Table 3, Table 4). Each species was grouped into one of four categories: broadleaf, graminoid, woody, and vine. Broadleaf species were characterized as herbaceous plants with leaves that are not blade-like or needle-like. Plants with woody stems, including trees and shrubs and excluding vine plants, were considered woody. Graminoid plants were those in the grass, rush, or sedge families, or those with similar morphology. Plants that climb by means of tendrils, bending or twining petioles or leaf stalks, or aerial adventitious roots, or have trailing woody stems with hooked prickles, were placed in the vine category (Godfrey 1988). These categories were chosen to characterize species because previous studies have suggested that plant morphology is an important factor in reducing nutrients and suspended particles (Brisson and Chazarenc 2009, Pettit et al. 2016). Percent cover of each category was calculated for each sample point and combined with water quality data. Additional NMDS ordinations were constructed for each sampling trip with water quality and growth form percent cover data. August data could not be analyzed by growth form because there was insufficient replication in growth form categories. These ordinations did not yield any indications of relationships between water quality and plant growth form by percent cover. The ordihull function in the vegan package (Oksanen et al. 2016) in R (Version 3.1.2; R Core Team 2014) was used to plot polygons onto the ordination to visualize groupings by nitrogen load category and by wetland type (restored or natural), but these polygons overlapped substantially (Figure 8).

Since data were not normally distributed, a Kruskal-Wallis test was performed using R (Version 3.1.2; R Core Team 2014) for each water quality variable to determine the difference in water quality measurements among dominant plant growth forms. This set of tests was performed separately for each sampling trip. Nemenyi post-hoc tests were used to determine difference among growth form levels for significant variables following the Kruskal-Wallis tests. The PMCMR package (Pohlert 2014) was used in R(Version 3.1.2; R Core Team 2014) to conduct Nemenyi tests. Linear regressions were then used to determine if patterns existed between significant variables identified in Kruskal-Wallis tests and percent cover of corresponding significant growth form levels identified by the Nemenyi tests. Linear regressions were carried out using R (Version 3.1.2; R Core Team 2014).

CHAPTER III

RESULTS

March and May NMDS ordinations did not reach convergence. August NMDS did converge, but no groupings were seen among sampling locations that would indicate relationships among water quality variables and plant species in NMDS ordinations of individual species. Additionally, no groupings were seen among sampling locations that would indicate relationships among water quality variables and plant growth forms in NMDS ordinations of water quality variables and plant growth forms (Figure 3). When polygons were plotted onto these ordinations to visualized any groupings by nitrogen load category or wetland type, all polygons overlapped substantially. This overlap suggests that there is no difference in plants or water quality among different nutrient loading categories or between natural and restored wetlands.

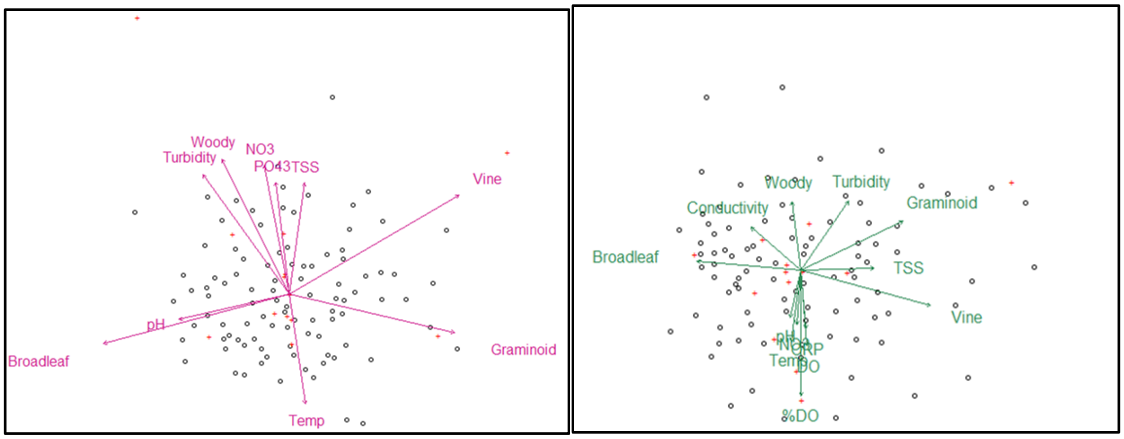

Figure 3 May and March NMDS ordinations

NMDS ordinations of growth form and water quality data. Left: March sampling trip ordination. Right: May sampling trip ordination.

