THE USE OF SOIL PARAMETERS AS INDICATORS OF QUALITY IN
FORESTED-DEPRESSIONAL WETLANDS

A Thesis

Presented in Partial Fulfillment of the Requirements for
the Degree Master in Sciences in the
Graduate School of The Ohio State University

By

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2007

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ABSTRACT

Current methods of wetland assessment rely strongly on the use of ecological indicators such as vegetation, amphibians and the presence or absence of landscape stressors. However, many lack an in-depth analysis of physical, chemical, and biological soil parameters. The objective of this research was to determine if soil parameters (aggregate stability, bulk density, organic matter, total carbon and nitrogen, microbial biomass C, and enzyme activity) could be used as indicators of condition in forested depressional wetlands. Because soil is the primary foundation for several biogeochemical functions that occur in wetlands the hypothesis was that soil parameters would be sensitive to disturbance. Three high and three low quality wetlands located in central Ohio were sampled four times throughout the study; quality was determined using the Ohio Rapid Assessment Method. Soil cores were taken at a depth of 10-cm in eight locations throughout each wetland. The soil biological, chemical and physical parameters measured did not follow similar trends in terms of their expected response to ecosystem condition. The percentage of the 2-8 mm size fraction of water stable aggregates and β -glucosidase and arylsulfatase enzyme activity were higher in the low quality wetlands. In contrast, organic matter, C, N, and S and microbial biomass were higher in the high quality wetlands. Bulk density was greater in the high quality wetlands. However, while positive and negative trends in the data were identified, very few of the soil parameters were able

to statistically distinguish between wetlands of high and low quality as defined prior to the study. The relatively high level of spatial variability and the unpredictable and fluctuating water level in wetlands suggest that intensive measurement of soil parameters may be most applicable to monitor the success or development of restored and created wetlands.

Dedicated to Dr. Dan Spetie
for saving my “natural wetlands”

And

Niki and Jessen Book
for their friendship and support

ACKNOWLEDGMENTS

I would like to thank my advisor, Virginie Bouchard, for her continuous support through out this study; her guidance (and patience with my very high learning curve in the laboratory) was crucial to my success as a graduate student. My committee, Drs. Richard Dick and Siobhan Fennessy also contributed greatly to my success and provided valuable input throughout the entire project.

The field and laboratory work for this project could not have been completed without the help of my colleagues: Becky Fauver, Gwen Dubelko, Nickla Louisy, Chad Kettlewell, Erin Rothman, Dan Gillenwater, Jarod Duquette, Evelyn Anamaet, Amanda Nahlik, Amy Barrett, Nicola Lorenz, and Katie Hossler. I would like to extend a special thanks to both Kyle Herrman who braved the elements to collect soil samples under the ice and provided much needed emotional and technical support in the laboratory and Hunter Anderson for his statistical assistance. Li Li Wu from Ohio State's statistical consulting service also provided assistance with data analysis.

The wetlands for this project were identified with the assistance of John Mack and Mick Micacchion of the Ohio Environmental Protection Agency (EPA); they provided

data that were previously collected in the wetlands chosen for this project. Sampling would not have been possible without site access and the support of local landowners, the Ohio EPA, The Ohio Department of Natural Resources (ODNR), Division of Natural Areas and Preserves and the Miami County Park District. Funding for this project was provided by the Environmental Studies Graduate Program (ESGP) and The School of the Environment and Natural Resources (SENR) at The Ohio State University.

I would like to also thank the employees, Phil Bertrand, and the other “regulars” at Staufs in Grandview, where I spent many of my graduate school evenings. Finally, thanks to my family, Don, Cindy, Emily, and Susie Rokosch and extended family, Dick and Donna Brust, Bill and Angie Kelly, Jessen and Niki Book, Jim and Marcie Steen, Allyson and Peter Casares, Amy Jacobs, Ian and Katie Schwabb, and Sarah and Brett Holcomb for their love and support throughout my entire academic career. Despite the obstacles that I have faced, they have always encouraged me and believed in my abilities as a scientist. Siobhan, the master plan continues!

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TABLE OF CONTENTS

	Page
Abstract	ii
Dedication	iv
Acknowledgments.....	v
Vita.....	vii
List of Tables	x
List of Figures	xii
 CHAPTERS:	
1. INTRODUCTION	1
2. METHODS	5
2.1 Site description.....	5
2.2 Ohio Rapid Assessment	6
2.3 Experimental Design and Sampling Procedures	9
2.4 Biological Parameters	10
2.5 Chemical Parameters	12
2.6 Physical Parameters	12
2.7 Statistical Analysis.....	13
3. RESULTS	16
3.1 Biological Parameters	16
3.2 Chemical Parameters	21
3.3 Physical Parameters	23
3.4 Relationship between Soil Parameters.....	26
4. DISCUSSION	30
4.1 Indicator Selection	30
4.1.2 Biological Parameters	31
4.1.3 Chemical Parameters	33
4.1.4 Physical Parameters	34
4.2 Relationship Between Soil Parameters	36
4.3 <i>A priori</i> wetland classification	37
4.4 Guidance for Future Research	38

Appendices.....	40
A. Site Pictures.....	41
B. Detailed Laboratory Protocol	47
C. Raw Data	59
Bibliography	75

LIST OF TABLES

Table	Page
1. Site characteristics for the six forested depressional wetlands studied including: size, location, vegetation community, Hydrogeomorphic (HGM) Classification, water source, soil series, Ohio Rapid Assessment score, and quality class.....	8
2. Betaglucosidase enzyme activity in each wetland for all four sampling seasons (July, August, November, and May).....	19
3. Arylsulfatase enzyme activity in each wetland for all four sampling seasons (July, August, November, and May).....	20
4. Microbial biomass in each wetland for three sampling periods (August, November, and May)	20
5. Summary of mean soil chemical parameters in each wetland	23
6. Summary of mean soil physical parameters in each wetland	26
7. Pearson's correlation (r and significance of r) of soil physical, chemical, and biological parameters measured in the study.	28
8. Arylsulfatase enzyme activity for July in high and low quality wetlands for each sampling station (n=8).	60
9. Betaglucosidase enzyme activity for July in high and low quality wetlands for each sampling station (n=8).	61
10. Arylsulfatase enzyme activity for August in high and low quality wetlands for each sampling station (n=8).	62
11. Betaglucosidase enzyme activity for August in high and low quality wetlands for each sampling station (n=8).	63
12. Arylsulfatase enzyme activity for November in high and low quality wetlands for each sampling station (n=8).	64

13.	Betaglucosidase enzyme activity for November in high and low quality wetlands for each sampling station (n=8).	65
14.	Arylsulfatase enzyme activity for May in high and low quality wetlands for each sampling station (n=8).	66
15.	Betaglucosidase enzyme activity for May in high and low quality wetlands for each sampling station (n=8).	67
16.	Water stable aggregate distribution for high quality wetlands (n=3).	68
17.	Water stable aggregate distribution for low quality wetlands (n=3).	69
18.	Bulk density (g/cm ³) for high and low quality wetlands for each sampling stations (n=8).....	70
19.	Soil chemical carbon, nitrogen, phosphorus, and sulfur in high quality wetlands for each sampling station (n=8)	71
20.	Soil chemical carbon, nitrogen, phosphorus, and sulfur in low quality wetlands for each sampling station (n=8)	72
21.	Soil moisture data in high quality wetlands for each sampling station (n=8).....	73
22.	Soil moisture data in low quality wetlands for each sampling station (n=8).....	73

LIST OF FIGURES

Figure	Page
1. Location of wetlands throughout central Ohio, USA	7
2. Comparison of soil biological parameters between high and low quality wetlands (n=3 for each category).....	18
3. Comparison of betaglucosidase and arylsulfatase enzyme activity across four sampling seasons for high and low quality wetlands (n=3 for each category)	19
4. Comparison of soil chemical parameters between high and low quality wetlands (n=3 for each category).....	22
5. Comparison of soil physical parameters between high and low quality wetlands (n=3 for each category).....	25
6. Comparison of soil moisture content across four sampling periods in high and low quality wetlands (n=3 for each category)	25
7. Principle components analysis (PCA) using soil moisture and soil biological (β -glucosidase, arylsulfatase), chemical (OM, pH, C, N, S, P) and physical (bulk density, water stable aggregates) parameters.....	29
8. Lawrence Woods (high quality wetland) in the spring sampling period	42
9. Gahanna Woods (high quality wetland) in the summer sampling period.....	43
10. Johnson Road (low quality wetland) in the spring sampling period.....	44
11. Graham Road (low quality wetland) in the summer sampling period	45
12. Orange Road (low quality wetland) in the summer sampling period	46

CHAPTER 1

INTRODUCTION

Wetlands support several ecological functions including nutrient cycling and storage, water retention, and habitat for amphibians and waterfowl (Mitsch and Gosselink, 2000; Faulkner, 2004; Ehrenfeld, 2004). These functions maintain the integrity of the surrounding landscape and provide services valued by society (e.g., pollutant transformation, flood control, and recreation) (Costanza et al., 1997; Woodward et al., 2001). However, wetlands are among the most degraded ecosystems on earth (Spencer et al., 1998) with losses estimated at more than 90% in many parts of the world (Dahl, 1990; Mitsch and Gosselink, 2000). The pressure of human activities on such valued ecosystems has driven the development of several assessment methods that evaluate the impact of human disturbance on wetland condition (Kussler and Nearing, 1998; Bartoldus, 1999).

A high quality wetland is one that is able to support a diverse community of organisms and perform functions comparable to that of a relatively unimpaired site (Spencer et al., 1998; Fennessy et al., 2004). To standardize methods of wetland

assessment and meet the requirements under section 305(b) of the Clean Water Act, which requires states to report on the condition of its surface waters, the United States Environmental Protection Agency (US EPA) has proposed a multilevel assessment and monitoring approach (Fennessy et al., 2004; Brooks et al., 2006). Level 1 consists of the collection and summary of land-use data using Geographical Information Systems (GIS) software or other forms of remote data sensing, level 2 requires the use of rapid field methods, and level 3 requires intensive collection of biological and physio-chemical data (Fennessy et al., 2004; Brooks et al., 2004; Mack, 2006). Common to each level of assessment are the use of ecological indicators, metrics that estimate the condition and magnitude of stress impacting the ecosystem in question (Breckinridge, 1995), and indirectly reflect specific wetland functions (Guntenspergen et al., 2002).

Examples of level 1 assessment include The Landscape Development Index (LDI) (Brown and Vivas, 2005; Mack, 2006). A remote landscape analysis is performed and land use indicators (e.g., road density and commercial development and amount of open or recreational space) are used to predict wetland condition. Examples of level 2 assessment include the Ohio Rapid Assessment Method (Mack, 2001a), the Penn State Stressor Check List (Brooks et al., 2002), and the Massachusetts CZM Rapid Assessment Method (Hicks et al., 1998). These methods require the user to identify indicators within the wetland, such as hydrological modifications (e.g., ditches and dikes), vegetation alteration (e.g., presence of invasive species and logging activities), sedimentation, and eutrophication to evaluate wetland condition. Examples of level 3 wetland assessment include The Index of Biological Integrity (IBI) and the Hydrogeomorphic (HGM) approach to wetland assessment (Brinson, 1993). The IBI, originally applied to river and

stream ecosystems to measure biological condition (Karr, 1981), has been adapted to wetlands where multiple indicators have been used including vegetation (Gernes and Helgen, 1999; Mack 2001(b), 2004; Fennessy et al., 2001), invertebrates (Helgen, 2000), and amphibians (Micacchion, 2002). The HGM approach evaluates the functional capacity of the wetland and uses indicators such as plant species composition, tree density, and the presence of hydrological disturbances. While these methods and the majority of other wetland assessment methods are comprised of a suite of variables describing multiple wetland components (Bartoldus, 1999; Innis et al., 2000), they lack an in-depth analysis of soil parameters.

When included in wetland assessment, soil parameters often consist of relatively simple field measurements such as color and texture, the depth of the organic horizon, and the presence or absence of sedimentation processes. In contrast, soil-based parameters are frequently used in terrestrial ecosystems as indicators of soil quality because they are known to reflect land use disturbance (Bandick and Dick, 1999; Carpenter-Boggs et al., 2003; Balota et al., 2003; Sicardi et al., 2004; Knight and Dick, 2004; Bending et al., 2004) and ecosystem recovery (Kuperman et al., 1997; Wick et al., 1998; Izquierdo et al., 2005; Acosta-Martinez et al., 2003; Villiar et al., 2004). Soil quality is a broad concept that describes the soils' ability to sustain biological productivity and maintain desired functions including net primary productivity, nutrient recycling and retention, and the accumulation of organic matter (Doran and Safley, 1997). Because soil is the primary medium for all biogeochemical processes that occur in wetlands, a comprehensive analysis of soil parameters should provide an indication of the magnitude of human disturbance within these ecosystems. At the same time, the

measurement of soil parameters should also validate existing wetland assessment methods. The objective of my study was to determine which soil parameters could be used as indicators of wetland condition in depression forested wetlands.

To achieve my objective I measured a combination of biological (enzyme activity and microbial biomass carbon), chemical (organic matter, pH, carbon, nitrogen, phosphorus, and sulfur), and physical (aggregate stability and bulk density) parameters. Multiple parameters were used because it is well accepted that a single parameter cannot adequately describe soil quality due to the multiple biological and biochemical transformations that occur in the soil (Scholter et al., 2003). Bulk density, soil moisture, organic matter, total carbon and nitrogen, and microbial biomass carbon were included in a minimum dataset proposed by Doran and Parkin (1994); these indicators relate to ecosystem functions such as carbon and nitrogen cycling. The hypothesis of my study was that soil parameters of high and low quality wetlands would be significantly different. I predicted that measurements of the wetlands soil composition would be sensitive to the degree of human disturbance affecting the wetland.

