WETLAND ASSESSMENT AND NUTRIENT DYNAMICS IN NORTH DAKOTA

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

Wetlands provide a variety of services and functions. Studies have highlighted the importance of wetlands in water purification, groundwater replenishment, flood control, sediment and nutrient retention and export, biodiversity, and climate change mitigation and adaptation. Additionally, wetlands are assets to food, fiber, cultural values, recreation, and tourism. These ecosystem services are provided to society free of charge and when eliminated can have negative implications. Therefore, wetland management is important, as wetlands can be lost to agriculture and urbanization. Monitoring wetland condition is a tool to analyze human impact on wetlands. Various types of wetland assessments have been created to measure biological condition. These include vegetative, rapid, functional, and intensive assessments. Data collected from assessments can be utilized for further study and analysis in addition to measuring condition. Physical characteristics can be identified that correlate with wetland condition, which provide clues to how well a wetland is functioning.

Wetlands are important to nutrient cycling and storage. The levels of nutrients in vegetation, soil, and water may vary based on parent material, surrounding land use, hydrology, the type of wetland, and types of species present. Wetlands can filter excess nutrients from agricultural and urban runoff to a certain extent. High nutrient loads can cause eutrophication and anoxia and affect the biological community and wetland function. High levels of nutrients and disturbance have been correlated with exotic species invasion and decreased diversity. Stable isotopes of nitrogen and carbon have been applied to measure anthropogenic impact, nutrient sources, and denitrification levels.

Four studies were completed during the summers of 2011 and 2012 on wetland assessment and nutrient dynamics across the state of North Dakota. The results indicated the importance of land use regarding wetland condition and nutrient levels. Wetlands in cropland tended to have lower floristic quality and biological condition and higher stable isotope $\delta^{15}N$ values. Additionally, levels of phosphorus, nitrogen, and carbon differed by plant type with some indication that cattail invasion alters nutrient cycling. Furthermore, classification and regression tree modeling links wetland buffer, soil, and water data to wetland condition.

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Lastly, I must thank all of my family and friends. I would like to thank my parents, Don and Sharon Meyers, for their unwavering support, faith, and love. I would like to thank my brother, Andrew Meyers, for being awesome in general. I would like to thank my grandparents, Bill and Marilyn Fairman and Don and Berniece Meyers, for their encouragement and guidance. I would like to thank Dirk Churchill for always having my back and reassuring me whenever I doubted myself. I would like to thank the rest of my family and friends for always being there to lend an ear to listen and a shoulder to lean on. You have all been an important part of this journey.

Lindsey Michele Meyers

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GENERAL INTRODUCTION

Little is known about the biological condition of the nation’s wetlands. Therefore, in the summer of 2011, the U.S. Environmental Protection Agency (USEPA) conducted the first ever nationwide wetland assessment. The National Wetland Condition Assessment (NWCA) collected data for the wetland buffer, hydrology, water quality, plants, soils, algae, and a rapid assessment (U.S. Environmental Protection Agency 2011). The USEPA is implementing the NWCA along with other lake and stream assessments in order to understand water quality issues and guide proper management of the nation’s water bodies. The NWCA is intended to identify wetland stressors and analyze the ecological integrity of wetlands so that wetland condition can be monitored. The USEPA collaborated with the U.S. Fish and Wildlife Service (USFWS), Natural Resource Conservation Service (NRCS), U.S. Department of Agriculture (USDA), and many other federal and state agencies, tribal programs, and academic, non-profit, and private organizations to complete the NWCA.

In North Dakota, North Dakota State University (NDSU) took the lead on the NWCA project. In order to provide statistically relevant data for the state, the sample size of 11 wetlands was increased to 53 wetlands. During the summer of 2010, permission to sample wetlands was acquired from landowners, and in 2011 the NWCA was completed. NDSU performed additional studies at each wetland in order to evaluate statewide wetland condition and nutrient levels in the vegetation and soils. The additional data collected included three regionally developed wetland assessment methods – Index of Plant Community Integrity (IPCI, Hargiss et al. 2008), North Dakota Rapid Assessment Method (NDRAM, Hargiss 2009), and Hydrogeomorphic (HGM) Model (Gilbert et al. 2006) – and nutrient samples of phosphorus (P) in plants and soils and carbon (C) and nitrogen (N) in plants.

The IPCI was used to assess wetland condition according to vegetation. It specifically measures vegetative aerial cover and species composition (Hargiss et al. 2008). Condition is then analyzed using nine metrics as outlined in detail by Hargiss et al. (2008). The NDRAM was used to rapidly assess the condition of wetlands based on vegetation, land use, habitat alteration, and disturbance/stressors (Hargiss 2009). The HGM Model, which was developed by the Army Corps of Engineers (COE) and NRCS, uses reference standards to assess wetland function (Gilbert et al. 2006). The HGM Model measures landscape, hydrologic, soil, and land use attributes in order to determine the extent of wetland alteration. GPS and GIS information, soil measurements, vegetation data, and wetland and catchment basin area assessments were measured and analyzed using several Functional Capacity Indices (FCI).