Kruskal-Wallis tests for the March sampling trip showed a significant difference among dominant plant growth forms for conductivity and pH. There was no significant difference among dominant growth forms for nitrate, ammonia, phosphate, total suspended solids, turbidity, dissolved oxygen, or oxidation reduction potential. Nemenyi tests of pH showed significant differences between sample points dominated by vine and broadleaf growth forms for pH, with vine growth forms being associated with lower pH and broadleaf growth forms being associated with a higher pH (Figure 4).

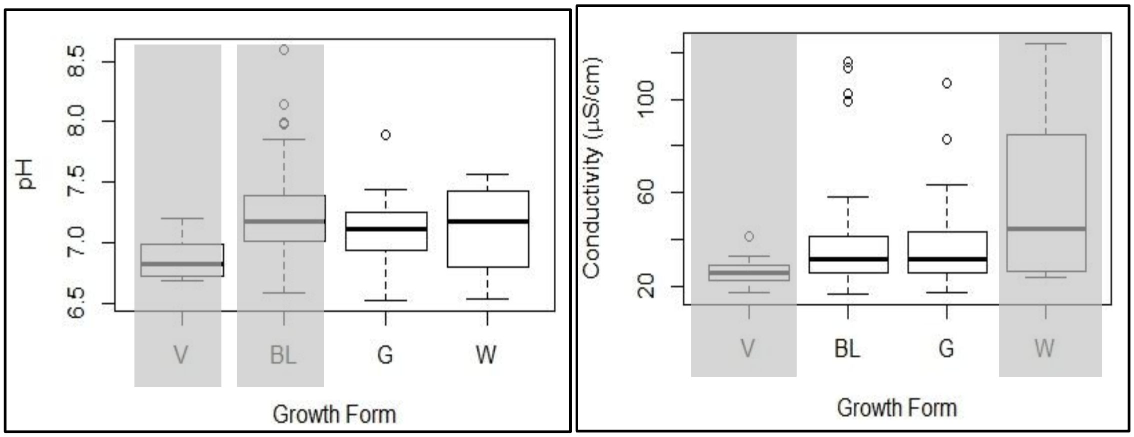

Figure 4 March pH and conductivity by dominant growth form

V: Vine species dominated assemblages, BL: Broadleaf dominated assemblages, G: Graminoid dominated assemblages, W: Woody dominated assemblages. Left: Assemblages dominated by vines exhibited lower water column pH than assemblages dominated by broadleaf plants. Right: Assemblages dominated by vines exhibited lower water conductivity than those dominated by woody vegetation. Gray boxes indicate significant difference.

Linear regressions showed a significant relationship between pH of the water column and percent cover of vine and broadleaf growth forms. As percent cover of vine species increased, pH decreased, and as percent cover of broadleaf species increased pH increased (Figure 5).

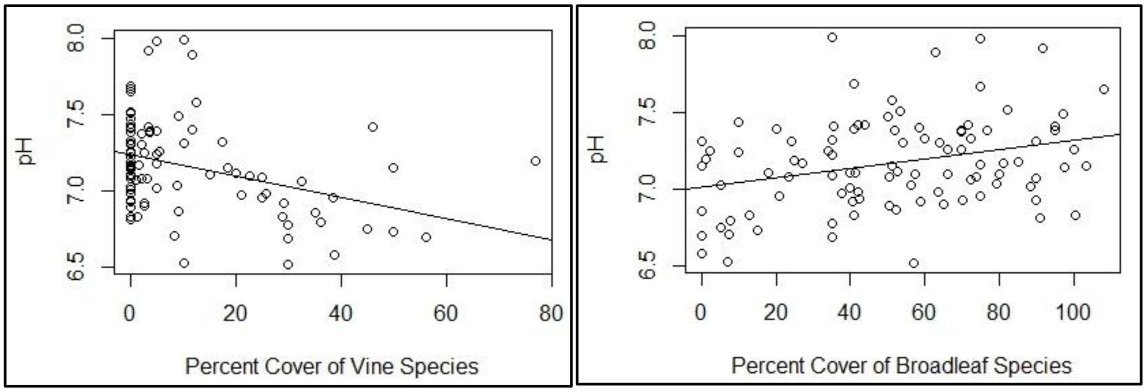

Figure 5 Linear relationships between pH and growth form cover in March

Right: A significant negative correlation existed between percent cover of vine species and water column pH (p=0.0002). Left: There is a significant positive correlation between percent cover of broadleaf species and water column pH (p=0.0026).