CHAPTER 2

MATERIALS AND METHODS

2.1 Site Description

Six forested wetlands located in Central Ohio (USA) were sampled in this study (Figure 1, Appendix A). Ecological condition was determined prior to the study using the Ohio Rapid Assessment method (ORAM) (v5.0) (Mack, 2001a); 3 low quality (Johnson Road, Graham Road, Orange Road) and 3 high quality (Bigwoods, Lawrence Woods, and Gahanna Woods) sites were selected. Wetlands were chosen based on common characteristics including size, vegetation community, soil class and hydrogeomorphic (HGM) classification (Cowardin et al., 1979) (Table 1). The forest community was dominated by *Acer rubrum* L., *Quercus* sp., and *Salix* sp., with very sparse understory vegetation. Lawrence Woods and Gahanna Woods had large shrub communities, composed primarily of *Cephalanthus occidentalis* L. Sampling plots were only established in the forested community to avoid confounding effects with different vegetation communities (Prenger and Reddy, 1999).

2.2 Ohio Rapid Assessment Method (ORAM)

The ORAM evaluates the biological quality of wetlands and was developed to categorize wetlands for regulatory and conditional assessment purposes. Category 1 wetlands (low quality) support minimal wildlife habitat, hydrological, and recreational functions and are often dominated by invasive species; category 2 wetlands (moderate quality) support moderate wildlife habitat, hydrological, and recreational function, and often have a high potential for restoration; category 3 wetlands (high quality) have superior habitat (i.e., they often support threatened and/or endangered species), hydrological, and recreational functions and are absent of invasive or non-native species (Mack, 2001a).

In the ORAM assessment protocol, 6 principle metrics are used to evaluate the wetland ecosystem: size, buffer, habitat, hydrology, vegetation and the presence of special wetland communities (e.g., mature forested wetland). Each metric is scored by evaluating a combination of related sub-indicators (see Mack, 2001a for a complete description); the principle metrics are weighted into a single quantitative score from 0-100, with 100 being the highest quality wetland of a particular subclass (i.e., depression or riverine). This score is used to categorize wetlands into one of the three quality classes.

The ORAM v4.0 was performed at each of the wetlands during the first sampling period (July 2005). The final score for each wetland was compared to previous assessments conducted by the Wetland Ecology Group at the Ohio Environmental Protection Agency. If scores were made, the rationale was noted in the new ORAM datasheet.

Figure 1: Location of wetlands throughout central Ohio, USA; 3 wetlands were high Quality (Bigwoods, Lawrence Woods, and Gahanna Woods) and 3 wetlands were low quality (Johnson Road, Graham Road, Orange Road). Wetland quality was determined using the Ohio Rapid Assessment Method v5.0 (ORAM).

Site	Size (ha)	Latitude	Longitude	Vegetation Community	HGM Classification (HGM)	Water Source	Soil Series	ORAM v5.0	Quality	n
Bigwoods	0.99	40.12889	-84.14972	Forested (<i>oak, maple ash</i>)	Depression	Surface	Crosby silt loam	68.5	High	8
Gahanna Woods	1.73	40.01157	-82.83795	Forested /Shrub (<i>oak, maple, ash</i>)	Depression	Surface	Carlisle muck	67.5	High	8
Lawrence Woods	3.07	40.56610	-83.62306	Forested/Shrub (<i>oak, maple, bultonbush</i>)	Depression	Surface	Pewamo silty clay loam	73	High	8
Johnson Road	0.48	39.89250	-83.18449	Forested (<i>maple, cottonwood, willow</i>)	Depression	Surface	Kokomo silty loam	21	Low	8
Graham Road	0.16	40.04389	-82.76222	Forested (<i>maple</i>)	Depression	Surface	Benninston silt loam	26	Low	8
Orange Road	0.63	40.18106	-83.00329	Forested (<i>oak, maple, ash</i>)	Depression	Surface	Pewamo silty clay loam	36	Low	8

Table 1: Six wetlands were selected for this study. The relative size, location (latitude and longitude), vegetation community, Hydrogeomorphic (HGM) Classification, primary water source, soil series, ORAM score, and quality class are indicated in the table, along with the number of sampling plots (n) established in each site. Data for each site were obtained by previous research conducted in 1999 and 2000 by the Ohio Environmental Protection Agency. The ORAM score for Orange Road was changed because of intensive development activities in the buffer area (e.g., elementary school and housing development) that were not present at the time of original assessment.

2.3 Experimental Design and Sampling Procedures

Each wetland was delineated by locating the mean-high water level and by other physical evidence including hydric soils, stained leaves and tree high water marks. Soil was collected four times throughout the duration of the study for biological analysis (June 2005, August 2005, November, 2005, and May 2006) and once to measure physical and chemical parameters (November, 2005). Soil samples were collected from 8 randomly located plots (1 m²) within each wetland; plots were marked with a polyvinyl chloride (PVC) pipe to ensure consistent sampling. Large woody and leaf debris were removed from the soil surface prior to coring and hydrological characteristics of each plot (i.e., water depth) were recorded. At each plot, 4 soil cores were taken to a depth of 10 cm using a 6 cm diameter stainless steel soil corer. Samples were homogenized and combined into one composite sample per plot; they were stored in sterile plastic bags until analysis. For physical analysis, the soil was air-dried for approximately 2 weeks before processed. For chemical analysis, the soil was sieved through a 2 mm mesh, air-dried, and finely ground using a mortar and pestle. For biological analysis, samples were sieved through a 2 mm mesh and stored at 4°C until analysis.

2.4 Biological Parameters

Prior to biological analysis, soil moisture for each sampling plot (n=8) within the wetland was determined. A subsample of soil was dried in the oven at 105 °C overnight; moisture was calculated by subtracting the dry weight (g) from the initial wet or field moist weight (g). This value (water loss) was divided by the dry weight to determine water content for use in the enzyme and microbial biomass determinations. Soil moisture was reported as g water g⁻¹ dry soil.

β-glucosidase and arylsulfatase enzyme activity were estimated using a method based on the colorimetric determination of *p*-nitrophenol released after incubation under ideal conditions. For each plot (n=8), four assays were performed; three replicates and one control, to account for color not derived from the *p*-nitrophenol released by enzyme activity. The value for the control was subtracted from each replicate; the replicates were averaged to produce one estimate per plot.

β-glucosidase activity was determined by incubating approximately 1 gram of field-moist soil combined with 1 mL of substrate, *p*-Nitrophenol-β-glucopyranoside (PNG) solution, 4 mL of a modified universal buffer (pH 6.0), and 0.25 mL of toluene for 1 hour at 37°C (Eivazi and Tabatabai, 1988 *in* Tabatabai, 1994). Toluene was used to reduce microbial growth and inhibit enzyme synthesis during incubation. After incubation, 1 mL of 0.5 M CaCl₂ and 4 mL of 0.1 M Tris (hydroxymethyl) aminomethane (THAM) were added to stop the reaction. The soil solution was filtered through a Whatman no. 2v folded filter paper. The intensity of the yellow filtrate, representing the amount of *p*-nitrophenol released, was measured using a Spectronic 401 spectrophotometer at an absorbance of 420 nm. For the control, 1 mL of PNG solution

was added after incubation (i.e., immediately before filtration of the soil solution). Activity was reported in μ -mols of PNP per gram of dry weight soil per hour. Arylsulfatase activity was measured as above, but by using an acetate buffer (pH 5.8) and *p*-Nitrophenol-sulfate as the substrate; the reaction was stopped with 0.5 M NaOH (Tabatabai and Brenner, 1970 *in* Tabatabai, 1994).

Microbial biomass- carbon was estimated using a modified version of the chloroform fumigation extraction method by Vance et al. (1987). For each plot (n=8), 2 fumigated samples and 2 controls (unfumigated) were analyzed. Five grams of field-moist soil were placed into a 50 mL Erlenmeyer flask. One-half milliliter of chloroform was added to the fumigated replicates. These samples were placed into a vacuum desiccator with a beaker containing 300 mL of chloroform and several boiling chips (White and Reddy, 1999). The desiccator was evacuated and incubated for 24-hours in the dark; control samples were incubated under the same conditions minus the addition of chloroform. After incubation, the desiccator was evacuated to remove chloroform still present in the soil and flasks. The chloroform-treated replicates and the controls were immediately extracted with 20 mL of K_2SO_4 , agitated for 30 minutes on a Lab line Orbit Environ-Shaker at 165 RPM's, and filtered through Whatman no. 42 filter paper. The filtrate was collected and refrigerated at 4°C until analysis on the DC-190 Rosemount/Dohrman Total Organic Carbon Analyzer. Microbial biomass- carbon was calculated by subtracting the extractable total organic carbon (TOC) in the controls from the TOC in the chloroform-treated replicates. An extraction efficiency (k_{ec}) factor of 0.37 was used to convert TOC contents to microbial biomass- carbon; this value has been calibrated for organic soils (Sparling et al., 1997).

2.5 Chemical Parameters

Total carbon (C) and nitrogen (N) were analyzed by dry combustion using a NC 2100 Soil Analyzer (CE Elantech, Inc. Lakewood, NJ). A 1:4 soil:water slurry was created and pH was measured using a Corning 430 pH meter. Percent organic matter was determined through loss on ignition (Sutherland, 1998). Sulfur (S) and phosphorus (P) were measured using the EPA 3051 microwave digestion method (OARDC STAR Laboratories).

2.6 Physical Parameters

Water-stable aggregates (WSA fractions; 2 to 8 mm, 1 to 2 mm, and 0.25-1 mm) were determined for each plot using a Yoder (1936) wet-sieving machine. Air-dried samples were sieved through an 8 mm sieve and retained on a 3.35 mm sieve; approximately 25-35 g of the retained soil were placed on a stack of nested sieves (2000, 1000, and 250 μm) (Kemper and Chepil, 1965). Samples were capillary wetted for 30 minutes and then wet sieved for 30 minutes. The remaining fractions on each sieve were oven-dried at 105°C for 24 hours and weighed. To correct for coarse particles, approximately 40 mL of 0.2% sodium hexametaphosphate (HMP) was added to each fraction and shaken for 24 hours on a Lab line Orbit Environ-Shaker (Nimmo and Perkins, 2000). After dispersion with HMP, fractions were sieved and oven-dried at 105 °C for 24 hours and weighed.

The % WSA for each fraction (2 to 8 mm, 1 to 2 mm, and 0.25-1 mm) was calculated by subtracting the corrected coarse particle weight of each fraction from the uncorrected weight; this value was divided by the initial sample weight and multiplied by 100. Bulk density was determined using the core method (Blake, 1965). Cores (8 cm x 10 cm) constructed of PVC piping were extracted from each plot (n=8).

2.7 Statistical Analyses

To determine if statistical differences existed between soil moisture and soil biological parameters of high and low quality wetlands, a Repeated Measures ANOVA was performed (SAS statistical software). An attribute of a useful indicator is the lack of temporal variability. The Repeated Measure ANOVA was used to detect seasonal differences in soil parameters *within* wetland quality as well as the interaction between season and wetland quality. Significance was determined at a p-value ≤ 0.05 ; p-values ≤ 0.1 were also reported.

To determine if statistical differences existed between soil physical and chemical parameters of high and low quality wetlands, a One-Way Analysis of Variance (ANOVA) was performed (MiniTab 14). Significance was determined at a p-value ≤ 0.05 ; p-values ≤ 0.1 were also reported. To determine if there were statistical differences between all soil parameters measured (i.e., biological, chemical, and physical) and the individual wetland sites (regardless of condition class), a one-way ANOVA was performed (MiniTab 14).

A Tukey's pairwise comparison was run to determine which sites were statistically different. In this analysis, differences in biological parameters were analyzed separately for each season (July, August, November, and May). Significance was determined at a p-value ≤ 0.05 ; p-values ≤ 0.1 were also reported.

To determine if there were statistical differences in the *variability* of soil parameter measurements between high and low quality wetlands, an analysis of covariance was performed (SAS statistical software). Significance was determined at a p-value ≤ 0.05 ; p-values ≤ 0.1 were also reported.

A Pearson Product Moment Correlation was performed to determine the strength of the association between soil biological, chemical, and physical parameters (Sigma Stat statistical software); values used for β -glucosidase, arylsulfatase, microbial biomass and soil moisture were averaged across all seasons. A correlation coefficient (r) was calculated for each parameter combination; r near + 1 indicated that there was a strong positive relationship between the two parameters, r near -1 indicated that there was a strong negative relationship between the two parameters, r of 0 indicated that there was no statistical relationship between parameters. The significance of the relationship was indicated at $p \leq 0.01$, $p \leq 0.05$, and $p \leq 0.1$.

A principle components analysis (PCA) was performed to identify patterns in the soil parameters as they related to wetland quality (Pcord v.4).

The purpose of the PCA in this study was to condense the variability contained in the 12 original soil parameters measured into a smaller set of composite dimensions (i.e., principle components); the percent of variability explained by the PCA was indicated on each axis. The position of the sites on the newly defined gradient was used to determine the relationship between the individual wetlands and the different soil parameters.