In addition to overall quality or condition, nutrient storage and cycling is another important measure in wetlands. Freshwater aquatic systems can be greatly affected by nutrient runoff from adjacent lands (Cooper 1993). Additionally, the amount and type of nutrients stored in wetlands can affect the overall biological community and functioning of the wetland. Wetlands are useful buffers and can be sinks for excess nutrients at low concentrations (Howard-Williams 1985). Additionally, nutrient accumulation in wetlands can influence species composition and productivity. It is not certain how C, N, and P are stored in North Dakota wetlands. Others have found that there is a significant increase in P levels in wetland soils located around agricultural lands (Reddy and DeLaune 2008). It is expected that more disturbed wetlands will have greater nutrient loadings, which could result in changes to the plant community. This may be especially prevalent in wetlands dominated by cattails (*Typha* species). Therefore, data is needed for accurate measurement of nutrients in wetlands and how they may be affected by land use practices.

As part of the NWCA, N and C soil isotope data were collected. The natural abundance of soil isotopes have been used to measure natural processes such as nutrient cycling and nutrient sources (Peterson and Fry 1987). They have also been utilized to reflect past land uses and levels of human disturbance to ecosystems (Koerner et al. 1999, Elliott and Brush 2006). Stable isotope levels in wetland soils can be used to indicate changes in land use and nutrient inputs, and has never been completed before in North Dakota wetlands (Chang et al. 2002, Elliott and Brush 2006). Natural abundance techniques using stable isotopes need to be developed for wetland systems. This study is the first step in applying stable isotope natural abundance techniques in Northern Prairie wetlands.

In addition to the 2011 data, 18 wetlands were sampled in the summer of 2012 for another study. These wetlands were previously in cropland and had been excavated for sediment removal in order to decrease cattail cover. The same methods used in 2011 minus the NWCA were used to sample these wetlands. Smith (2011) found that sediment removal had reduced cattail cover in the shallow marsh and that vegetative composition was similar to native wetlands that had not been surrounded by cropland. Therefore, we wanted to analyze the nutrient content of these wetlands.

This dissertation has been written in four papers. Paper 1 analyzes the 2011 nutrient data and relates it to cattail biomass, surrounding land use, and floristic quality. Paper 2 is the analysis from the 2012 data in the wetlands with sediment removal. The results were compared with values from Paper 1. Paper 3 is the synthesis of the soil isotopes; variables such as surrounding land use, wetland condition, floristic quality, and soil data from the NWCA were used to compare with the soil isotope data. The large amount of data collected in 2011 from the four wetland assessments and nutrient samples was modelled in Paper 4 using Classification and

Regression Trees (CART). The results from the CART models are compared with the IPCI and NDRAM results. The goal of these studies was to collect statewide wetland condition and nutrient data that can provide a baseline for future studies.

PAPER 1. WETLAND PLANT NUTREINT CONTENT, CATTAIL BIOMASS, FLORISTIC QUALITY, AND SOIL PHOSPHORUS

Introduction

Nutrient enrichment or limitation can lead to declines in species diversity, exotic invasion, and changes in species composition (Tilman and Pacala 1993, Bedford et al. 1999). Moderate nutrient levels promote optimal diversity allowing native and rare species to compete with invasive and exotic species. Shifts in nutrient levels in wetlands can cause eutrophication, exotic invasion, and declines in species diversity (Bedford et al. 1999). In wetlands with high nutrient input, plant species diversity has severely declined (Verhoeven et al. 1993). These effects are seen in wetlands that are severely impacted by agricultural practices and urban development, which are common in the United States (Simmons et al. 1992, Jordan et al. 1997). One of the predominant land use practices in the Northern Great Plains is agriculture (Martin and Hartman 1987, Wright and Wimberly 2013). Agricultural practices can increase sediment deposition in wetlands, which can transport nutrients, pesticides, and/or other contaminants into wetlands. Long-term sediment deposition can reduce the size or eliminate wetlands. Agricultural lands can result in wetland degradation, with wetlands in the poorest condition most often associated with cropping (Kantrud and Newton 1996). Therefore, there is concern about declines in species diversity and detrimental alteration of wetlands (Russi et al. 2013).

Due to worldwide declines in species diversity and habitat loss, ecologists have sought ways to measure the quality of natural systems and monitor changes over time. Wetland assessments have been developed regionally and nationwide for these purposes (Kantrud and Newton 1996, Hargiss et al. 2008, U.S. Environmental Protection Agency 2011). Assessment using floristic quality follows the premise that disturbance significantly affects the composition of plant communities (Kantrud and Newton 1996, Hargiss et al. 2008). Floristic quality indexes (FQIs) have been used to determine how conservative an area is toward native based on the flora present at the wetland and are region-specific (Wilhelm and Ladd 1988, Swink and Wilhelm 1994, Taft et al. 1997).

In addition to condition, plants have been used as an indicator of nutrient availability in the soil (Koerselman and Meuleman 1996). Plants may regulate nutrient levels to a certain extent, but nutrient inputs into an ecosystem result in increased nutrient levels in vegetation (Shaver and Melillo 1984). Phosphorus (P) and nitrogen (N) nutrient levels in plants can be used to indicate if there are nutrient limitations or enrichments in wetlands. Koerselman and Meuleman (1996) and Verhoeven et al. (1996) showed that plant N:P ratios could be used to determine the limiting nutrient in wetlands. Wetlands with plant N:P > 16 were P-limited, < 14 were N-limited, and between 14 and 16 were co-limited by N and P. This was expanded upon by Bedford et al. (1999) and applied in plants and soils of North American wetlands. Their conclusions showed marshes having significantly lower plant N:P ratios than bogs, fens, and swamps. Furthermore, surface soil N:P ratios were significantly lower in marshes and swamps than in bogs and fens, and marshes were the only wetland type to consistently indicate N-limitation (N:P < 14) in plants and soils.