For conductivity, Nemenyi tests showed a significant difference between vine and woody growth form-dominated assemblages, with vine being associated with lower conductivity, and woody being associated with higher conductivity (Figure 4). Vine species had a significant linear relationship with conductivity, but woody species did not. As the percent cover of vine species increased, conductivity decreased (Figure 6).

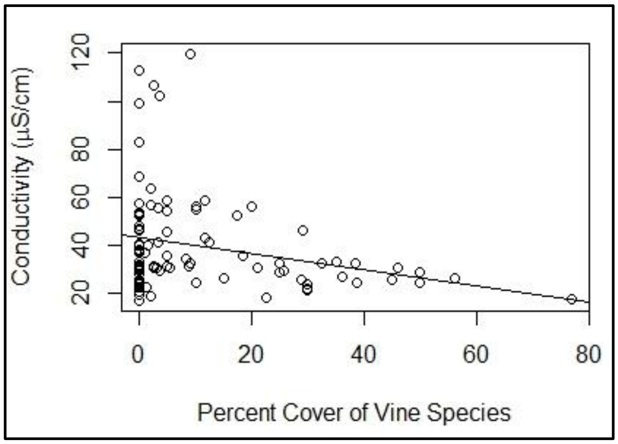

Figure 6 Linear relationship between conductivity and vine cover in March

Percent cover of vine species was negatively correlated with conductivity in data from March (p=0.0112).

Kruskal-Wallis tests for the May sampling trip showed a significant difference among dominant growth forms for turbidity only. There was no significant difference among dominant growth forms for nitrate, ammonia, phosphate, total suspended solids, conductivity, pH, dissolved oxygen, or oxidation reduction potential. A Nemenyi test showed significant difference between sampled assemblages dominated by vine and those dominated by broadleaf growth forms, with broadleaf being associated with lower turbidity and vine being associated with higher turbidity (Figure 7). There was no significant linear relationship between either growth form and turbidity.

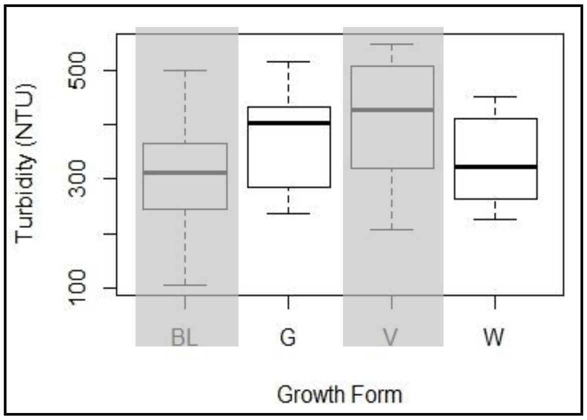

Figure 7 Turbidity by growth form in May

BL: Broadleaf dominated assemblages, G: Graminoid dominated assemblages, V: Vine species dominated assemblages, W: Woody dominated assemblages. Dominant plant growth form was found to be correlated with turbidity in data collected in May. Assemblages dominated by vines were more turbid than assemblages dominated by broadleaf growth forms. Gray boxes indicate significant difference.

CHAPTER IV

DISCUSSION

Since most studies of differential nutrient removal focus on species level nutrient removal, I first examined the relationship between species presence and abundance and water quality measurements. Despite these previous findings, ordinations showed no indications of correlations among these variables in models that converged. Studies have attributed differences in plant characteristics such as root and leaf surface area to nutrient removal differences (Brisson and Chazarenc 2009). To examine this relationship, species were grouped by growth forms with similar above ground architecture.

In March, water in wetland plant assemblages dominated by plants with trailing or climbing growth forms had a significantly lower pH than assemblages dominated by plants with herbaceous broad leaved growth forms. Increases in pH can occur as carbon dioxide is reduced due to use in photosynthesis (Wetzel 1983). If vine species create a canopy that shades algae, reduction in photosynthesis due to reduced light penetration could contribute to lower water column pH in vine dominated assemblages.

Plant assemblages dominated by woody vegetation were associated with significantly higher water conductivity than assemblages dominated by vines in wetlands sampled in March. No significant difference was found in nitrate or phosphate concentrations of water sampled among any of the dominant growth forms categories of plant assemblages. This lack of difference might suggest that some other ion(s), which is better tolerated or used by some growth forms, is driving this relationship. Also, a significant difference in water column pH among growth forms was found between vine and broadleaf species dominated assemblages, not vine and woody dominated assemblages, suggesting this difference in conductivity is not due to pH. In a study of aquatic plants in a tropical floodplain, assemblages dominated by emergent plants with dense vertical stems had higher conductivity (Pettit et al. 2016). Most other studies that examine the effects of different plant species on water quality improvement have not included conductivity measurements.