CHAPTER 3

RESULTS

3.1 Biological Parameters

β -glucosidase enzyme activity was similar in high and low quality wetlands ($p < 0.352$, $df=1,3$) (Figure 2). There was a seasonal difference in β -glucosidase activity across the four sampling periods for the low quality sites ($p < 0.01$, $f=5.5$, $df=3,12$) (Figure 3). Differences in β -glucosidase activity were identified between the individual wetlands in the July, August, and November sampling periods ($p \leq 0.001$, $F=25.9$, $df=5,42$; $p < 0.004$, $F=4.04$, $df=5,42$; $p \leq 0.001$, $F=6.6$, $df=5,38$, respectively) (Table 2). In the May sampling period, β -glucosidase activity was similar across the individual wetlands ($p \leq 0.001$, $F=1.7$, $df=5,42$). Within site variability for β -glucosidase activity was greater in the low quality wetlands ($p < 0.04$, $F=2.19$)

Arylsulfatase activity was higher in the low quality wetlands ($p=0.02$, $F=6.2$, $df=1,16$) (Figure 2). A seasonal difference in the low quality sites was observed for arylsulfatase activity ($p \leq 0.001$, $F=8.8$, $df=3,12$) (Figure 3).

Differences in arylsulfatase activity were identified between the individual wetlands in each sampling period ($p \leq 0.001$, $F=6.3$, $df=5,42$; $p < 0.016$, $F=3.2$, $df=5,42$; $p \leq 0.001$, $F=5.05$, $df=5,32$; $p < 0.03$, $F=2.6$, $df=5,42$, July, August, November, and May, respectively) (Table 3). Within site variability for arylsulfatase activity was also greater in the low quality wetlands ($p < 0.054$, $F=1.94$)

Microbial biomass activity was higher in the high quality sites; the difference was marginally significant ($p < 0.08$, $F=3.7$, $df=1,16$) (Figure 2). Seasonal differences were not detected in microbial biomass ($p < 0.62$, $f=0.501$, $df=2, 12$). Microbial biomass was different between the individual wetlands in each sampling season ($p \leq 0.001$, $F=13.6$, $df=5,41$; $p \leq 0.001$, $F=6.9$, $df=5,38$; $p \leq 0.001$, $F=31.1$, $df=5,41$, August, November, May, respectively) (Table 4). Within site variability was similar for microbial biomass in high and low quality sites.

Figure 2: Comparison of soil biological parameters between high and low quality wetlands (n=3 for each category). Values in the figure represent the mean of all sampling seasons combined. Error bars represent the standard error. Statistical significance at p-value ≤ 0.1 and p-value ≤ 0.05 are reported, * and ** respectively. BG= β -glucosidase, AS= arylsulfatase, MB-C= Microbial Biomass Carbon.

Figure 3: Comparison of BG and AS enzyme activity across four sampling seasons for high and low quality wetlands. Values in the figure represent the mean of each sampling season ($n=3$ for each category). Error bars represent the standard error. Statistical significance at $p\text{-value} \leq 0.05$ is indicated by different letters; comparisons are only made within category class. BG= β -glucosidase, AS= arylsulfatase.

Site Name	July	Aug	Nov	May	MEAN
$\mu\text{g PNP g}^{-1} \text{h}^{-1}$					
Bigwoods	71 ± 44^a	310 ± 176^a	103 ± 31^a	94 ± 40^a	145 ± 111
Gahanna Woods	174 ± 97^b	242 ± 146^{ab}	266 ± 79^b	144 ± 88^a	207 ± 57
Lawrence Woods	98 ± 43^a	121 ± 49^b	90 ± 30^a	105 ± 45^a	272 ± 184
Johnson Road	262 ± 158^b	214 ± 90^{ab}	262 ± 160^b	77 ± 56^a	204 ± 88
Graham Road	519 ± 131^b	305 ± 46^a	134 ± 43^a	130 ± 24^a	104 ± 13
Orange Road	405 ± 56^b	304 ± 76^a	173 ± 21^a	114 ± 37^a	249 ± 131

Table 2: β -glucosidase enzyme activity in each wetland during 4 sampling seasons, July (2005), August (2005), November (2005), and May (2006). Values within a column followed by the same number are not significantly different at $p \leq 0.05$. Bigwoods, Gahanna Woods, and Lawrence Woods are high quality sites; Johnson Road, Graham Road and Orange Road are low quality sites.

Site Name	July	Aug	Nov	May	MEAN
	$\mu\text{g PNP g}^{-1}\text{h}^{-1}$				
Bigwoods	196 $\pm$ 144 ^a	300 $\pm$ 189 ^{ab}	77 $\pm$ 45 ^a	135 $\pm$ 73 ^a	177 $\pm$ 96
Gahanna Woods	326 $\pm$ 186 ^a	363 $\pm$ 214 ^{ab}	323 $\pm$ 168 ^b	280 $\pm$ 141 ^a	323 $\pm$ 34
Lawrence Woods	248 $\pm$ 119 ^{ab}	264 $\pm$ 112 ^a	198 $\pm$ 113 ^{ab}	126 $\pm$ 42 ^a	360 $\pm$ 263
Johnson Road	486 $\pm$ 329 ^{ab}	340 $\pm$ 227 ^{ab}	190 $\pm$ 151 ^{ab}	221 $\pm$ 211 ^a	309 $\pm$ 135
Graham Road	705 $\pm$ 257 ^b	423 $\pm$ 99 ^{ab}	152 $\pm$ 33 ^{ab}	158 $\pm$ 38 ^a	209 $\pm$ 62
Orange Road	395 $\pm$ 132 ^{ab}	567 $\pm$ 140 ^b	93 $\pm$ 34 ^a	270 $\pm$ 109 ^a	331 $\pm$ 200

Table 3: Arylsulfatase enzyme activity in each wetland during 4 sampling seasons, July (2005), August (2005), November (2005), and May (2006). Values within a column followed by the same number are not significantly different at $p \leq 0.05$. Bigwoods, Gahanna Woods, and Lawrence Woods are high quality sites; Johnson Road, Graham Road and Orange Road are low quality sites.

Site Name	Aug	Nov	May	MEAN
	mg C kg soil			
Bigwoods	2442 $\pm$ 1282 ^a	1823 $\pm$ 746 ^a	1347 $\pm$ 278 ^a	1871 $\pm$ 549
Gahanna Woods	849 $\pm$ 236 ^{bc}	685 $\pm$ 236 ^b	445 $\pm$ 274 ^b	660 $\pm$ 203
Lawrence Woods	2299 $\pm$ 664 ^{ac}	531 $\pm$ 330 ^b	3692 $\pm$ 1399 ^c	2174 $\pm$ 1584
Johnson Road	612 $\pm$ 155 ^{bc}	868 $\pm$ 627 ^b	465 $\pm$ 206 ^b	648 $\pm$ 204
Graham Road	1371 $\pm$ 223 ^{bc}	690 $\pm$ 236 ^b	996 $\pm$ 362 ^{ab}	1019 $\pm$ 341
Orange Road	734 $\pm$ 166 ^b	867 $\pm$ 271 ^b	591 $\pm$ 175 ^{ab}	731 $\pm$ 80

Table 4: Microbial biomass in each wetland during 3 sampling seasons, August (2005), November (2005), and May (2006). Values within a column followed by the same number are not significantly different at $p \leq 0.05$. Bigwoods, Gahanna Woods, and Lawrence Woods are high quality sites; Johnson Road, Graham Road and Orange Road are low quality sites.

3.2 Chemical Parameters

Soil C, N, S and P content were similar between the two wetland conditions ($p < 0.18$, $F = 2.7$, $df = 1,4$; $p < 0.19$, $F = 2.5$, $df = 1,4$; $p < 0.21$, $F = 2.2$, $df = 1,4$; $p < 0.68$, $F = 0.2$, $df = 1,4$, respectively) (Figure 4). However, among wetlands C, N, and S values were significantly different, ($p < 0.001$, $F = 12.5$, $df = 5,42$; $p < 0.00$, $F = 12.6$, $df = 5,42$; $p < 0.001$, $F = 24.9$, $df = 5,42$, respectively) (Table 5). These differences were driven by Bigwoods, which had higher soil C, N, and S compared to the other 5 wetlands. Although, differences in P did exist between wetlands ($p < 0.001$, $F = 8.9$, $df = 5,42$), the difference was not driven by a particular wetland (Table 5). For soil C and N, within site variability was less predictable between the high quality wetlands ($p < 0.015$, $F = 2.99$; $p < 0.015$, $F = 2.97$, respectively). Within site variability was similar for soil S and P ($p < 0.424$, $F = 0.203$; $p < 0.169$, $F = 1.06$).

Soil organic matter in high quality sites ($28 \% \pm 20$) was higher compared to low quality sites ($17 \% \pm 2$) but this difference was not significant ($p < 0.44$, $F = 0.73$, $df = 1,4$). Significant differences were found between wetlands ($p < 0.001$, $F = 16.9$, $df = 5,42$ (Table 5). This difference was driven by Bigwoods, which had higher OM compared to the other five wetlands. Within site variability was greater for OM in high quality wetlands ($p < 0.02$, $F = 2.66$).

pH levels of high (5.3 ± 0.36) and low (5.2 ± 0.26) quality wetlands were similar ($p < 0.78$, $F=0.1$, $df=1,4$). Although, differences in pH did exist between wetlands, ($p < 0.001$, $F=6.6$, $df=5,42$) (Table 5), this difference was not driven by a particular wetland. pH within site variability was larger between the low quality wetlands ($p < 0.036$, $F=2.26$).

Figure 4: Comparison of soil chemical parameters between high and low quality wetlands ($n=3$ for each category). Values represent the mean of 8 sampling plots within each wetland. Error bars represent the standard error.

Site Name	pH	C %	N %	P μg/g	S μg/g	OM %
Bigwoods	5.5 ± .23 ^a	26 ± 12 ^a	2 ± 0.8 ^a	1140 ± 129 ^{ac}	9480 ± 3775 ^a	51 ± 20 ^a
Gahanna Woods	4.9 ± .15 ^b	12 ± 5 ^b	0.8 ± 0.3 ^b	912 ± 190 ^{bc}	3033 ± 1682 ^b	14 ± 31 ^b
Lawrence Woods	5.6 ± .23 ^a	10 ± 2 ^b	0.8 ± 0.1 ^b	822 ± 135 ^b	2422 ± 525 ^b	18 ± 9 ^b
Johnson Road	5.1 ± .54 ^{ab}	8 ± 1 ^b	0.6 ± 0.1 ^b	872 ± 122 ^{bc}	1868 ± 770 ^b	17 ± 4 ^b
Graham Road	5.5 ± .24 ^a	7 ± 1 ^b	0.5 ± 0.06 ^b	762 ± 109 ^b	1714 ± 507 ^b	20 ± 5 ^b
Orange Road	5.1 ± .34 ^{ab}	8 ± 2 ^b	0.6 ± 0.1 ^b	1065 ± 130 ^{ac}	1309 ± 38 ^b	16 ± 6 ^b

Table 5: Summary of mean soil chemical parameters measured in each wetland. Values reported are the mean ± standard deviation of 8 sampling plots per wetland; standard error is in parenthesis. Values within a column followed by the same number are not significantly different at $p \leq 0.05$. Bigwoods, Gahanna Woods, and Lawrence Woods are high quality sites; Johnson Road, Graham Road and Orange Road are low quality sites.

3.3 Physical Parameters

Three different water stable aggregate (WSA) size fractions were measured (*large*: 2-8 mm, *medium*: 1-2 mm, and *small*: 0.25-1 mm). WSA fractions were similar in high and low quality wetlands ($p < 0.46$, $F = 0.67$, $df=1,4$; $p < 0.26$, $F=1.7$, $df=1,4$; $p < 0.18$, $F=2.7$, $df=1,4$, respectively) (Figure 5). However, between the 6 wetlands sampled, WSA size fractions were significantly different ($p < 0.001$, $F=9.2$, $df=5,37$; $p < 0.001$, $F=68$, $df=5,37$; $p < 0.001$, $F=9.8$, $df=5,37$, large, medium, and small, respectively) (Table 6). Within site variability was larger between the low quality wetlands for each WSA size fraction ($p < 0.078$, $F=1.67$; $p < 0.048$, $F=2.04$; $p < 0.026$, $F=2.52$, large, medium, and small, respectively).

Bulk density was lower in the high quality wetlands, however the difference was not statistically significant ($p < 0.22$, $F=2.07$, $df=1,4$) (Figure 5). Between the individual wetlands, bulk density was significantly different ($p < 0.001$, $F=13.9$, $df=5,42$) (Table 6). This difference was driven primarily by Bigwoods, which had lower bulk density

compared to the other five wetlands. Lawrence Woods also had lower bulk density values as compared to Orange Road. Within site variability of bulk density measurements were similar between high and low quality wetlands ($p < 0.255$, $F = 0.709$).

Soil moisture content was greater in the high quality wetlands (0.82 ± 0.50 g water g^{-1} dry soil) as compared to the low quality sites (0.40 ± 0.04 g water g^{-1} dry soil) but values were not statistically different ($p < 0.16$, $F = 2.92$, $df = 1, 4$). Moisture content of the high quality wetlands appeared to fluctuate over time whereas the moisture content in the low quality sites remained relatively stable; however, this seasonal trend was not significant ($p < 0.32$, $F = 2.34$, $df = 3, 12$) (Figure 6). Between the individual wetlands, differences in soil moisture content were detected for each sampling period ($p \leq 0.001$, $F = 11.6$, $df = 5, 42$; $p \leq 0.001$, $F = 8.6$, $df = 5, 42$; $p \leq 0.001$, $F = 11.12$, $df = 5, 42$; $p \leq 0.001$, $F = 11.02$, $df = 5, 42$, July, August, November, and May, respectively). These differences were driven primarily by Bigwoods, which had higher soil moisture compared to the other five wetlands. However, during the August sampling period, there were no significant moisture differences between Bigwoods and Lawrence Woods.

Figure 5: Comparison of soil physical parameters between high and low quality wetlands (n=3 for each category). Values in the figure represent the mean of 8 sampling plots within each wetland. Error bars represent the standard error.