Some wetland systems with nutrient enrichment have shown a rise in cattail cover (Maio and Sklar 1998, Newman et al. 1998). For example, anthropogenic disturbance in the Florida Everglades, such as increases in nutrient-rich agricultural runoff and agricultural ditching, has altered floristic composition and hydrology of this wetland complex (Newman et al. 1998). Nutrient enrichment has also led to increased soil phosphorus levels (Newman et al. 1998, DeBusk et al. 2001). Cattails were better adapted to high phosphorus environments and had higher seed output than sawgrass, allowing the shift to a cattail-dominated marsh community under disturbed conditions (Miao and Sklar 1998). Water depth and litter cover also have significant effects on cattail spread (Wilcox et al. 2008, Farrer and Goldberg 2009). Stable, moderate flooding promoted cattail expansion around Lake Ontario since cattails could outcompete sedges and grasses under these conditions (Wilcox et al. 2008). Furthermore, Farrer and Goldberg (2009) found that cattail litter may create a positive feedback that promotes further cattail invasion. Higher litter depths promoted taller cattails causing increased shading. These changes decreased the abundance and diversity of native plants and promoted cattail invasion. Therefore, anthropogenic effects as well as cattail-induced changes in the environment may promote cattail invasion and persistence. In the past few decades, cover of hybrid cattail, *Typha x glauca* Godr., has increased in wetlands in the Northern Great Plains (Galatowitsch et al. 1999). The causal pathway of cattail invasion of marshes in the Northern Great Plains has yet to be determined.

This study was conducted to survey wetlands across North Dakota of various types and surrounded by several land uses. This survey provided information on floristic quality; plant carbon (C), N and P nutrient levels; and soil P (P_{soil}) levels in different land use settings, different landscape positions within the wetland basin, and for different plant types. The objectives of this study were to 1) compare the biomass of different plant types and FQI scores between surrounding land uses and landscape positions; 2) compare plant C:N ($C:N_{plant}$), N:P ($N:P_{plant}$), and P (P_{plant}) of different plant types, surrounding land use, and landscape position; and 3) correlate P_{plant} with cattail biomass and P_{soil}. We predicted that wetlands in cropland would have reduced floristic quality and increased nutrient levels (Martin and Hartman 1987, Jordan et al. 1997). We also hypothesized that cattails would correlate with high P levels in the plants and soil (Newman et al. 1998, DeBusk et al. 2001). The data were intended to provide a baseline for wetlands to develop condition indices and inform future studies of nutrient cycling, land use changes, and plant community composition in North Dakota wetlands.

Methods

Study Sites

Fifty-five wetlands were sampled in the summer of 2011 as part of the United States Environmental Protection Agency's (USEPA) National Wetland Condition Assessment (NWCA, Figure 1). Fifty-three of the wetlands were randomly chosen from the Fish and Wildlife Services' Status and Trends Plots and two were selected as reference wetlands. Reference wetlands were selected by the USEPA for the NWCA. The reference wetlands were intended to represent the most native wetlands. According to the Status and Trends wetland classifications, four different wetland types were sampled (Dahl 2011). Fifty were emergent palustrine wetlands, 3 were forested palustrine wetlands, 1 was a scrub shrub palustrine wetland, and 1 was a farmed palustrine wetland.

At each wetland, three landscape positions – shallow marsh, wet meadow, and upland – were delineated based on topography and vegetation (Stewart and Kantrud 1971). The shallow marsh and wet meadow zones were located in the wetland. Shallow marsh zones contain water most of the year, and wet meadow zones hold water after spring melt and heavy rainfall events (Stewart and Kantrud 1971). The upland is the area immediately surrounding the wetland edge, which is only inundated during periods of unusually high water levels. For this study, the upland was defined as at least a 1 m elevation rise and within 50 m of the wetland edge. A list of all plant species present was recorded by landscape position. Land use surrounding each wetland was defined as farmed, grazed/hayed, or idle. A comprehensive plant species list is located in Appendix B.