Vine dominated wetland assemblages were significantly more turbid than broadleaf dominated assemblages in samples collected in May. Since vine species create canopies that shade out phytoplankton, this higher turbidity is most likely not due to increased algae. These vine canopies may cause decreased stem density if they shade out other species and can be supported by relatively few stems of their own. Lower stem density may lead to less sediment interception, and therefore less decrease in turbidity in assemblages dominated by vine species. While studies have addressed the impact of submersed macrophytes on water clarity, few have investigated impacts of emergent macrophytes, and no studies were found that examined emergent macrophytes of different growth forms.

Due to strong evidence for differences in nitrogen removal among species in previous studies, I expected to see species assemblages associated with water quality parameter levels closer to or within criteria for the support of aquatic life in the restored and naturally occurring wetlands examined here. Seasonal variability in the inundated area of wetlands, number of sites, funding limitations, and distance of sites from Mississippi State University made frequent sampling of wetlands from the same sample location impossible. This study was only able to examine the conditions of a location at a few distinct points of time during this research. If the study had been designed to examine a rate of change in nutrients, the outcome of the study may have been different. For example, in a mesocosm study, over 90% of nutrients applied to vegetated mesocosms were removed from the water in a 48 hour period (Taylor et al. 2015). If nutrients can be removed at a similar rate in natural wetlands, levels in the wetlands examined here may be more indicative of water quality after most nutrients have been removed since most data were collected long after runoff would have entered the wetland.

Previous studies have been conducted in treatment wetlands, mesocosms, and microcosms in which many other environmental factors were controlled. Because this study took place in restored and naturally occurring wetlands, it is possible that other environmental factors that were not accounted for, such as disturbance due to management, depth and duration of water, or availability of organic carbon, could be playing a larger role on nutrient levels or plant composition. Additionally, many of our wetlands were surrounded by other conservation lands which may be acting as buffers to reduce nutrients before they enter the wetland. Vegetated buffers are also effective at trapping sediments and nutrients through reduction in water velocity, uptake of nutrients by plants, and infiltration of water and some nutrients into the soil (Dosskey 2001). Lack of correlations among water quality and plant assemblages may be explained by the relatively low concentrations of parameters investigated, which likely results from water quality improvement by conservation lands prior to flow into a wetland.

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APPENDIX A

SUPPLEMENTAL TABLES

Table 2 Mean and maximum water quality variables

Water Quality Variable	March		May		Mississippi Fish and Wildlife criteria (MDEQ)
	Mean	**Max**	**Mean**	**Max**	
pH	7.168	7.990	7.399	8.230	6-9
Conductivity(µS/cm)	39.473	119.750	69.776	243.800	1000
ORP (mV)	358.241	433.000	337.604	548.000	No criteria
Turbidity (NTU)	121.028	560.000	120.737	624.000	No criteria
Ammonia (mg/L)	0.089	0.356	0.117	0.863	No criteria
Phosphate(mg/L)	0.104	0.324	0.166	1.900	No criteria
Nitrate (mg/L)	0.079	0.263	0.075	1.200	No criteria
TSS (g)	0.003	0.029	0.001	0.014	750 mg/L

The US Environmental protection agency and Mississippi Department have not set criteria for nutrient levels in waterways that are not used for drinking water, but Wetzel (2001) lists maximum ranges for mesotrophic lakes as 1387 mg/m^3 for total nitrogen and 95.6 mg/m^3 for total phosphorus.