Figure 6: Comparison of soil moisture content across four sampling periods in high and low quality wetlands. Values in the figure represent the mean of each sampling season (n=3 for each category). Error bars represent the standard error.

Site Name	WSA 2-8 mm %	WSA 1-2 mm %	WSA 0.25-1 mm %	BD g/cm ³
Bigwoods	32 ± 11 ^a	21 ± 6 ^a	16 ± 4 ^a	0.23 ± 0.09 ^a
Gahanna Woods	46 ± 20 ^{abc}	18 ± 6 ^a	19 ± 7 ^a	0.64 ± 0.13 ^{bc}
Lawrence Woods	65 ± 15 ^b	10 ± 4 ^{ab}	7 ± 3 ^b	0.48 ± 0.18 ^b
Johnson Road	53 ± 17 ^{abc}	18 ± 10 ^a	16 ± 7 ^a	0.56 ± 0.16 ^{bc}
Graham Road	84 ± 6 ^c	5 ± 3 ^b	2 ± 1 ^b	0.66 ± 0.08 ^{bc}
Orange Road	46 ± 17 ^{abc}	18 ± 6 ^a	13 ± 7 ^a	0.67 ± 0.10 ^c

Table 6: Summary of mean soil physical parameters measured in each wetland. Values reported are the mean ± standard deviation of 8 sampling plots per wetland; standard error is in parenthesis. Values within a column followed by the same number are not significantly different at $p \leq 0.05$. Bigwoods, Gahanna Woods, and Lawrence Woods are high quality sites; Johnson Road, Graham Road and Orange Road are low quality sites. WSA= water stable aggregates; BD= bulk density.

3.4 Relationship between Soil Parameters

A correlation analysis identified significant relationships between several soil physical, chemical, and biological parameters (Table 7). The largest fraction of WSA (2-8 mm) was positively correlated with soil carbon content. Bulk density was negatively correlated with several soil parameters including C, N, P, S, organic matter, and microbial biomass. There were positive correlations between bulk density and β -glucosidase and arylsulfatase enzyme activity. Soil moisture was negatively correlated with bulk density, β -glucosidase, and arylsulfatase activity and positively correlated with microbial biomass. Arylsulfatase enzyme activity was positively correlated with soil C, N, and S content. No significant relationships were found between β -glucosidase activity and soil chemical parameters.

A principle components analysis was run with the original 12 soil physical, chemical, and biological parameters. Only two principle components (PCs) out of the six computed were considered for interpretation because their observed eigenvalues, 8.6

(axis 1) and 3.2 (axis 2) exceeded those of the broken stick eigenvalues, 3.2 (axis 1) and 2.3 (axis 2). The combined PCs explained approximately 82% of the total variation in the multivariate dataset. However, the ordination did not reveal a spatial separation between high and low quality wetlands (Figure 7). Bigwoods, one of the high quality wetlands, was distinctly separated in ordination space from the other five wetlands. Lawrence woods (high quality) and Graham road (low quality) were grouped near one another; these sites were in closest proximity to Bigwoods. Johnson Road and Graham Road (low quality sites) and Gahanna Woods (high quality site) were tightly grouped in ordination space.

	BD	WSA L	WSA M	WSA S	C	N	P	S	pH	OM	BG	AS	MB-C
SM	-0.99***	-0.53	0.37	0.09	0.93***	0.95***	0.56	0.92***	0.541	0.91***	-0.74*	-0.94***	0.78*
BD	-	0.52	-0.39	-0.17	-0.91***	-0.93***	-0.52	-0.91***	-0.53	-0.91***	0.73*	0.92***	-0.73*
WSA L	-	-	-0.97***	0.23	-0.68*	-0.68*	-0.81***	-0.62	0.39	-0.49	0.32	0.46	-0.01
WSA M	-	-	-	-0.18	0.53	0.53	0.82**	0.49	-0.54	0.35	-0.20	-0.31	-0.18
WSA S	-	-	-	-	0.05	0.08	0.062	0.13	0.40	0.39	0.38	0.09	-0.03
C	-	-	-	-	-	0.99***	0.71*	0.99***	0.30	0.93***	-0.53	-0.78*	0.54
N	-	-	-	-	-	-	0.72*	0.99***	0.32	0.944***	-0.55	-0.81**	0.57
P	-	-	-	-	-	-	-	0.66	-0.16	0.62	-0.15	-0.43	0.09
S	-	-	-	-	-	-	-	-	0.33	0.96***	-0.49	-0.75*	0.52
pH	-	-	-	-	-	-	-	-	-	0.49	-0.43	-0.56	0.84**
OM	-	-	-	-	-	-	-	-	-	-	-0.39	-0.71*	0.56
BG	-	-	-	-	-	-	-	-	-	-	-	0.91***	-0.82**
AS	-	-	-	-	-	-	-	-	-	-	-	-	-0.87**
MB-C	-	-	-	-	-	-	-	-	-	-	-	-	-

$p \leq 0.01$ ***

$p \leq 0.05$ **

$p \leq 0.1$ *

Table 7: Pearson's correlation (r and significance of r) of soil physical, chemical, and biological parameters measured in the study. Values used were the average of 8 sampling stations within each wetland (n=6 wetlands); biological and moisture data were averaged across all 4 sampling seasons. BD= bulk density; WSA L= water stable aggregates 2-8 mm; WSA M= water stable aggregates 1-2 mm; WSA S= water stable aggregates 0.25-1 mm; C= carbon, N= nitrogen, P= phosphorus, S= sulfur, OM= organic matter, BG= β -glucosidase; AS= arylsulfatase, MB-C= microbial biomass carbon.

Figure 7: Principle components analysis (PCA) using soil moisture and soil physical (bulk density, water stable aggregates), chemical (OM, pH, C, N, S, P) and biological (β -glucosidase, arylsulfatase, and microbial biomass carbon) parameters. Values for biological parameters were the average of 4 sampling seasons. Ohio Rapid Assessment (ORAM) scores, which were used to determine wetland condition prior to sampling, are shown in parenthesis after each wetland site.

CHAPTER 4

DISCUSSION

4.1 Indicator Selection

Hydrology is considered the most important component of a wetland ecosystem because it determines and modifies the physiochemical environment and regulates the establishment of biotic communities (Mitsch and Gosselink, 2000). However, the soil environment is the physical foundation of wetland ecosystems (Stolt et al., 2000). It affects water storage, nutrient cycling, the root environment, plant and microbe productivity, and the accumulation of organic matter (Bossuyt et al., 2001; Logsdon et al., 2004). In terrestrial ecosystems, soil quality has been shown to be affected by both inherent and dynamic soil properties (Karlen et al., 2003). In this study, a combination of soil biological, chemical, and physical parameters were measured to identify which could potentially be used as indicators of wetland condition.

However, the different sampling designs used for biological versus chemical and physical parameters did not allow comparisons to be made between the strength of parameter type. Biological parameters were measured across four seasons, which allowed greater statistical power during analysis whereas chemical and physical parameters were only measured once.

4.1.2 Biological Parameters

In terrestrial ecosystems, biological and/or biochemical soil parameters have proven to be reliable indicators of soil quality because they are sensitive to environmental change and anthropogenic stress and provide an early estimate of changes occurring in the soil (Dick, 1994; Filip, 2002; Gil-Sotres et al., 2005; Winding et al., 2005). Soil microbial biomass and enzyme activity often decrease as the result of land-use change (e.g., cultivation techniques) or stress (e.g., nutrient enrichment and pollutants) (Kuperman et al., 1997; Chander et al., 1997; Garcia-Gil et al., 2000; Sicardi et al., 2004; Barbhuiya et al., 2004). In my study, the trend of biological indicators varied; microbial biomass was higher in the high quality sites while β -glucosidase and arylsulfatase enzyme activity was unexpectedly higher in the low quality wetlands (though only significantly higher for arylsulfatase). In a similar study conducted in mangrove forests, Dinesh et al. (2004) found that in comparison to disturbed mangroves, microbial biomass C and N and enzyme activities (phosphomonoesterase, phosphodiesterase, β -glucosidase, urease, BAA-protease, casein-protease, arylsulfatase, invertase, and carboxymethylcellulase) were higher in undisturbed mangroves.

Microbial biomass, the labile component of the soil organic C fraction is an index of the size of microbial biomass and the rate of organic matter turnover (Sparling, 1997) therefore has been often used as an indicator of soil quality. Higher microbial biomass C at the undisturbed mangroves was attributed to the greater accumulation of plant litter and organic carbon, which increased substrate availability for the soil microbial community; this was reflected in the strong correlation found between microbial biomass C and organic C (Dinesh et al., 2004). While the data collected in my study indicated a marginal significant difference in microbial biomass between high and low quality wetlands, the data did not reveal significant correlation between microbial biomass and organic C. The pooled variance of high quality wetlands was significantly greater for soil total carbon and greater for microbial biomass. Greater variability within the high quality wetlands could have confounded the relationship between these two parameters.

The measurement of specific enzymes, usually related to C, N, P, and S cycles, can reflect the biological status of the soil ecosystem (Dick, 1997). A possible explanation for lower β -glucosidase and arylsulfatase enzyme activities measured in high quality wetlands was the observed difference in soil moisture content between the two wetland quality classes. Indeed, there was a negative relationship between β -glucosidase and arylsulfatase activities and soil moisture. Additionally, high quality sites had higher soil moisture content; based on field observations, these wetlands were flooded more frequently, retained water for a longer period of time, and had saturated soils even during “draw down” periods. The degree of soil saturation in the high quality wetlands could have suppressed β -glucosidase and arylsulfatase enzyme activity.

Anaerobic conditions, which are typically found in wetlands, have been shown to inhibit microbial activity. Kang and Freeman (1999) found that waterlogging, measured by water table height, restricted both arylsulfatase and phosphatase enzyme activity in two different wetland types, swamps (freshwater forested wetlands) and fens (nutrient rich wetlands). Similarly, lower β -glucosidase, β -N-acetylglucosaminidase, phosphatase, and arylsulfatase activity was found in wetland sediments as compared to surrounding upland sites (Kang et al., 1998). Reduced enzyme activity has been attributed to the increased solubility of inhibitory metal ions, particularly Fe^{+2} and Mn, which are mobilized in reduced conditions (Freeman et al., 1996). A detailed study of wetland hydrology (i.e., groundwater and surface water depth) and metal concentrations with corresponding enzyme activities during each sampling period could help validate this conclusion.

4.1.3 Chemical Parameters

Nutrient levels within a wetland are often reflective of nutrient regeneration from plant detritus, organic matter decomposition, and microbial activity. In terrestrial ecosystems, soils nutrient status has been used as an indicator of soil quality and is included in the minimum data set proposed by Doran and Parkin (1994); generally, higher nutrient levels are found in less disturbed or degraded ecosystems. In this study, the degree of difference in soil C, N, S, and P nutrient levels between high and low quality wetlands could have been affected by the greater level of spatial variability exhibited in the high quality wetland sites.

Natural wetlands often exhibit a relatively high level of variability in soil chemical content (Stolt et al., 2001; Bruland and Richardson, 2005; Corstanje et al., 2006). This inherent variability could make it difficult to discover significant differences among wetland populations.

A limited amount of research has been conducted in natural wetlands that have measured soil nutrients as indicator of site quality. Higher levels of organic matter, organic C, and P were found in both undisturbed mangrove forests (Dinesh et al., 2004) and prairie potholes un-impacted by cultivation activities (Freeland et al., 1999). Organic C was among the variables measured to determine wetland condition in the development of a rapid assessment wetland index in Australia (Spencer et al., 1998) and in Florida (Reiss, 2006); higher levels of organic C reflected a less disturbed wetland. Nutrient levels, specifically organic matter, have also been a common metric of comparison in the function of natural and created and/or restored wetland ecosystems; similar to ecosystem disturbance, levels in natural wetlands are typically greater (Bishel-Machung et al., 1996; Stolt et al., 2000; Edwards and Proffit, 2003; Bruland and Richardson, 2006).

4.1.4 Physical Parameters

Characterization of soil physical properties are more closely related to inherent, genetic, soil parameters that are used in traditional soil classification (Karlen et al., 2003). These parameters are included in the assessment of soil quality because they are influenced by both biological and chemical processes. In this study, percent water stable aggregates did not appear to be sensitive to wetland quality. The main agencies of aggregate stabilization are organic materials, including the decomposition products of

plant, animal and microbial remains and microorganisms, which are also important components of a wetlands soil composition. It was expected that because of the higher organic carbon content in the high quality wetlands, there would be a greater percentage of macroaggregates (2-8 mm and 1-2 mm). However, the opposite relationship was observed; organic carbon was negatively correlated with macroaggregate formation (2-8 mm).

This inconsistent relationship could have been driven by the low percentage of 2-8 mm aggregates measured in Big Woods, one of the high quality wetlands, which had a thicker leaf litter and organic duff layer. The comparison of water stable aggregates across a range of disturbance in natural wetland ecosystems has not been widely studied. In a study by Hossler (2005) macroaggregate stability of natural emergent wetlands was greater than created wetlands. However, aggregate stability has demonstrated higher sensitivity between agricultural management practices, specifically till versus no-till (Stine and Weil, 2002; Balota et al., 2003; Roldán et al., 2005(a); Roldán et al., 2005(b)).

Bulk density has been included in the development of wetland assessment methods (van Dam et al. 1998; Spencer et al., 1998; Innis et al., 2000; Pennings et al., 2002; Reiss, 2006) and similar to my study, it is generally lower in less disturbed or reference standard wetlands. The comparison of natural and created and/or restored wetlands has also indicated that bulk density tends to be lower in natural wetlands (Bishel-Machung et al., 1996; Craft, 2000; Stolt et al., 2000; Campbell et al., 2002; Edwards and Proffit, 2003).