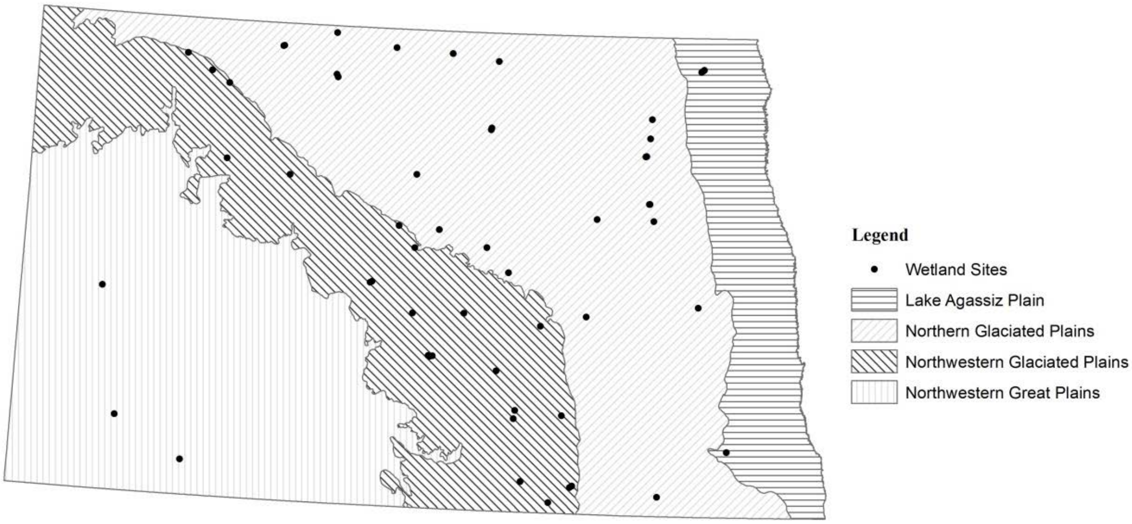

Figure 1. Locations of 55 wetland sites across North Dakota sampled in the summer of 2011. The legend indicates the labels of the four main ecoregions in the state: Lake Agassiz Plain, Northern Glaciated Plains, Northwestern Glaciated Plains, and Northwestern Great Plains. For a description of the ecoregions see Bryce et al. (1998). Refer to Appendix A for a list of wetland locations.

Vegetation Samples

Vegetation samples were collected within each landscape position of the wetland. Samples were not collected in upland landscape positions that were actively cropped. At each landscape position, five 0.25 m^2 quadrats of live vegetation were clipped 2 cm from the soil surface and separated by plant type. The plant types were cool season grasses, warm season grasses, grass-likes (sedges, rushes, etc.), forbs and shrubs (current year’s growth), and cattails. Cattails included *Typha latifolia* L., *Typha angustifolia* L., and *Typha x glauca* Godr. Most cattails were *Typha x glauca* Godr. This resulted in a total of 15 quadrats clipped per wetland.

Samples were stored in labelled paper bags. Several wetlands were sampled per week, so samples collected at the beginning of the week were stored in the back of trucks and laid out during the day (unless it was raining). Once all samples were collected for the week, they were transported to North Dakota State University (NDSU) and placed in a large drying oven for two weeks at 90 °C. At this time, vegetation was checked for dryness and removed if dry; otherwise they were left in the dryer for a few more days. The dried vegetation was weighed for biomass and then ground through a 2 mm screen using a Wiley Mill. Wet plant weight was not measured.

Biomass measurements were adjusted according to time of collection, plant type, and if the zone had been grazed to represent maximum plant growth. This was accomplished using plant growth curves and visual estimation of grazing severity (Sedivec et al. 2009, Sedivec et al. 2010). Based on recommendations by Sedivec et al. (2009) and Sedivec et al. (2010) and professional judgment, plant functional groups were adjusted according to time of harvest: cool season grasses, sedges and rushes, cattails, and forbs were considered at 70% growth from June 13th through June 17th, 80% growth from June 20th through June 24th, and 95% growth from June 27th through June 30th. Only seven sites had warm season grasses. The growth adjustments were as follows: 60% on June 21st and 90% from July 13th through 20th.

Nutrient analysis of vegetation samples was completed by the NDSU Soil Testing Laboratory from October of 2011 to August of 2012 using standard methods and procedures as outlined for the North Central Region (North Central Region-13 1998). Plant C and N were analyzed using an Elementar Vario Macro Cube CNS Analyzer with a thermal conductivity detector. P_{plant} was analyzed using a nitric acid digestion with peroxide using a block digester (Wolf et al. 2003). For the plant P, N, and C content data refer to Appendix C.

Soil Samples

Soil samples were collected at three locations within each landscape position. At each location, one 500 g soil core was collected at two depths – 0-15 cm and 15-30 cm from the soil surface – using a small metal soil corer. A total of 18 soil cores were collected per wetland (3 for each depth at each landscape position). Stepping or kneeling on areas for sample collection was avoided to prevent soil compaction around the soil pits. Samples were stored in coolers on ice at the site and kept on ice until return to NDSU. Upon return, samples were stored field-moist at 4°C until analyzed for P content.

The P analysis on the soil samples was completed by the North Dakota State University (NDSU) Soil Testing Laboratory from April to December of 2012 using standard methods and procedures as outlined for the North Central Region (North Central Region-13 1998). P_{soil} was analyzed using two extractions: water soluble extractions (WEP) to test the amount of P in solution in the soil and Olsen extractions (bicarbonate extraction) to test the amount of plant available P in the soil (Olsen et al. 1954, Self-Davis et al. 2009). Olsen extractions were completed 5 to 8 hours after adding the extracting solution. WEP samples were acidified with two drops of Hydrochloric acid (HCl, pH of 2.0) and frozen one day to two weeks until analysis when they were left to thaw at room temperature. For quality assurance, a duplicate, blank, and standard was run every tenth sample. The final units of measurement were mg/kg and converted to ppm. The detections limits for Olsen P were 0 to 4 ppm and WEP were 0 to 1 ppm.