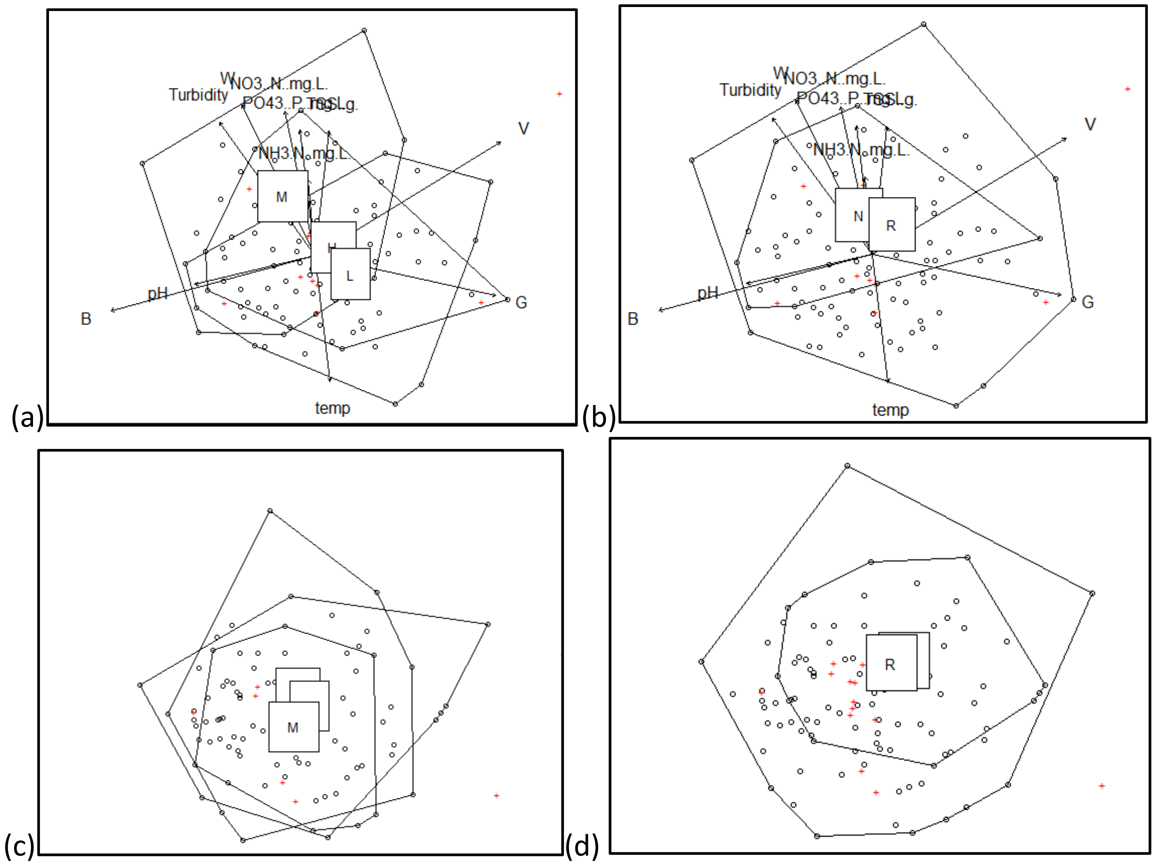

Figure 8 Ordinations with type and load polygons

(a) March ordination of form with nitrogen load category polygons overlaid
(b) March ordination of form with wetland type polygons overlaid
(c) May ordination of form with nitrogen load category polygons overlaid
(d) May ordination of form with wetland type polygons overlaid

Table 3 March species

March species	Growth form	Sites Present
Ambrosia artemisiifolia	Broadleaf	Duckbriar
Ammannia auriculata	Broadleaf	Burrell South,Caney Lake, Cessions Towhead, County Line, Donahoe, Duckbriar
Apocynum cannabinum	Broadleaf	Clear Lake
Baccharis halimifolia	Woody	Donahoe
Boehmeria cylindrica	Broadleaf	Long Lake Reference
Brunnichia ovata	Vine	Mussel Lake, Yellow, Twin Lakes Lakes, Tallahatchie, Sledge, Parchman, Muddy Bayou, Moon Lake, Lurand, Howden Brake, Duckbriar, County Line, Coldwater, Clear Lake, Caney Lake, Burrell Oxbow
Campsis radicans	Vine	Coldwater, County Line, Parchman, Sledge, Tallahatchie, Yellow
Cardiospermum halicacabum	Broadleaf	Cessions Towhead, Duckbriar, Long Lake, Mound Bayou, Tallahatchie
Carex triangularis	Graminoid	Clear Lake
Carya illinoinensis	Woody	Clear Lake
Celtis laevigata	Woody	Clear Lake, Porters
Cephalanthus occidentalis	Woody	Mussel Lake, Long Lake Reference, Howden Brake, Burrell Oxbow
Chamaesyce maculata	Broadleaf	Twin Lakes
Commelina communis	Broadleaf	Twin Lakes
Commelina virginica	Broadleaf	Howden Brake
Coreopsis tinctoria	Broadleaf	Sledge, Duckbriar
Cynodon dactylon	Graminoid	Caney Lake
Cyperus erythrorhizos	Graminoid	Yellow
Cyperus iria	Graminoid	Sledge, Twin Lakes, Yellow
Cyperus odoratus	Graminoid	Mound Bayou, Yellow
Cyperus pseudovegetus	Graminoid	Campbell, Sledge
Cyperus strigosus	Graminoid	Yellow

Table 3 (continued)