4.2 Relationship between Soil Parameters

Correlations between soil parameters suggest that the number and activity of soil microorganisms are dependant on soil structure, the quantity of mineralizeable substrate, and the availability of nutrients (Dinesh et al., 2004). Soil biological parameters, β -glucosidase, arylsulfatase, and microbial biomass, were highly correlated. Arylsulfatase activity was also correlated with both C and S. However, there was no relationship between β -glucosidase and microbial biomass, organic carbon, or organic matter content. This was unexpected as β -glucosidase is linked to the C cycle; it is one of the final steps in the C cycle. β -glucosidase releases glucose, a low molecular compound that is an important energy source for soil microbes (Dick, 1997). The lack of correlation could be reflective of differences in soil moisture content. In contrast to my study, significant positive correlations between organic C, total N, microbial biomass C, and enzyme activity, which included both arylsulfatase and β -glucosidase were found in mangrove forests (Dinesh et al., 2004) and studies in terrestrial ecosystems (Wick et al., 1998; Turner et al., 2002; Wick et al., 2002).

Another factor that could have affected the degree of correlation was the location of enzymes within the soil matrix. Most enzyme activities, including β -glucosidase and arylsulfatase, have approximately 40-50% of their activity associated with enzymes that are stabilized in the soil clay and organic matrix. Relative enzyme activity may be more reflective of a soil type effect as stabilized enzymes are affected by clay content and soil genesis. However, a significant positive relationship was found between bulk density and soil organic matter, C, N, S, β -glucosidase, arylsulfatase, and microbial biomass.

4.3 A priori wetland classification

The ORAM can be used to categorize natural wetlands for regulatory purposes and to contribute to the development of indicators of biological integrity (Mack, 2001; Stapanian et al., 20004). Prior to data collection, wetland sites were classified into two different quality categories based on their respective Ohio Rapid Assessment (ORAM) scores. The forested depressional wetlands in this study had ORAM scores that ranged from 21 to 68.5; a score of 100 represented the highest quality wetland of its respective hydrogeomorphic class. The ORAM, as a wetland assessment technique, has been validated by Ohio EPA's Vegetation Index of Biological Integrity (VIBI), a more intensive level III sampling method (Mack, 2004). Significant correlations existed between emergent VIBI scores and ORAM scores for depressional, riverine, slope, impounded, and mitigation wetlands (Mack, 2004). Additionally, ORAM scores were good predictors of total avian species richness and species richness of birds of conservation concern (Stapanian et al., 2004).

A principle component analysis (PCA) using all of the soil parameters measured did not separate wetlands according to their respective ORAM scores (i.e., high and low quality wetlands were not grouped). This could be a factor of the degree of disturbance impacting the forested wetlands included in my study. The ORAM user's manual identifies limitations of the assessment method pertaining to forested wetlands; highly degraded forested wetlands are cited as less common because they have been harvested and by definition are no longer forested. Therefore, the lowest quality of forested depressional wetlands may have been excluded from my sampling design. The total scores of these sites are often higher because they are confounded by the presence of a

mature canopy cover despite other disturbances impacting the assessment area (Mack, 2001). The low quality forested wetlands included in our study had mature forested canopies and were not affected by invasive species colonization. Additionally, disturbances to these sites were primarily indirect and occurred as the result of buffer modification; these included hydrological disturbances such as the presence of roads and residential and/or business development in close proximity to the wetland sites.

4.4 Guidance for future research

Indicators can be powerful tools for wetland assessment because they indirectly measure functional attributes of wetland ecosystems, which give scientists and managers a greater understanding of the wetlands functional capacity and/or condition. Ecological indicators have become standard in most wetland assessment procedures. Researchers in both aquatic and terrestrial disciplines have documented qualities of ‘good’ indicators; in summary, an ideal indicator should (a) be easy and inexpensive to measure, (b) be sensitive to human-induced stress or disturbance, (c) be consistent in its response to disturbance or degradation, (d) relate to specific ecosystem function and correlate well with ecosystem processes, (e) be relevant to all habitat types and (f) have a minimum amount of seasonal and spatial variability (Breckenridge et al., 1995; Turner et al., 2002; Doran and Safley, 1997; van Damm et al., 1998; Schlöter et al. 2003; Gil-Sotres et al., 2005).

Bulk density warrants more research as an indicator of wetland condition because: it was highly correlated with other soil parameters, relates to plant root growth and productivity, demonstrated similar levels of variability between high and low quality

sites, and is relatively easy to collect in the field and process in the laboratory. Microbial biomass and soil C content have potential as indicators of wetland condition because of their close link to carbon cycling and storage. Soil enzymes are often included in the suite of soil parameters used to assess soil quality in terrestrial ecosystems and have been shown to be sensitive to human-induced disturbance in mangrove ecosystems (Dinesh et al., 2004). However, results from my study suggest that because of their dependence on soil moisture, the observed seasonal variability across sampling periods, the cost of enzyme substrate, and the sensitivity of enzyme activity to soil storage and processing procedures, the measurement of soil enzyme activity is not suited for the discrimination of the forested wetlands used in this study. Enzyme activity in emergent wetlands also appears to be confounded by vegetation communities and could not differentiate between areas of high and low nutrient concentrations (Prenger and Reddy, 2004).

Before final conclusions can be drawn on the use of soil indicators to determine wetland condition, soil from the wetlands surrounding buffer should also be analyzed. The majority of the human disturbance affecting the forested wetlands included in my study occurred outside wetland boundaries. However, the high level of spatial and temporal variability found in my study and other wetland and terrestrial ecosystems and the unpredictable and fluctuating water level in wetlands suggest that the measurement of soil parameters may be most applicable to monitor the success or development of restored and created wetlands. Soil biological and biochemical parameters exhibited sensitivity to Conservation Reserve Program (CRP) restoration practices (Reeder et al., 1998; Acosta-Martínez et al., 2003) and to other soil management practices such as organic amendments and cover crops (Bandick and Dick, 1999; Knight and Dick, 2004;

Cespedes et al., 2006). Furthermore, the inclusion of a combination of biological, chemical, and physical soil measurements in wetland assessment methods may not be feasible; in many assessment methods, individual wetland are only visited once. This sampling design provides scientists and managers with only a snapshot of wetland condition; a single visit does not take into account seasonal variation or the effect of environmental variables such as soil moisture (Reiss, 2006).

APPENDIX A

SITE PICTURES

Figure 8: Lawrence Woods (high quality wetland) in the spring sampling period.
Photograph taken by Abby Rokosch.

Figure 9: Gahanna Woods (high quality wetland) in the summer sampling period.

Photograph taken by Abby Rokosch.

Figure 10: Johnson Road (low quality wetland) in the spring sampling period. Photograph taken by Abby Rokosch.

Figure 11: Graham Road (low quality wetland) in the summer sampling period.

Photograph taken by Abby Rokosch.

Figure 12: Orange Road (low quality wetland) in the summer sampling period.

Photograph taken by Abby Rokosch.

APPENDIX B

DETAILED LABORATORY PROTOCOLS

BETAGLUCOSIDASE ACTIVITY

Complete description of this assay can be found in *Methods of Soil Analysis. Part 2, Microbiological and Biochemical Properties. 1994. Soil Science Society of America book series no 5*. Pages 823-826

A. Special Apparatus

1. Erlenmeyer flasks (50 mL)
2. Stoppers (no.2)
3. Incubator- ordinary incubator OR temperature-controlled water bath (37° C)
4. Spectrophotometer that can be adjusted to a wavelength of 400 to 420 nm
5. 1000 mL Volumetric flasks for solutions

B. Reagents

1. Toluene

2. MUB Stock solution and MUB pH 6.0 (37-3.2.3.1.1 page 808)

a. Modified Universal Buffer (MUB) stock solution:

- 1- Create **1 N NaOH**: add 40 g of **NaOH** into 1 L of DI water (does not need to be stored in fridge)
- 2- Put 488 mL of **1 N NaOH** solution into a 1 L volumetric flask
- 3- Dissolve 12.1 g of **tris(hydroxymethyl)aminomethane (THAM)**
- 4- Dissolve 11.6 g of **maleic acid**
- 5- Dissolve 14.0 g of **citric acid**
- 6- Dissolve 6.3 g **boric acid (H₃B₃O₃)**
- 7- Dilute to 1 L (after dissolve in 488 mL **NaOH** solution)
- 8- Store in refrigerator

b. MUB pH 6.0:

- 1- Place 200 mL of **MUB stock solution** in a 500-mL beaker containing a magnetic stirring bar
- 2- Place beaker on magnetic stirrer
- 3- Titrate the solution to pH 6.0 with **0.1 M hydrochloric acid (HCL)** and adjust the volume to 1 L with water

3. 1 N Sodium hydroxide (NaOH)

4. Calcium chloride (CaCl₂) 0.5 M: Dissolve 73.5 g **CaCl₂ · 2H₂O** in ~ 700 mL of water, and dilute the volume to 1 L with water. (37-3.2.3.1.2 page 808)

5. Standard *p*-nitrophenol: Dissolve 1.0 g of ***p*-nitrophenol** in ~ 700 mL of water, and dilute the solution to 1 L with water. Store in refrigerator. (37-3.2.3.1.2 page 808)

6. *p*-Nitrophenol- β -D-glucoside (PNG) solution, 0.05 M: Dissolve 0.654 g of *p*-nitrophenyl- β -D- glucoside (PNG) (Sigma Chemical Co., St. Louis, MO) in ~ 40 mL of MUB pH 6.0, and adjust the volume to 50 mL with the same buffer. Store the solution in a refrigerator. (37-3.6.3 page 825)

7. *Tris(hydroxymethyl)aminomethane (THAM) buffers (0.1 M), pH 12: Dissolve 12.2 g of THAM (Fisher certified reagent, Fisher Scientific Co., Chicago, IL) in ~800 mL of water, adjust the pH of the solution to 12 by titration in ~ 800 mL water with 0.5 M NaOH, and dilute the volume to 1 L with water. (37-3.2.3.2.2 page 809)

8. **Tris(hydroxymethyl)aminomethane (THAM diluent), (0.1 M), pH ~10: Dissolve 12.2 g THAM in ~800 mL of water, adjust volume to 1 L with water (37-3.2.3.2.2 page 809)

*Used after 1 hour incubation

**Used for dilution of aliquot after extraction

C1. Procedure

1. Place 1 g soil (<2mm) in a 50-mL Erlenmeyer flask (modified from 1 gram)
2. Add 0.25 mL of **toluene**
3. Add 4 mL of MUB pH 6.0
4. Add 1 mL of *p*-Nitrophenol- β -D-glucoside (PNG) solution
- 4b**. DO NOT ADD PNG TO CONTROL—SEE 10b.**
5. Swirl the flask for a few seconds to mix contents
6. Stopper the flask
7. Place in incubator at 37° for 1 hr
8. Remove the stopper
9. Add 1 mL of 0.5 M CaCl₂
10. Add 4 mL of 0.1 M THAM buffer pH 12

10b. Add 1mL *p*-Nitrophenol- β -D-glucoside (PNG) solution to control**

11. Swirl the flask for a few seconds
12. Filter the soil suspension through a Whatman no. 2v folded filter paper
13. Measure the yellow color intensity of the filtrate
14. If color intensity of the filtrate exceeds that of 200 μ g (modified from 50 μ g) of the *p*-nitrophenol standard, an aliquot of the filtrate should be diluted THAM pH ~10 until the colorimeter reading falls within the limits of the calibration. Record dilution on data sheet.

D. Calibration graph

Summary: Calculate the *p*-nitrophenol content of the filtrate by reference to a calibration graph plotted from results obtained with standards containing 0, 10, 20, 30, 40, and 50 µg of *p*-nitrophenol. Used modified calibration curve.

Calibration Curve 37-3.2.3.1.3 (page 808-809)

1. Dilute 1 mL of the **standard *p*-nitrophenol solution** to 100 mL in a volumetric flask and mix the solution thoroughly.
 2. Pipette 0-, 1-, 2-, 3-, 4-, 5-mL* aliquots of this diluted standard solution into 50-mL erlenmeyer flasks.
 3. Adjust the volume to 5 mL by addition of **water**.
 4. Add 1 mL of 0.5 M **CaCl₂**
 5. Add 4 mL of 0.5 M of **NaOH**
 6. Mix and filter the resultant suspension
- * Corresponds to 0-50 µg of *p*-nitrophenol solution

If color intensity of filtrate exceeds that of 50µg of the *p*-nitrophenol standard, an aliquot of the filtrate should be diluted with water until the colorimeter reading falls within the limits of the calibration graph.

Modified calibration curve:

1. Dilute 4 mL of the **standard *p*-nitrophenol solution** to 100 mL in a volumetric flask and mix the solution thoroughly (modified from 1 mL)
 2. Pipette 0-, .5-, 1-, 2-, 3-, 4- 5-mL* aliquots of this diluted standard solution into 50-mL erlenmeyer flasks
 3. Adjust the volume to 5 mL by addition of **water**
 4. Add 1 mL of 0.5 M **CaCl₂**
 5. Add 4 mL of 0.5 M of **THAM buffer ph 12**
 6. Mix and filter the resultant suspension
- * Corresponds to 0-200 µg of *p*-nitrophenol solution

If color intensity of filtrate exceeds that of 200µg of the *p*-nitrophenol standard, an aliquot of the filtrate should be diluted with water until the colorimeter reading falls within the limits of the calibration graph.