Statistical Analysis

Floristic quality was calculated for each landscape position using the Floristic Quality Index (FQI) for the Dakotas and adjacent grasslands (The Northern Great Plains Floristic Quality Assessment Panel 2001). Plant species were assigned a coefficient of conservatism, or c-value, representing the tolerance of the species to disturbance. Higher c-values were assigned to species that were more sensitive to disturbance with a higher fidelity to a specific habitat. The FQI is the average c-value multiplied by the square root of the total number of species and is unitless. For cattails n = 27, shallow marsh grasses and grass-likes n = 38, shallow marsh forbs and shrubs n = 21, wet meadow grasses and grass-likes n = 53, wet meadow forbs and shrubs n = 44, upland grasses and grass-likes n = 48, and upland forbs and shrubs n = 42.

In total, 27 wetlands contained cattails, 38 wetlands contained shallow marsh grasses and grass-likes, 21 wetlands contained shallow marsh forbs and shrubs, 53 wetlands contained wet meadow grasses and grass-likes, 44 wetlands contained wet meadow forbs and shrubs, 48 wetlands contained upland grasses and grass-likes, and 42 wetlands contained upland forbs and shrubs for a total of 273 samples for biomass and nutrient analysis. Multi-Response Permutation Procedures (MRPP) were calculated to test between groups for landscape position, land use, and plant type using PC-ORD version 6.0 software (McCune and Mefford 2011). This was completed for plant N:P_{plant}, C:N_{plant}, P_{plant}, FQI scores, and P_{total} (plant and Olsen soil P combined). The Bonferroni correction was used to correct for multiple comparisons. Linear regression was used to model correlations between P_{soil} and P_{plant}, P_{plant} and cattail biomass, and P_{soil} and cattail biomass. Linear regressions were performed for each soil extraction method (Olsen and WEP) and depth (0-15 and 15-30 cm). We defined a p-value of < 0.05 as denoting significant differences and a p-value of < 0.10 as denoting marginal differences. MRPP results were reported as means with standard errors. Linear regressions and graphs were created in in MS Excel 2010. In graphs and in the text, the means are reported with standard error (SE).

Results

Plant Types

Comparisons among groups plant type from the MRPP analysis showed several key differences. Forbs and shrubs were significantly lower in biomass than cattails and grasses and grass-likes regardless of landscape position (Figure 2a). Mean shallow marsh, wet meadow, and upland forbs and shrubs were 546 (±215), 340 (±51.3), and 490 (±67.3) kg/ha, respectively. Mean shallow marsh, wet meadow, and upland grasses and grass-likes were 1070 (±136), 1810 (±181), and 1750 (±198) kg/ha, respectively, and cattails were 2020 (±337) kg/ha.

Mean C:N_{plant} was significantly different among plant types (Figure 2b). The mean C:N_{plant} for wet meadow grasses and grass-likes was higher than all other plant types at 35.3 (±2.30). This was significantly higher than cattails and shallow marsh, wet meadow, and upland forbs and shrubs (22.0 ±1.77, 16.6 ±1.18, 18.3 ±1.06, and 17.6 ±1.14, respectively). The shallow marsh and upland grasses and grass-likes were 25.7 (±2.57) and 29.5 (±2.21), respectively. These were significantly higher than the shallow marsh, wet meadow, and upland forbs and shrubs, but not cattails. Cattails were also significantly higher than the shallow marsh and wet meadow forbs and shrubs.

Mean P_{plant} was significantly different for certain plant types (Figure 2c). Cattails were significantly greater in P_{plant} than all other plant types at 3.97 (±0.58) kg/ha. Wet meadow forbs were significantly lower in P_{plant} than shallow marsh, wet meadow, and upland grasses and grass-likes (0.83 ±0.18 kg/ha, 1.90 ±0.26 kg/ha, 1.92 ±0.25 kg/ha, and 2.10 ±0.34 kg/ha, respectively). P_{plant} in shallow marsh and upland forbs and shrubs was not significantly different than the wet meadow forbs and shrubs or grasses and grass-likes, regardless of landscape position (2.03 ±0.85 kg/ha and 1.10 ±0.20 kg/ha, for shallow marsh and upland forbs and shrubs, respectively).