Cyperus virens	Graminoid	Clear Lake, Donahoe, Long Lake, Lurand, Mound Bayou, Yellow
Desmanthus illinoensis	Broadleaf	Clear Lake, Parchman
Dichanthelium spretum	Graminoid	Sledge, Tallahatchie
Digitaria sanguinalis	Graminoid	Long Lake
Diospyros virginiana	Woody	Burrell Oxbow, Tallahatchie, Clear Lake
Echinochloa colona	Graminoid	Moon Lake, Duckbriar, Burrell South
Echinochloa crus-galli	Graminoid	Clear Lake, County Line, Moon Lake, Twin Lakes
Echinochloa frumentacea	Graminoid	Mound Bayou, Muddy Bayou
Echinochloa muricata	Graminoid	Caney Lake, Duckbriar
Echinochloa walteri	Graminoid	Tallahatchie
Echinodorus cordifolius	Broadleaf	Campbell, Caney Lake, Howden Brake, Long Lake, Moon Lake, Mound Bayou
Eclipta prostrata	Broadleaf	Burrell South, Caney Lake, Cessions Towhead, Howden Brake, Long Lake, Long Lake Reference, Moon Lake, Mound Bayou
Eleocharis obtusa	Graminoid	Burrell South, Campbell, Caney Lake, Cessions Towhead, County Line, Donahoe, Duckbriar, Lurand, Moon Lake, Sledge, Yellow
Eleocharis quadrangulata	Graminoid	Mound Bayou, Campbell
Eupatorium perfoliatum	Broadleaf	Muddy Bayou
Eupatorium serotinum	Broadleaf	Caney Lake
Fraxinus pensylvanica	Woody	Sledge, Campbell
Heliotropium indicum	Broadleaf	Muddy Bayou
Heteranthera limosa	Broadleaf	Burrell South, Donahoe
Hibiscus moscheutos	Broadleaf	County Line, Long Lake Reference, Tallahatchie
Hydrolea quadrivalvis	Broadleaf	Burrell Oxbow, Caney Lake, Clear Lake, Coldwater, Donahoe, Long Lake
Ipomoea wrightii	Vine	Coldwater, County Line, Long Lake, Long Lake Reference, Yellow
Iva annua	Broadleaf	Caney Lake, Cessions Towhead, Clear Lake, County Line, Long Lake, Parchman, Sledge, Twin Lakes, Yellow
Juncus acuminatus	Graminoid	Tallahatchie
Juncus diffusissimus	Graminoid	Burrell South

Table 3 (continued)

Juncus effusus	Graminoid	Cessions Towhead, Sledge, Tallahatchie, Twin Lakes, Yellow
Juncus nodatus	Graminoid	Donahoe, Lurand
Leptochloa fusca	Graminoid	County Line, Caney Lake, Twin Lakes
Lindernia dubia	Broadleaf	Donahoe, Long Lake
Ludwigia alternifolia	Broadleaf	Sledge, Burrell South, Yellow
Ludwigia decurrens	Broadleaf	Donahoe, Caney Lake
Ludwigia glandulosa	Broadleaf	Moon Lake, Lurand, Campbell, Burrell South
Ludwigia linearis	Broadleaf	Burrell South, Duckbriar
Ludwigia palustris	Broadleaf	Burrell South, Coldwater, Donahoe, Duckbriar, Mound Bayou, Yellow, County Line
Ludwigia peploides	Broadleaf	Mussel Lake, Long Lake, Coldwater, Campbell, Burrell South
Mikania scandens	Vine	Howden Brake, Long Lake Reference
Najas guadalupensis	Broadleaf	Porters
Nelumbo lutea	Broadleaf	Mound Bayou
Panicum anceps	Graminoid	Lurand
Panicum dichotomiflorum	Graminoid	Caney Lake, Cessions Towhead, Moon Lake, Sledge, Yellow
Panicum hians	Graminoid	Clear Lake, Lurand
Paspalum laeve	Graminoid	Twin Lakes, Mound Bayou, Duckbriar, Yellow
Phyla lanceolata	Broadleaf	Moon Lake
Physalis angulata	Broadleaf	Muddy Bayou
Physalis virginiana	Broadleaf	Muddy Bayou
Polygonum amphibium	Broadleaf	Burrell Oxbow
Polygonum hydropiperoides	Broadleaf	Burrell Oxbow, Cessions Towhead, Clear Lake, Coldwater, Donahoe, Long Lake Reference, Mound Bayou, Porters, Tallahatchie, Yellow
Polygonum lapathifolium	Broadleaf	Long Lake Reference, Yellow
Polygonum pensylvanicum	Broadleaf	Long Lake, Moon Lake, Muddy Bayou
Populus deltoides	Woody	Donahoe
Potamogeton diversifolius	Broadleaf	Lurand
Pyrrhopappus carolinianus	Broadleaf	Moon Lake, Muddy Bayou