ARYLSULFATASE ENZYME ACTIVITY

Complete description of this assay can be found in *Methods of Soil Analysis. Part 2, Microbiological and Biochemical Properties. 1994. Soil Science Society of America book series no 5. Pages 814-818*

A. Special Apparatus

1. Incubation Erlenmeyer flasks (50 mL)
2. Stoppers (no.2)
3. Incubator- ordinary incubator OR temperature-controlled water bath (37° C)
4. Spectrophotometer that can be adjusted to a wavelength of 400 to 420 nm
5. 1000 mL Volumetric Flasks for solution

B. Reagents

1. **Toluene**, Fisher certified reagent (Fisher Scientific Co.)
2. **Acetate buffer, 0.5 M, pH 5.8**: Dissolve 68 g **sodium acetate trihydrate** in ~ 700 mL of water, add 1.70 mL **glacial acetic acid** (99%), and dilute volume to 1L with water. (37-3.3.3.2 page 816)
3. **p-Nitrophenol sulfate solution, 0.5 M**: Dissolve 0.614 g of **potassium p-nitrophenol sulfate** in ~ 40 mL of acetate buffer, and dilute the solution to 50 mL with buffer. Store solution in refrigerator. 37-3.3.3.2 page 816)
4. **Calcium chloride (CaCl₂) 0.5 M**: Dissolve 73.5 g **CaCl₂ · 2H₂O** in ~ 700 mL of water, and dilute the volume to 1 L with water. (37-3.2.3.1.2 page 808)
5. **Standard p-nitrophenol**: Dissolve 1.0 g of **p-nitrophenol** in ~ 700 mL of water, and dilute the solution to 1 L with water. Store in refrigerator. (37-3.2.3.1.2 page 808)
6. **Sodium hydroxide (NaOH, 0.5 M)**: Dissolve 20 g of NaOH in ~700 mL of water, and dilute the solution to 1 L with water. (37-3.2.3.1.2 page 808) **NOTE THAT THIS IS NOT THE SAME NaOH THAT IS USED FOR MAKING THE MUB BUFFER SOLUTION—THIS ONE HAS A DIFFERENT MOLARITY!!**

C1. Procedure

1. Place 1 g of soil (<2mm) in a 50-mL Erlenmeyer flask
2. Add 0.25 mL of **toluene**
3. Add 4 mL of **acetate buffer**
4. Add 1 mL of ***p*-Nitrophenol sulfate solution**

4b. **Do NOT add in CONTROL SAMPLES—SEE BELOW 10b.

5. Swirl the flask for a few seconds to mix contents
6. Put stopper on flask
7. Place in incubator at 37° for 1 hr
8. Remove the stopper
9. Add 1 mL of 0.5M **CaCl₂**
10. Add 4 mL of 0.5 M **NaOH**

10b.Add 1 mL of *p*-nitrophenol sulfate solution for control**

11. Swirl flask for a few seconds
12. Filter the soil suspension through a Whatman No.2v folded filter paper
13. Measure the yellow color intensity of the filtrate
14. If color intensity of the filtrate exceeds that of 200 µg (modified from 50 µg) of the ***p*-nitrophenol standard**, an aliquot of the filtrate should be diluted with water until the colorimeter reading falls within the limits of the calibration. Record dilution on datasheet.

D. Calibration graph

Summary: Calculate the *p*-nitrophenol content of the filtrate by reference to a calibration graph plotted from results obtained with standards containing 0, 10, 20, 30, 40, and 50 µg of *p*-nitrophenol. Used modified calibration curve.

Calibration Curve 37-3.2.3.1.3 (page 808-809)

1. Dilute 1 mL of the **standard *p*-nitrophenol solution** to 100 mL in a volumetric flask and mix the solution thoroughly.
 2. Pipette 0-, 1-, 2-, 3-, 4-, 5-mL* aliquots of this diluted standard solution into 50-mL erlenmeyer flasks.
 3. Adjust the volume to 5 mL by addition of **water**.
 4. Add 1 mL of 0.5 M **CaCl₂**
 5. Add 4 mL of 0.5 M of **NaOH**
 6. Mix and filter the resultant suspension
- * Corresponds to 0-50 µg of *p*-nitrophenol solution

If color intensity of filtrate exceeds that of 50µg of the *p*-nitrophenol standard, an aliquot of the filtrate should be diluted with water until the colorimeter reading falls within the limits of the calibration graph.

Modified calibration curve:

1. Dilute 4 mL of the **standard *p*-nitrophenol solution** to 100 mL in a volumetric flask and mix the solution thoroughly (modified from 1 mL)
 2. Pipette 0-, .5-, 1-, 2-, 3-, 4- 5-mL* aliquots of this diluted standard solution into 50-mL erlenmeyer flasks
 3. Adjust the volume to 5 mL by addition of **water**
 4. Add 1 mL of 0.5 M **CaCl₂**
 5. Add 4 mL of 0.5 M of **NaOH**
 6. Mix and filter the resultant suspension
- * Corresponds to 0-200 µg of *p*-nitrophenol solution

If color intensity of filtrate exceeds that of 200µg of the *p*-nitrophenol standard, an aliquot of the filtrate should be diluted with water until the colorimeter reading falls within the limits of the calibration graph.

MICROBIAL BIOMASS CARBON

- (1) Howarth and Paul, 1994 *in* Methods of Soil Analysis. Part 2, Microbiological and Biochemical Properties. 1994. Soil Science Society of America book series no 5.
- (2) Vance, E.D., P.C. Brookes, and D.S. Jenkinson. 1987. An extraction method for measuring soil microbial biomass C. Soil Biology and Biogeochemistry 19:703-707.
- (3) White, J.R., and K.R. Reddy. 1999. Influence of nitrate and phosphorus loading on denitrifying enzyme activity in Everglades wetland soils. Soil Sci. Soc. Am. J. 63:1945-1954.

A. Soil Samples

1. Add 5 g of soil into 25 mL centrifuge tubes
 - a. 4 samples for fumigation
 - b. 4 samples not fumigated
2. Add .5 mL of chloroform to the replicates to be fumigated and place centrifuge tubes into vacuum dessiccator

B. Fumigation/Incubation of Soil Samples

1. All work must be done in fume hood b/c carcinogenic-volatile properties
2. Line desiccator with moist paper towels to prevent desiccation
3. Place beaker of 300 mL ethanol-free chloroform and antibumping granules with soil samples into vacuum desiccator
4. Place soil samples to be fumigated into desiccator (HAS TO BE LABELED IN PENCIL)
5. Evacuate desiccator until chloroform boils vigorously- repeat x 4 (modified x 3 because of wet soil); let air pass back through desiccator to facilitate distribution of chloroform (do not let too much air pass through each time or chloroform will not boil)
6. Evacuate for 5th time until chloroform boils for 2 minutes
7. Close the valve/ place desiccator in dark at 25 °C for 18-24 hrs
8. Unfumigated samples are also stored in dark at 25° C while fumigation process
9. After incubation period- remove paper towels under fume hood
10. Evacuate desiccator for 3 min x 10 (modified from 8 because of wet soils)
11. Begin K₂S₀₄ extraction for fumigated and nonfumigated samples

C. K₂S₀₄ extraction

1. Extract with 20 mL of 0.5M K₂S₀₄
2. Agitate samples on a shaker for 30 minutes
3. Filter through no.42 Whatman filter paper
4. Supernatant collected at refrigerated at 4 C until analyzed on TOC

D. Microbial Biomass Determination

1. Subtract the extractable total organic C from the controls from the total organic carbon from the fumigated samples and divide by K_{ec}
2. An extraction efficiency of 0.37 is used based on previous calibration from organic soils (Sparling et al., 1990)

AGGREGATE STABILITY

The method I used for water stable aggregates was taken from a protocol written by Hossler, 2005. The protocol was based on the following references:

- (1) Kemper, W. D. & Chepil, W. S. (1965). Size distribution of aggregates. In C. Black (Ed.), *Methods of soil analysis, part 1* (pp. 499–510). Madison, WI: American Society of Agronomy, Inc.
- (2) Nimmo, J. & Perkins, K. (2002). Aggregate stability and size distribution. In J. Dane & G. Topp (Eds.), *Methods of soil analysis, part 4: physical methods* (pp. 317–328). Madison, WI: Soil Science Society of American, Inc.

A. Procedure

Collection of 2-8 mm, 1-2 mm, 0.25-1 mm and 53-250 μ m

1. Air dry soil
2. Grind to pass 8 mm (0.31 in) sieve and collect on 3.35 mm (0.13 in) sieve
3. Weigh and record 25-30 g of sieved soil sample
4. Stack sieves for wet-sieving machine: 2.0, 1.0, 0.25, and 0.05-mm
5. On wet-sieving machine, position sieves at top of stroke
6. Raise water level to form a thin film on the top sieve screen
7. Spread soil sample thinly over top sieve in nested stack
8. Capillary wet for 30-min
9. Wet-sieve for 30-min
10. Dry sieves in oven overnight at 40°C
11. Remove samples from sieves and place in weighed tins
12. Dry at 40°C for ~ 48 h (or at 25°C for several days)
13. Record weights of aggregate fractions

Moisture correction

1. Weigh and record 2-3 g subsample of 3.35-8 mm sample
2. Weigh and record 0.5-1 g subsample of aggregate fraction
3. Dry at 105°C for ~ 24 h
4. Record weights of oven-dried subsamples

Coarse-particle corrections

1. Prepare 0.2% (w/w) sodium hexametaphosphate (HMP) [i.e., 2 g per 1 L]
2. Weigh and record remaining aggregate fraction
3. Place remaining aggregate fraction in 50 mL conical centrifuge tube
(probably split into two tubes if sample much more than 10 g)
4. Add ~ 40 mL 0.2% HMP (leaving space at top) and cap
5. Shake overnight (12-18 h) on Eberbach Reciprical Shaker (180 osc/min)
6. Collect coarse-particles on appropriate sieve
i.e., 2-8 mm fractions are sieved through 2 mm sieve, 1-2 through 1 mm sieve, etc
7. Wash coarse-particles into weighed tin
8. Dry at 105°C for ~ 48 h
9. Record weights of coarse-particles

Calculations

SW Sample Weight (3.35-8 mm)

FW Aggregate Fraction Weight (dried at 40°C, minus tin weight)

WSW Wet Sample Weight (3.35-8 mm subsample, minus tin weight)

DSW Dry Sample Weight (3.35-8 mm subsample dried at 105°C, minus tin weight)

WFW Wet Fraction Weight (aggregate subsample, minus tin weight)

DFW Dry Fraction Weight (aggregate subsample dried at 105°C, minus tin weight)

RFW Remaining Aggregate Fraction Weight (minus tin weight)

CPW Coarse-Particle Weight (dried at 105°C, minus tin weight)

UAF Uncorrected Water-Stable Aggregate

MAF Moisture Corrected Water-Stable Aggregate

WSA Percent Water-Stable Aggregate (corrected for moisture and coarse-particles)

Uncorrected % aggregate fraction:

$$UAF = 100 \times \frac{FW}{SW}$$

Moisture-corrected % aggregate fraction:

$$MAF = UAF \times \frac{DFW}{WFW} \times \frac{WSW}{DSW}$$

Percent water-stable aggregate (moisture and coarse-particle corrected)

$$WSA = MAF \times \left(1 - \frac{CPW}{RFW} \times \frac{WFW}{DFW} \right)$$

APPENDIX C

RAW DATA

High Quality Wetland Sites					Low Quality Wetland Sites				
Site	Station	JULY AS Activity			Site	Station	JULY AS Activity		
		$\mu\text{g PNP g}^{-1} \text{ h}^{-1}$	SD	SE			$\mu\text{g PNP g}^{-1} \text{ h}^{-1}$	SD	SE
Bigwoods	1	110	19	11	Johnson Road	1	713	13	7
Bigwoods	2	59	9	5	Johnson Road	2	841	41	24
Bigwoods	3	279	10	6	Johnson Road	3	227	23	13
Bigwoods	4	136	26	15	Johnson Road	4	305	69	40
Bigwoods	5	120	10	6	Johnson Road	5	400	71	41
Bigwoods	6	359	73	42	Johnson Road	6	255	56	32
Bigwoods	7	63	20	12	Johnson Road	7	124	28	16
Bigwoods	8	439	77	44	Johnson Road	8	1025	24	14
Lawrence Woods	1	146	11	7	Graham Road	1	710	46	26
Lawrence Woods	2	210	20	11	Graham Road	2	633	25	14
Lawrence Woods	3	351	70	40	Graham Road	3	1009	44	26
Lawrence Woods	4	133	35	20	Graham Road	4	347	12	7
Lawrence Woods	5	491	107	62	Graham Road	5	683	43	25
Lawrence Woods	6	226	30	17	Graham Road	6	1075	78	45
Lawrence Woods	7	193	81	47	Graham Road	7	784	46	27
Lawrence Woods	8	231	28	16	Graham Road	8	400	23	13
Gahanna Woods	1	641	76	44	Orange Road	1	446	6	4
Gahanna Woods	2	374	34	20	Orange Road	2	361	22	13
Gahanna Woods	3	496	155	90	Orange Road	3	317	20	11
Gahanna Woods	4	234	93	54	Orange Road	4	242	99	57
Gahanna Woods	5	147	33	19	Orange Road	5	598	14	8
Gahanna Woods	6	168	15	9	Orange Road	6	574	21	12
Gahanna Woods	7	417	67	39	Orange Road	7	277	15	8
Gahanna Woods	8	132	14	10	Orange Road	8	348	15	9

Table 8: Arylsulfatase enzyme activity for July in high and low quality wetlands for each sampling station (n=8).