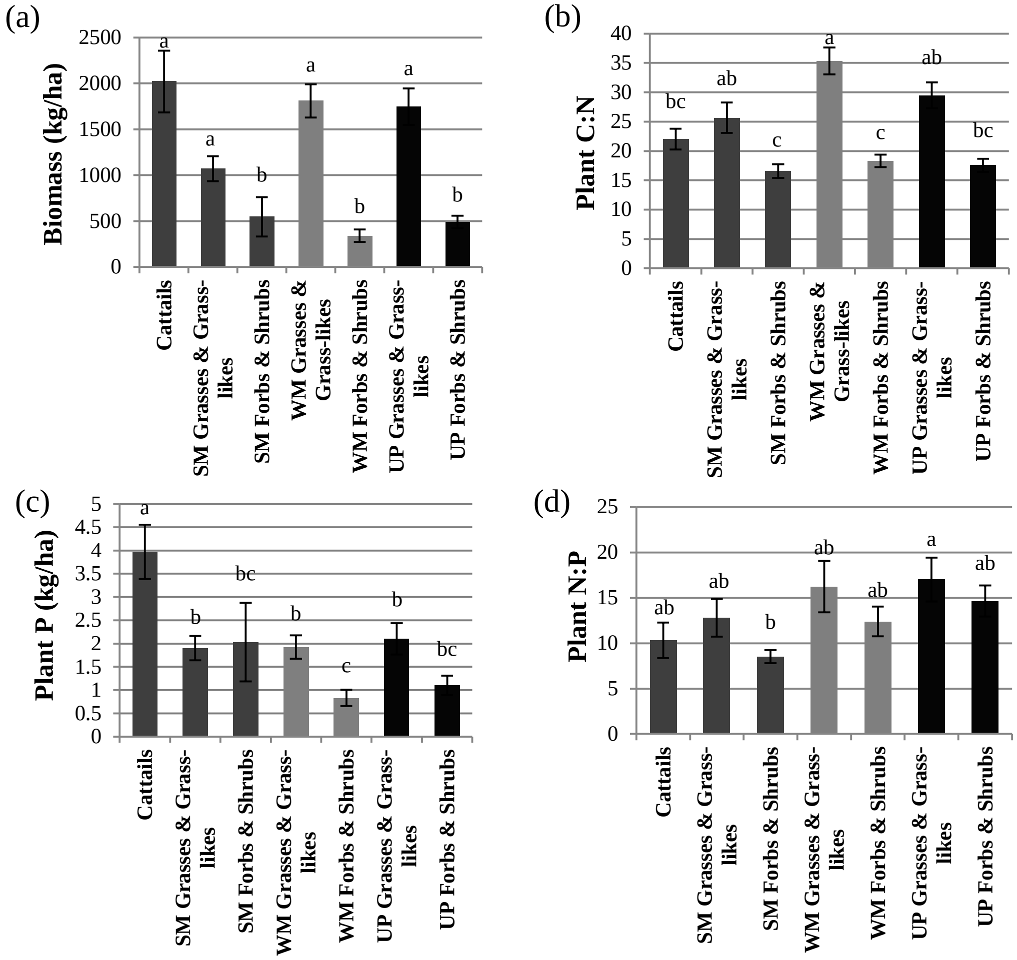

Figure 2. Graphs of mean (a) biomass, (b) plant C:N, (c) plant P, and (d) plant N:P for plant type. Bars represent standard errors. SM = shallow marsh, WM = wet meadow, and UP = upland. For cattails n = 27, shallow marsh grasses and grass-likes n = 38, shallow marsh forbs and shrubs n = 21, wet meadow grasses and grass-likes n = 53, wet meadow forbs and shrubs n = 44, upland grasses and grass-likes n = 48, and upland forbs and shrubs n = 42. Different letters denote significant differences ($p < 0.05$).

For plant type, $N:P_{plant}$ was significantly lower in shallow marsh forbs and shrubs than in upland grasses and grass-likes (8.54 ±0.72 and 17.0 ±2.40, respectively; Figure 2d). Cattails, shallow marsh and wet meadow grasses and grass-likes, and wet meadow and upland forbs and shrubs were not significantly different than any other plant type (10.3 ±1.96, 12.8 ±2.07, 16.2 ±2.82, 12.4 ±1.64, and 14.6 ±1.70, respectively). Overall, cattails and grasses and grass-likes tended to contain higher biomass and store greater amounts of nutrients than forbs and shrubs for all analyses presented in Figure 2.

Landscape Position

FQI scores were significantly lower in shallow marsh zones than in wet meadow or low prairie zones (11.9 ±0.62, 17.7 ±1.07, and 18.0 ±1.49, respectively; Figure 3). C:N_{plant}, P_{plant}, N:P_{plant}, and P_{total} were not significantly different for landscape position (41.1 ±1.88, 3.97 ±0.42 kg/ha, 18.6 ±4.04, and 18.5 ±5.04 kg/ha, respectively; data not shown).

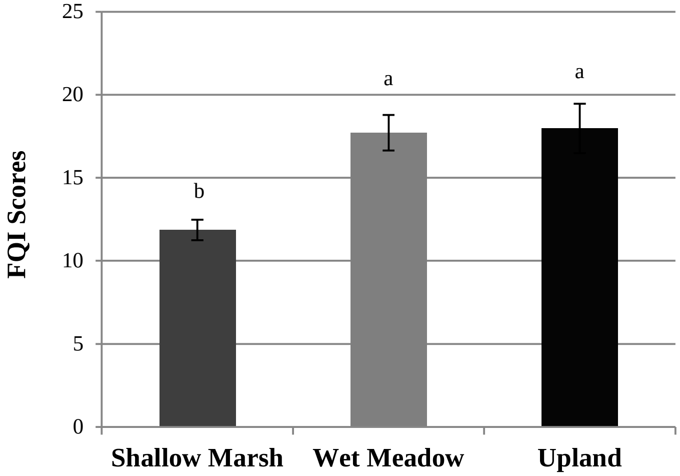

Figure 3. Graph of mean FQI scores and landscape position. Bars represent standard errors. Different letters denote significant differences ($p < 0.05$).