Table 3 (continued)

Quercus nigra	Woody	Sledge
Quercus texana	Woody	Coldwater
Rhynchospora corniculata	Graminoid	Burrell Oxbow, Burrell South, Campbell, Caney Lake, Cessions Towhead, County Line, Donahoe, Long Lake, Mound Bayou, Tallahatchie
Robinia pseudoacacia	Woody	Porters
Rubus argutus	Vine	Tallahatchie
Rubus trivialis	Vine	Sledge
Rumex crispus	Broadleaf	Duckbriar, Sledge
Saccharum giganteum	Graminoid	Sledge, Tallahatchie
Sagittaria lancifolia	Broadleaf	Campbell, Long Lake, Lurand, Moon Lake
Sagittaria latifolia	Broadleaf	Muddy Bayou
Salix nigra	Woody	Tallahatchie, Porters, Moon Lake, Long Lake Reference, Donahoe, Cessions Towhead, Burrell Oxbow
Saururus cernuus	Broadleaf	Burrell Oxbow, Long Lake Reference, Muddy Bayou
Senna obtusifolia	Broadleaf	Twin Lakes
Sesbania herbacea	Broadleaf	Yellow, Muddy Bayou, Moon Lake, Long Lake, Howden Brake, Duckbriar, County Line, Cessions Towhead, Burrell South
Setaria pumila	Graminoid	Clear Lake
Sida spinosa	Broadleaf	Duckbriar, Long Lake, Moon Lake, Twin Lakes
Solanum carolinense	Broadleaf	Duckbriar
Sorghum bicolor	Graminoid	Caney Lake
Sorghum halepense	Graminoid	Long Lake
Styrax americanus	Woody	Burrell Oxbow
Taxodium distichum	Woody	Howden Brake, Mussel Lake
Toxicodendron radicans	Vine	Clear Lake, Mussel Lake
Typha latifolia	Graminoid	Donahoe, Howden Brake, Long Lake Reference, Lurand, Muddy Bayou, Twin Lakes
Ulmus alata	Woody	Burrell Oxbow
Ulmus americana	Woody	Coldwater
Verbena brasiliensis	Broadleaf	Sledge, Moon Lake
Xanthium strumarium	Broadleaf	Coldwater, Duckbriar
Zizaniopsis miliacea	Graminoid	Porters

List of species identified in March, the form they were assigned, and sites where they were found.

Table 4 May species

May species	Growth form	Sites present
Acer saccharum	Woody	Burrell Oxbow
Apocynum cannabinum	Broadleaf	Lurand, Parchman
Baccharis halimifolia	Broadleaf	Donahoe
Boltonia asteroides	Broadleaf	Yalobusha
Brunnichia ovata	Vine	Burrell North, Burrell South, Clear Lake, Duckbriar, Long Lake, Lurand, Moon Lake, Muddy Bayou, Parchman, Tallahatchie
Campsis radicans	Vine	Burrell North, Burrell Oxbow, Burrell South, Duckbriar, Howden Brake, Lurand, Parchman, Sledge, Tallahatchie, Yalobusha, Yellow
Cardiospermum halicacabum	Vine	Cessions Towhead, Long Lake, Yalobusha
Carex aureolensis	Graminoid	Burrell North, Cessions Towhead
Carex crus-corvi	Graminoid	Cessions Towhead, Yellow
Carex tribuloides	Graminoid	Cessions Towhead
Carex vulpinoidea	Graminoid	Cessions Towhead
Carya illinoinensis	Graminoid	Clear Lake, Howden Brake
Celtis laevigata	Graminoid	Clear Lake, Howden Brake, Parchman
Cephalanthus occidentalis	Woody	Parchman, Mussel Lake, Howden Brake, Cessions Towhead, Burrell South, Burrell Oxbow
Cyperus pseudovegetus	Graminoid	Donahoe, Yalobusha
Cyperus virens	Graminoid	Donahoe
Diodia virginiana	Broadleaf	Burrell North, Parchman, Tallahatchie, Yalobusha
Diospyros virginiana	Woody	Cessions Towhead
Echinodorus cordifolius	Broadleaf	Long Lake, Moon Lake, Muddy Bayou, Tallahatchie, Yalobusha
Eclipta prostrata	Broadleaf	Long Lake
Eleocharis obtusa	Graminoid	Campbell, Cessions Towhead, Duckbriar, Moon Lake, Tallahatchie
Eleocharis quadrangulata	Graminoid	Lurand
Eupatorium serotinum	Broadleaf	Donahoe, Moon Lake