High Quality Wetland Sites					Low Quality Wetland Sites				
Site	Station	JULY BG Activity			Site	Station	JULY BG Activity		
		$\mu\text{g PNP}$ $\text{g}^{-1} \text{h}^{-1}$	SD	SE			$\mu\text{g PNP}$ $\text{g}^{-1} \text{h}^{-1}$	SD	SE
Bigwoods	1	60	8	5	Johnson Road	1	475	31	18
Bigwoods	2	34	1	1	Johnson Road	2	366	26	15
Bigwoods	3	71	7	4	Johnson Road	3	184	7	4
Bigwoods	4	46	23	14	Johnson Road	4	241	6	4
Bigwoods	5	115	15	9	Johnson Road	5	172	23	13
Bigwoods	6	57	10	6	Johnson Road	6	149	1	1
Bigwoods	7	30	3	2	Johnson Road	7	45	22	15
Bigwoods	8	158	13	8	Johnson Road	8	468	29	17
Lawrence Woods	1	152	60	35	Graham Road	1	502	17	10
Lawrence Woods	2	46	5	3	Graham Road	2	489	77	45
Lawrence Woods	3	70	13	7	Graham Road	3	771	16	9
Lawrence Woods	4	56	16	9	Graham Road	4	323	16	10
Lawrence Woods	5	88	37	21	Graham Road	5	491	60	35
Lawrence Woods	6	95	6	3	Graham Road	6	538	64	37
Lawrence Woods	7	163	42	24	Graham Road	7	611	112	65
Lawrence Woods	8	114	20	12	Graham Road	8	433	160	92
Gahanna Woods	1	344	11	7	Orange Road	1	483	48	28
Gahanna Woods	2	206	111	64	Orange Road	2	377	12	7
Gahanna Woods	3	267	9	5	Orange Road	3	359	32	19
Gahanna Woods	4	164	23	13	Orange Road	4	374	46	27
Gahanna Woods	5	81	7	4	Orange Road	5	469	37	21
Gahanna Woods	6	117	22	13	Orange Road	6	431	24	14
Gahanna Woods	7	154	50	29	Orange Road	7	426	31	18
Gahanna Woods	8	54	6	3	Orange Road	8	321	4	2

Table 9: β -glucosidase enzyme activity for July in high and low quality wetlands for each sampling station (n=8).

High Quality Wetland Sites					Low Quality Wetland Sites				
Site	Station	AUGUST AS Activity			Site	Station	AUGUST AS Activity		
		$\mu\text{g PNP}$ $\text{g}^{-1} \text{h}^{-1}$	SD	SE			$\mu\text{g PNP}$ $\text{g}^{-1} \text{h}^{-1}$	SD	SE
Bigwoods	1	444	28	16	Johnson Road	1	488	29	17
Bigwoods	2	119	12	7	Johnson Road	2	731	38	22
Bigwoods	3	65	9	5	Johnson Road	3	175	9	5
Bigwoods	4	312	6	3	Johnson Road	4	206	6	3
Bigwoods	5	120	7	4	Johnson Road	5	293	12	7
Bigwoods	6	517	33	19	Johnson Road	6	223	17	10
Bigwoods	7	276	29	17	Johnson Road	7	56	9	5
Bigwoods	8	549	89	51	Johnson Road	8	550	42	25
Lawrence Woods	1	91	6	4	Graham Road	1	474	23	13
Lawrence Woods	2	318	29	17	Graham Road	2	325	18	11
Lawrence Woods	3	329	70	40	Graham Road	3	577	20	12
Lawrence Woods	4	259	14	8	Graham Road	4	357	8	5
Lawrence Woods	5	258	44	25	Graham Road	5	367	63	36
Lawrence Woods	6	178	7	4	Graham Road	6	556	17	10
Lawrence Woods	7	466	26	15	Graham Road	7	372	5	3
Lawrence Woods	8	216	6	4	Graham Road	8	354	21	12
Gahanna Woods	1	531	12	7	Orange Road	1	707	8	5
Gahanna Woods	2	494	47	27	Orange Road	2	635	30	18
Gahanna Woods	3	609	14	8	Orange Road	3	434	15	9
Gahanna Woods	4	366	22	12	Orange Road	4	384	14	8
Gahanna Woods	5	106	17	12	Orange Road	5	701	12	8
Gahanna Woods	6	548	75	43	Orange Road	6	413	44	26
Gahanna Woods	7	106	4	3	Orange Road	7	703	71	41
Gahanna Woods	8	146	20	11	Orange Road	8	556	21	12

Table 10: Arylsulfatase enzyme activity for August in high and low quality wetlands for each sampling station (n=8).

High Quality Wetland Sites					Low Quality Wetland Sites				
Site	Station	AUGUST BG Activity			Site	Station	AUGUST BG Activity		
		$\mu\text{g PNP g}^{-1} \text{h}^{-1}$	SD	SE			$\mu\text{g PNP g}^{-1} \text{h}^{-1}$	SD	SE
Bigwoods	1	325	12	7	Johnson Road	1	266	49	28
Bigwoods	2	184	11	6	Johnson Road	2	249	19	11
Bigwoods	3	99	21	12	Johnson Road	3	113	35	20
Bigwoods	4	357	10	6	Johnson Road	4	106	19	11
Bigwoods	5	91	19	11	Johnson Road	5	254	7	4
Bigwoods	6	557	12	7	Johnson Road	6	295	19	11
Bigwoods	7	352	26	15	Johnson Road	7	110	22	13
Bigwoods	8	517	43	25	Johnson Road	8	324	5	3
Lawrence Woods	1	41	3	2	Graham Road	1	347	27	16
Lawrence Woods	2	140	13	7	Graham Road	2	251	16	9
Lawrence Woods	3	161	15	9	Graham Road	3	338	77	45
Lawrence Woods	4	143	6	4	Graham Road	4	327	41	24
Lawrence Woods	5	90	23	14	Graham Road	5	367	51	30
Lawrence Woods	6	81	4	2	Graham Road	6	289	31	18
Lawrence Woods	7	195	14	8	Graham Road	7	250	30	17
Lawrence Woods	8	119	3	2	Graham Road	8	268	14	8
Gahanna Woods	1	345	15	9	Orange Road	1	415	39	22
Gahanna Woods	2	264	13	8	Orange Road	2	346	18	11
Gahanna Woods	3	287	11	6	Orange Road	3	236	9	5
Gahanna Woods	4	280	13	7	Orange Road	4	255	27	16
Gahanna Woods	5	116	20	12	Orange Road	5	370	30	18
Gahanna Woods	6	444	29	17	Orange Road	6	232	10	6
Gahanna Woods	7	92	6	4	Orange Road	7	359	7	4
Gahanna Woods	8	111	8	5	Orange Road	8	220	25	14

Table 11: β -glucosidase enzyme activity for August in high and low quality wetlands for each sampling station (n=8).

High Quality Wetland Sites					Low Quality Wetland Sites				
Site	Station	NOVEMBER AS Activity			Site	Station	NOVEMBER AS Activity		
		$\mu\text{g PNP g}^{-1} \text{ h}^{-1}$	SD	SE			$\mu\text{g PNP g}^{-1} \text{ h}^{-1}$	SD	SE
Bigwoods	1	55	9	5	Johnson Road	1	353	40	23
Bigwoods	2	38	5	3	Johnson Road	2	445	16	10
Bigwoods	3	*	*	*	Johnson Road	3	43	5	3
Bigwoods	4	64	10	6	Johnson Road	4	33	1	1
Bigwoods	5	165	11	6	Johnson Road	5	194	26	15
Bigwoods	6	66	9	5	Johnson Road	6	225	8	5
Bigwoods	7	71	3	1	Johnson Road	7	51	2	1
Bigwoods	8	*	*	*	Johnson Road	8	172	2	1
Lawrence Woods	1	372	42	24	Graham Road	1	174	38	22
Lawrence Woods	2	*	*	*	Graham Road	2	118	4	2
Lawrence Woods	3	281	41	23	Graham Road	3	205	28	16
Lawrence Woods	4	213	18	10	Graham Road	4	132	5	3
Lawrence Woods	5	120	12	7	Graham Road	5	126	22	13
Lawrence Woods	6	122	21	12	Graham Road	6	181	11	6
Lawrence Woods	7	*	*	*	Graham Road	7	163	45	26
Lawrence Woods	8	78	12	7	Graham Road	8	117	8	4
Gahanna Woods	1	483	19	11	Orange Road	1	77	1	1
Gahanna Woods	2	399	14	8	Orange Road	2	125	12	8
Gahanna Woods	3	591	20	12	Orange Road	3	65	8	6
Gahanna Woods	4	350	28	16	Orange Road	4	53	2	1
Gahanna Woods	5	137	18	11	Orange Road	5	133	9	6
Gahanna Woods	6	228	5	3	Orange Road	6	57	1	0
Gahanna Woods	7	298	38	22	Orange Road	7	101	11	8
Gahanna Woods	8	100	63	36	Orange Road	8	133	24	17

Table 12: Arylsulfatase enzyme activity for November in high and low quality wetlands for each sampling station (n=8).

High Quality Wetland Sites					Low Quality Wetland Sites				
Site	Station	NOVEMBER BG Activity			Site	Station	NOVEMBER BG Activity		
		$\mu\text{g PNP g}^{-1} \text{ h}^{-1}$					$\mu\text{g PNP g}^{-1} \text{ h}^{-1}$		
		SD	SE				SD	SE	
Bigwoods	1	118.21	9.2	5.3	Johnson Road	1	352.8	40	23
Bigwoods	2	42.15	3.3	1.9	Johnson Road	2	454.1	28	16
Bigwoods	3	*	*	*	Johnson Road	3	78.05	8.9	5.1
Bigwoods	4	101.46	6	3.4	Johnson Road	4	58.83	2.5	1.5
Bigwoods	5	125	23	13	Johnson Road	5	348.7	46	27
Bigwoods	6	105.31	14	8.1	Johnson Road	6	405.11	14	8.3
Bigwoods	7	124.1	4	2.3	Johnson Road	7	91.49	2.9	2
Bigwoods	8	*	*	*	Johnson Road	8	310.21	3.1	1.8
Lawrence Woods	1	121.03	14	8.2	Graham Road	1	67.06	16	9.1
Lawrence Woods	2	*	*	*	Graham Road	2	151.35	5	2.9
Lawrence Woods	3	82.4	18	10	Graham Road	3	183.5	20	11
Lawrence Woods	4	98.306	0.6	0.3	Graham Road	4	99.37	3.2	1.9
Lawrence Woods	5	53.48	3.2	1.9	Graham Road	5	91.6	29	17
Lawrence Woods	6	126.5	20	11	Graham Road	6	176.14	0.9	0.6
Lawrence Woods	7	*	*	*	Graham Road	7	137.5	26	19
Lawrence Woods	8	61.79	5	2.9	Graham Road	8	166	16	11
Gahanna Woods	1	328.61	8.7	5	Orange Road	1	186.23	5	2.9
Gahanna Woods	2	239	20	12	Orange Road	2	187.6	33	19
Gahanna Woods	3	319.9	20	11	Orange Road	3	162.04	11	6.3
Gahanna Woods	4	300.23	10	5.9	Orange Road	4	132.8	8.3	4.8
Gahanna Woods	5	132.9	15	8.6	Orange Road	5	184.59	14	8.3
Gahanna Woods	6	334.09	9.6	5.6	Orange Road	6	153.3	32	19
Gahanna Woods	7	313.3	22	13	Orange Road	7	188.62	6.7	3.9
Gahanna Woods	8	162.9	35	20	Orange Road	8	190.07	17	9.7

Table 13: β -glucosidase enzyme activity for November in high and low quality wetlands for each sampling station (n=8).

High Quality Wetland Sites					Low Quality Wetland Sites				
Site	Station	MAY AS Activity			Site	Station	MAY AS Activity		
		$\mu\text{g PNP}$ $\text{g}^{-1} \text{h}^{-1}$	SD	SE			$\mu\text{g PNP}$ $\text{g}^{-1} \text{h}^{-1}$	SD	SE
Bigwoods	1	250	27	16	Johnson Road	1	536	8	4
Bigwoods	2	66	2	1	Johnson Road	2	148	7	4
Bigwoods	3	177	13	7	Johnson Road	3	85	8	5
Bigwoods	4	186	23	14	Johnson Road	4	101	10	6
Bigwoods	5	182	8	5	Johnson Road	5	146	9	5
Bigwoods	6	78	3	2	Johnson Road	6	113	3	2
Bigwoods	7	90	7	4	Johnson Road	7	59	8	4
Bigwoods	8	47	5	3	Johnson Road	8	582	21	12
Gahanna Woods	1	126	9	5	Graham Road	1	159	19	11
Gahanna Woods	2	326	64	37	Graham Road	2	111	12	7
Gahanna Woods	3	483	12	7	Graham Road	3	124	17	10
Gahanna Woods	4	409	26	15	Graham Road	4	123	17	10
Gahanna Woods	5	351	19	11	Graham Road	5	192	18	11
Gahanna Woods	6	299	17	10	Graham Road	6	197	7	4
Gahanna Woods	7	100	16	9	Graham Road	7	212	15	8
Gahanna Woods	8	146	11	7	Graham Road	8	148	16	9
Lawrence Woods	1	48	8	5	Orange Road	1	349	68	39
Lawrence Woods	2	153	40	23	Orange Road	2	209	19	11
Lawrence Woods	3	137	27	16	Orange Road	3	241	22	13
Lawrence Woods	4	158	21	12	Orange Road	4	172	5	3
Lawrence Woods	5	102	2	1	Orange Road	5	246	12	7
Lawrence Woods	6	181	31	18	Orange Road	6	155	7	4
Lawrence Woods	7	126	25	14	Orange Road	7	301	42	24
Lawrence Woods	8	105	12	7	Orange Road	8	487	27	16

Table 14: Arylsulfatase enzyme activity for May in high and low quality wetlands for each sampling station (n=8).