Land Use

Wetlands in cropped systems had a mean FQI score of 14.3 (±1.52) which was significantly lower than idle and grazed/hayed wetlands at 25.0 (±2.35) and 27.9 (±2.95), respectively (Figure 4a). C:N_{plant}, P_{lant}, and P_{total} were not significantly different for land use (23.1 ±2.12, 11.2 ±1.42 kg/ha, and 62.5 ±18.7 kg/ha, respectively; data not shown). N:P_{plant} was significantly lower in cropped systems (7.83 ±0.58) than idle systems (19.0 ±3.88) and marginally lower than grazed/hayed systems (12.2 ±1.53; Figure 4b).

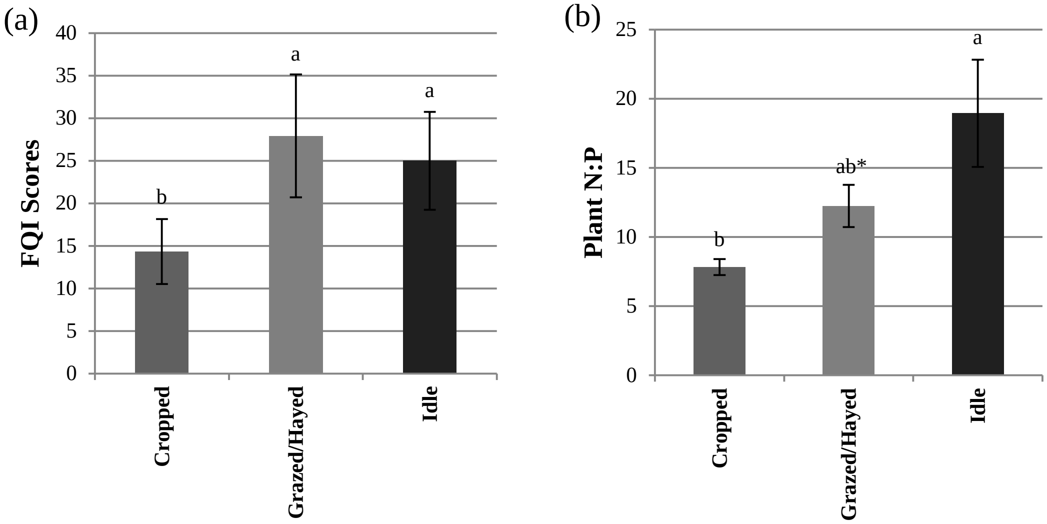

Figure 4. Graph of mean (a) FQI scores and (b) plant N:P for surrounding land use. Bars represent standard errors. For cropped n = 15, grazed/hayed n = 19, and idle n = 21. Different letters denote significant differences ($p < 0.05$). *Grazed/hayed wetlands were marginally different from cropped wetlands ($p < 0.10$).

Regressions

The linear regression models were either not significant, showed moderate to weak correlations, or had high variability. Increasing P_{plant} was correlated with decreasing FQI scores ($R = 0.31$, $p = 0.020$; Figure 5a), and increasing shallow marsh P_{plant} was significantly correlated with cattail biomass ($R = 0.40$, $p = 0.005$; Figure 5b). No correlations were found between P_{soil} and cattail biomass (data not shown). However, increasing P_{plant} was correlated with increasing P_{soil}, except for the shallow marsh at 0-15 cm (Table 1). The WEP at 15-30 cm showed a marginal correlation with P_{plant}. Overall, Olsen P tended to have higher R values than WEP, although these were weak correlations.

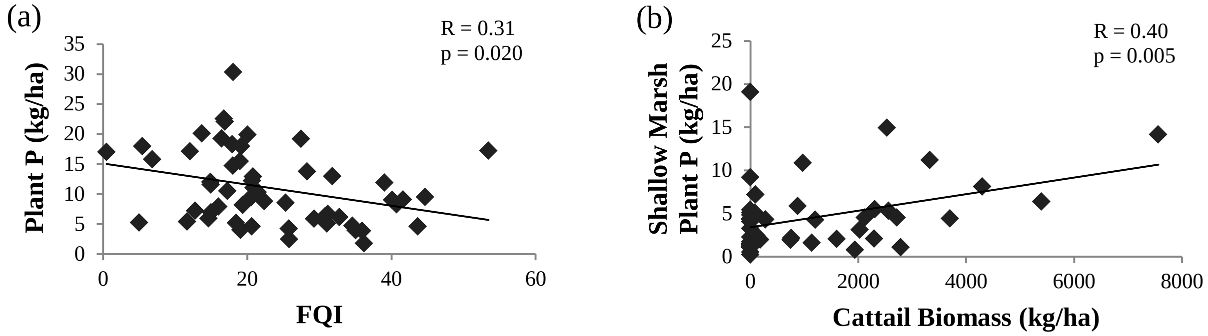

Figure 5. Linear correlations between (a) plant P and FQI and (b) shallow marsh plant P and cattail biomass.

Table 1. R values and p-values of linear correlations between cattail biomass and soil P for the Olsen extraction and WEP at 0-15 and 15-30 cm and plant P at different landscape positions and soil P for the Olsen extraction and WEP at 0-15 and 15-30 cm. Significant p-values ($p<0.05$) are in bold.