Table 4 (continued)

Fraxinus pennsylvanica	Woody	Campbell, Lurand, Parchman
Gleditsia aquatica	Woody	Burrell Oxbow, Parchman
Hibiscus moscheutos	Broadleaf	Donahoe
Hydrolea quadrivalvis	Broadleaf	Burrell Oxbow, Clear Lake, Donahoe, Porters, Sledge, Tallahatchie, Yalobusha
Ipomoea wrightii	Vine	Long Lake
Iva annua	Broadleaf	Duckbriar, Burrell South, Burrell North
Juncus acuminatus	Graminoid	Burrell North, Duckbriar
Juncus diffusissimus	Graminoid	Burrell North
Juncus effusus	Graminoid	Cessions Towhead, Tallahatchie, Yellow
Juncus nodatus	Graminoid	Yellow
Juncus tenuis	Graminoid	Parchman
Lindernia anagallidea	Broadleaf	Duckbriar
Ludwigia decurrens	Broadleaf	Buzzard Bayou, Burrell North, Duckbriar, Donahoe, Muddy Bayou, Yalobusha
Ludwigia palustris	Broadleaf	Campbell, Yalobusha
Ludwigia peploides	Broadleaf	Burrell North, Burrell South, Campbell, Cessions Towhead, Donahoe, Long Lake, Moon Lake, Mussel Lake, Porters, Yalobusha, Yellow
Ludwigia repens	Broadleaf	Campbell, Yellow
Nelumbo lutea	Broadleaf	Cessions Towhead Reference
Populus deltoides	Woody	Donahoe
Quercus phellos	Woody	Burrell Oxbow
Ranunculus pusillus	Broadleaf	Duckbriar, Muddy Bayou
Rhynchospora corniculata	Graminoid	Donahoe
Rumex crispus	Broadleaf	Duckbriar
Saccharum giganteum	Graminoid	Tallahatchie
Sagittaria lancifolia	Broadleaf	Long Lake, Lurand, Moon Lake
Sagittaria latifolia	Broadleaf	Lurand, Muddy Bayou

Table 4 (continued)

Salix nigra	Woody	Burrell North, Cessions Towhead, Donahoe, Moon Lake, Muddy Bayou, Porters, Yellow
Saururus cernuus	Broadleaf	Burrell Oxbow
Sesbania herbacea	Broadleaf	Buzzard Bayou, Moon Lake
Sida spinosa	Broadleaf	Duckbriar, Long Lake, Yalobusha
Taxodium distichum	Woody	Clear Lake, Mussel Lake
Toxicodendron radicans	Vine	Clear Lake, Howden Brake, Lurand
Typha latifolia	Graminoid	Campbell, Donahoe, Howden Brake, Lurand
Ulmus americana	Woody	Burrell Oxbow
Xanthium strumarium	Broadleaf	Buzzard Bayou, Duckbriar, Long Lake
Zizaniopsis miliacea	Graminoid	Porters

List of species identified in May, the form they were assigned, and sites where they were found.

Table 5 Location of wetlands sampled

Wetland	**GPS**	
	Latitude	**Longitude**
Burrell North	34.368	-90.22657
Burrell Oxbow	34.354233	-90.23172
Burrell South	34.355833	-90.23065
Buzzard Bayou	33.998900	-90.251800
Campbell	34.189783	-90.40048
Caney Lake	33.7981	-90.12043
Cessions Towhead	34.082067	-90.86043
Cessions Towhead Reference	34.1875	-90.5803
Clear Lake	34.153317	-90.73852
Coldwater	34.362083	-90.35995
County Line	34.339617	-90.40533
Donahoe	33.575083	-90.63038
Duck Briar	33.930683	-90.6173
Howden Brake	34.059717	-90.71265
Long Lake	33.860217	-90.53053
Long Lake Reference	33.851983	-90.54102
Lurand	34.1509	-90.51828
Moon Lake	34.041217	-90.81383
Mound Bayou	33.876617	-90.62223
Muddy Bayou	34.064567	-90.40538
Mussell Lake	34.394583	-90.36608
Parchman	33.892467	-90.47557
Porters	33.561733	-90.71895
Sledge	34.42425	-90.21008
Tallahatchie	33.782067	-90.1358
Twin Lakes	33.7018	-90.13917
Yalobusha	33.726117	-90.136567
Yellow	34.464783	-90.23038