High Quality Wetland Sites					Low Quality Wetland Sites				
Site	Station	MAY BG Activity			Site	Station	MAY BG Activity		
		$\mu\text{g PNP g}^{-1} \text{ h}^{-1}$	SD	SE			$\mu\text{g PNP g}^{-1} \text{ h}^{-1}$	SD	SE
Bigwoods	1	185.4	26	15	Johnson Road	1	160	7	4
Bigwoods	2	73.01	4.4	2.5	Johnson Road	2	52	24	14
Bigwoods	3	97.07	10	6	Johnson Road	3	26	3	2
Bigwoods	4	98.34	9	5.2	Johnson Road	4	22	1	1
Bigwoods	5	80.78	8.5	4.9	Johnson Road	5	66	3	2
Bigwoods	6	73.62	2.5	1.5	Johnson Road	6	88	11	7
Bigwoods	7	91.84	7.9	4.6	Johnson Road	7	39	7	4
Bigwoods	8	53.21	7.1	4.1	Johnson Road	8	162	6	4
Lawrence Woods	1	42.67	7.9	4.6	Graham Road	1	137	7	4
Lawrence Woods	2	201.85	15	8.4	Graham Road	2	138	3	2
Lawrence Woods	3	99.47	2.8	1.6	Graham Road	3	116	4	2
Lawrence Woods	4	118.24	8.6	5	Graham Road	4	112	1	1
Lawrence Woods	5	105.63	8.9	5.2	Graham Road	5	88	1	0
Lawrence Woods	6	81.255	0.5	0.3	Graham Road	6	128	14	8
Lawrence Woods	7	87.58	8.8	5.1	Graham Road	7	160	13	7
Lawrence Woods	8	102.98	1.4	0.8	Graham Road	8	158	14	8
Gahanna Woods	1	86.82	7.4	4.3	Orange Road	1	139	17	10
Gahanna Woods	2	143.08	7.4	4.3	Orange Road	2	109	9	5
Gahanna Woods	3	288.07	14	10	Orange Road	3	98	9	5
Gahanna Woods	4	249.4	20	11	Orange Road	4	100	10	5
Gahanna Woods	5	113.01	8.3	4.8	Orange Road	5	89	5	3
Gahanna Woods	6	163.09	8.4	4.9	Orange Road	6	75	2	1
Gahanna Woods	7	23.97	5.9	3.4	Orange Road	7	110	15	9
Gahanna Woods	8	87.7	26	15	Orange Road	8	194	11	6

Table 15: β -glucosidase enzyme activity for May in high and low quality wetlands for each sampling station (n=8).

% WSA Fractions High Quality Wetlands				
Site	Station	2-8 mm	1-2 mm	0.25-1 mm
Bigwoods	1			
Bigwoods	2	23.7	21.8	14.5
Bigwoods	3	37.8	21.6	16.0
Bigwoods	4	38.2	13.2	15.9
Bigwoods	5	46.8	20.8	13.9
Bigwoods	6			
Bigwoods	7	16.2	31.6	24.1
Bigwoods	8	30.5	19.8	14.5
Lawrence Woods	1	82.0	3.6	2.5
Lawrence Woods	2	68.5	7.5	4.8
Lawrence Woods	3	63.5	13.6	7.5
Lawrence Woods	4	76.3	5.4	3.3
Lawrence Woods	5	75.0	8.8	
Lawrence Woods	6	41.8	13.7	10.2
Lawrence Woods	7	70.5	11.3	6.8
Lawrence Woods	8	41.5	13.8	11.3
Gahanna Woods	1	40.5	18.9	20.8
Gahanna Woods	2	75.2	20.9	29.5
Gahanna Woods	3			
Gahanna Woods	4	21.8	22.7	22.2
Gahanna Woods	5	39.6	18.8	19.9
Gahanna Woods	6	27.8	24.8	20.2
Gahanna Woods	7	46.2	7.9	11.9
Gahanna Woods	8	69.9	11.7	7.8

Table 16: Water stable aggregate distribution for high quality wetlands (n=3).

% WSA Fractions Low Quality Wetlands				
Site	Station	2-8 mm	1-2 mm	0.25-1 mm
Johnson Road	1	56.8	16.7	14.5
Johnson Road	2	36.5	23.9	20.8
Johnson Road	3	48.7	16.0	19.4
Johnson Road	4	48.1	34.5	16.2
Johnson Road	5	50.5	15.3	16.5
Johnson Road	6	27.7	29.2	25.5
Johnson Road	7	75.9	5.3	4.7
Johnson Road	8	77.3	6.1	6.2
Graham Road	1			
Graham Road	2	76.7	4.7	2.9
Graham Road	3	79.6	1.1	1.2
Graham Road	4	82.9	7.1	3.1
Graham Road	5	94.2	2.6	0.9
Graham Road	6	87.8	3.9	1.4
Graham Road	7	82.5	10.0	1.3
Graham Road	8	84.0	5.9	2.4
Orange Road	1	18.5	28.5	26.3
Orange Road	2	38.8	22.4	15.9
Orange Road	3	53.4	18.3	12.3
Orange Road	4	54.8	18.2	10.5
Orange Road	5			
Orange Road	6	44.3	16.0	9.6
Orange Road	7	74.9	9.3	4.8
Orange Road	8	36.6	15.7	12.2

Table 17: Water stable aggregate distribution for low quality wetlands (n=3).

Bulk Density High Quality Wetlands			Bulk Density Low Quality Wetlands		
Site Name	Station	g/ cm³	Site Name	Station	g/ cm³
Bigwoods	1	0.17	Johnson Road	1	0.68
Bigwoods	2	0.30	Johnson Road	2	0.71
Bigwoods	3	0.12	Johnson Road	3	0.35
Bigwoods	4	0.20	Johnson Road	4	0.66
Bigwoods	5	0.33	Johnson Road	5	0.66
Bigwoods	6	0.14	Johnson Road	6	0.44
Bigwoods	7	0.35	Johnson Road	7	0.34
Bigwoods	8	0.23	Johnson Road	8	0.62
Lawrence Woods	1	0.39	Graham Road	1	0.72
Lawrence Woods	2	0.55	Graham Road	2	0.56
Lawrence Woods	3	0.70	Graham Road	3	0.52
Lawrence Woods	4	0.45	Graham Road	4	0.67
Lawrence Woods	5	0.64	Graham Road	5	0.64
Lawrence Woods	6	0.48	Graham Road	6	0.75
Lawrence Woods	7	0.52	Graham Road	7	0.74
Lawrence Woods	8	0.11	Graham Road	8	0.67
Gahanna Woods	1	0.54	Orange Road	1	0.57
Gahanna Woods	2	0.81	Orange Road	2	0.72
Gahanna Woods	3	0.69	Orange Road	3	0.80
Gahanna Woods	4	0.75	Orange Road	4	0.61
Gahanna Woods	5	0.69	Orange Road	5	0.59
Gahanna Woods	6	0.52	Orange Road	6	0.75
Gahanna Woods	7	0.67	Orange Road	7	0.55
Gahanna Woods	8	0.44	Orange Road	8	0.78

Table 18: Bulk density (g/ cm³) for high and low quality wetlands for each sampling stations (n=8).

Chemical Parameters High Quality Wetlands

Site	Station	% C	%N	P µg/g	S µg/g
Bigwoods	1	34	2.2	1097.5	10872
Bigwoods	2	40	2.3	1094.7	13335
Bigwoods	3	8	0.6	1143.8	8977
Bigwoods	4	34	2.4	1279.5	12500
Bigwoods	5	13	0.8	876.5	3784
Bigwoods	6	38	2.5	1173.9	13341
Bigwoods	7	14	1.0	1165.8	4436
Bigwoods	8	27	1.8	1289.2	8592
Lawrence Woods	1	9	0.7	796.6	2144
Lawrence Woods	2	12	0.9	763.3	2564
Lawrence Woods	3	13	0.9	688.1	2745
Lawrence Woods	4	11	0.7	903.9	2473
Lawrence Woods	5	10	0.7	1113.8	1377
Lawrence Woods	6	12	0.8	710.8	2732
Lawrence Woods	7	6	0.5	811.1	2214
Lawrence Woods	8	12	0.8	793.4	3126
Gahanna Woods	1	11	0.8	1038.1	3299
Gahanna Woods	2	14	0.9	983.2	3180
Gahanna Woods	3	6	0.4	679.4	1272
Gahanna Woods	4	19	1.1	986.9	4639
Gahanna Woods	5	6	0.4	670.2	1119
Gahanna Woods	6	9	0.6	903.1	2473
Gahanna Woods	7	10	0.6	804.2	2190
Gahanna Woods	8	17	1.1	1231.9	6090

Table 19: Soil chemical carbon (C), nitrogen (N), phosphorus (P), and sulfur (S) in high quality wetlands for each sampling station (n=8).

Chemical Parameters Low Quality Wetlands

Site Name	Station	% C	%N	P µg/g	S µg/g
Johnson Road	1	9	0.6	764	1554
Johnson Road	2	7	0.5	878	1082
Johnson Road	3	9	0.7	962	2410
Johnson Road	4	7	0.6	956	1952
Johnson Road	5	8	0.6	900	2056
Johnson Road	6	7	0.5	634	1410
Johnson Road	7	10	0.9	1013	3381
Johnson Road	8	7	0.5	875	1096
Graham Road	1	7	0.5	876	1672
Graham Road	2	7	0.5	595	1643
Graham Road	3	6	0.5	946	1060
Graham Road	4	7	0.5	678	1484
Graham Road	5	6	0.5	780	1572
Graham Road	6	9	0.6	750	2615
Graham Road	7	8	0.6	746	2307
Graham Road	8	6	0.4	729	1357
Orange Road	1	10	0.8	1245	1527
Orange Road	2	9	0.6	1114	1305
Orange Road	3	8	0.6	1098	1081
Orange Road	4	8	0.6	902	1043
Orange Road	5	8	0.6	877	1982
Orange Road	6	7	0.6	997	1121
Orange Road	7	12	0.8	1187	1616
Orange Road	8	5	0.42	1107	796

Table 20: Soil chemical carbon (C), nitrogen (N), phosphorus (P), and sulfur (S) in low quality wetlands for each sampling station (n=8)

Soil Moisture High Quality Wetlands

Site	Station	July	August	November	May
Bigwoods	1	2.46	1.06	0.87	0.68
Bigwoods	2	2.18	3.99	1.51	2.18
Bigwoods	3	2.53	3.65	*	0.82
Bigwoods	4	0.74	1.57	1.00	0.91
Bigwoods	5	2.21	0.75	0.44	0.85
Bigwoods	6	0.87	1.11	1.30	1.99
Bigwoods	7	1.92	0.86	0.72	1.00
Bigwoods	8	1.00	0.97	*	2.35
Lawrence Woods	1	0.95	1.72	0.41	0.37
Lawrence Woods	2	1.66	1.40	*	0.34
Lawrence Woods	3	0.66	0.57	0.37	0.44
Lawrence Woods	4	1.32	2.09	0.57	0.28
Lawrence Woods	5	0.51	0.98	0.54	0.76
Lawrence Woods	6	1.61	1.39	0.35	0.49
Lawrence Woods	7	0.30	0.82	*	1.06
Lawrence Woods	8	0.76	1.71	1.05	0.34
Gahanna Woods	1	0.20	0.40	0.32	0.33
Gahanna Woods	2	0.50	0.35	0.33	0.30
Gahanna Woods	3	0.17	0.31	0.31	0.41
Gahanna Woods	4	0.38	0.31	0.28	0.52
Gahanna Woods	5	0.53	0.55	0.34	0.40
Gahanna Woods	6	1.92	0.38	0.32	0.31
Gahanna Woods	7	0.50	0.77	0.32	0.31
Gahanna Woods	8	0.62	0.48	0.33	0.31

Table 21: Soil moisture data in high quality wetlands for each sampling station (n=8).

Soil Moisture Low Quality Wetlands

Site	Station	July	August	November	May
Johnson Road	1	0.25	0.31	0.29	0.35
Johnson Road	2	0.51	0.34	0.31	0.35
Johnson Road	3	1.32	0.45	0.50	0.39
Johnson Road	4	0.92	0.39	0.45	0.75
Johnson Road	5	0.56	0.34	0.33	0.29
Johnson Road	6	1.00	0.28	0.31	0.60
Johnson Road	7	1.05	0.79	0.54	0.19
Johnson Road	8	0.01	0.25	0.28	0.57
Graham Road	1	0.16	0.42	0.40	0.50
Graham Road	2	0.14	0.38	0.50	0.61
Graham Road	3	0.11	0.38	0.44	0.36
Graham Road	4	0.24	0.38	0.42	0.27
Graham Road	5	0.11	0.33	0.39	0.40
Graham Road	6	0.04	0.39	0.53	0.36
Graham Road	7	0.05	0.27	0.49	0.43
Graham Road	8	0.33	0.37	0.47	0.24
Orange Road	1	0.29	0.42	0.45	0.26
Orange Road	2	0.32	0.39	0.39	0.32
Orange Road	3	0.38	0.46	0.38	0.43
Orange Road	4	0.30	0.34	0.46	0.68
Orange Road	5	0.25	0.37	0.49	0.39
Orange Road	6	0.28	0.35	0.47	0.45
Orange Road	7	0.35	0.42	0.48	0.17
Orange Road	8	0.27	0.46	0.36	0.00

Table 22: Soil moisture data in low quality wetlands for each sampling station (n=8).

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