Soil P Extraction	Plant P Upland (kg/ha)	Plant P Wet Meadow (kg/ha)	Plant P Shallow Marsh (kg/ha)
Olsen (0-15 cm)	**R = 0.48** **p = 0.000**	**R = 0.56** **p = 0.000**	R = 0.17 p = 0.236
Olsen (15-30 cm)	**R = 0.48** **p = 0.001**	**R = 0.52** **p = 0.000**	**R = 0.33** **p = 0.023**
WEP (0-15 cm)	**R = 0.40** **p = 0.005**	**R = 0.27** **p = 0.049**	R = 0.16 p = 0.290
WEP (15-30 cm)	R = 0.25 p = 0.096	**R = 0.56** **p = 0.000**	**R = 0.39** **p = 0.007**

Discussion

Changes in land use can affect plant community composition, which can in turn affect nutrient cycling (Hobbie 1992, Verhoeven et al. 1996). Our results indicate that land use affects floristic quality and whether P or N is the limiting nutrient in the wetland. Our results also show that different plant types store different amounts of P, N, and C. Increasing P_{plant} is correlated with decreasing floristic quality, increasing cattail biomass, and increasing P_{soil}. This indicates that floristic quality may be influenced by P levels. Additionally, when P_{soil} was combined with P_{plant}, there were no differences in landscape position or land use. However, the large amount of variability in the data due to the variety of wetlands surveyed show there may be other factors to consider.

Wetlands in severely disturbed landscapes exhibit reduced diversity, function, and quality (Novitzki et al. 1997). This is reflected in our study, where wetlands in cropped systems were significantly lower in floristic quality than wetlands in idle or grazed/hayed systems. Cattails and grasses and grass-likes had significantly greater biomass than forbs and shrubs, which allowed for more nutrient storage in the aboveground tissues of these plant types. Although there were less plant species in the shallow marsh than wet meadow or low prairie, there were no differences in plant nutrient levels. C:N, N:P, and P in plants showed differences by plant type, most likely due to the variation between species of nutrient loss and uptake (Güsewell 2004). Similar to our results, Güsewell (2004) found that plant N:P ratios are higher in graminoids than in forbs and higher in stress-tolerant species than in ruderals. However, C:N, N:P, and P in plants were not different between landscape positions, indicating that plant uptake of C, N, and P was not greater in the wetland than the surrounding upland.

We found that wetlands in different land use settings exhibited different plant N:P ratios. Plant N:P ratios above 16 indicate P-limitation, below 14 indicate N-limitation, and between 14 and 16 indicate a limitation of both nutrients (Bedford et al. 1999, Güsewell et al. 2003). Therefore, wetlands in idle systems were P-limited, and wetlands in cropped or grazed/hayed systems were N-limited (idle: 19.0 ±4.04, cropped: 7.83 ±2.09, grazed/hayed: 12.2 ±2.81). The cropped systems had marginally lower plant N:P ratios than the grazed/hayed systems, which could indicate a severe N-limitation in cropped systems, affecting fertilization rates for farmers.

Historically, prairie landscapes are N-limited and have evolved with grazing and fire (Seastedt et al. 1991). The grazed/hayed wetlands appear to reflect the historical norm of N-limitation with moderate amounts of disturbance. P-limitation can occur in grasslands dominated by graminoids and may eventually lead to reduced plant diversity (Hobbs and Huenneke 1992, Güsewell 2004). This may be why the idle wetlands were P-limited. Therefore, leaving prairie areas idle may have effects on how nutrients are cycled in wetlands. Changes from an N- to a P-limited environment and subsequent increases in graminoid cover can result in decreased species richness (Güsewell 2004). However, the P-limited idle wetlands in this study were not significantly different than the N-limited grazed/hayed wetlands in plant N:P ratios or floristic quality. Based on this data, there is no indication that idle wetlands are significantly altered by suppressing grazing. However, this study was not able to assess specific management practices, such as stocking rates of grazers and fire regimes. Further study into nutrient cycling under different anthropogenic impacts (e.g. cropping, grazing, and fire) may reveal other factors that could be important for management decisions.

Increasing P_{plant} was correlated with decreasing floristic quality, which is contrary to past studies that show moderate amounts of nutrients as the ideal level (Tilman and Pacala 1993, Bedford et al. 1999). According to those studies, floristic quality should be highest with moderate P levels, although ranges of nutrient levels vary among wetland types. Since four wetland types were sampled in this study, this may be a reason for the high variability reflected in the R values. Bedford et al. (1999) reported means and ranges of percent N and P of wetland plants from 215 samples of 65 different studies. They found P ranged from 0.004 to 0.64% with a mean of 0.14%. Mean P levels in our study were 1.6 times higher than the Bedford et al. (1999) paper at 0.23% with a range of 0.048 to 0.72%. Emery and Perry (1995) analyzed P levels in cattails in 12 central Minnesota wetlands that had undergone minimal disturbance, but were dominated by either *Typha* species and/or *Lythrum salicaria* L. Their cattail P_{plant} values were similar to ours, ranging from 5.5 to 17.6 kg/ha, with one wetland containing no cattails. Therefore, our cattail P_{plant} range of 0.08 to 13.7 kg/ha is within their measurements.

Mean percent plant N levels were 1.9 times higher in our results than in the Bedford et al. (1999) paper. Their percent N ranged from 0.08 to 4.20% with a mean of 1.34%, and our N levels had a larger range from 0.76 to 15.5% with a mean of 2.58%. Overall, percent P and N are elevated in our study compared to the Bedford et al. (1999) results. Thormann and Bayley (1997) analyzed percent plant N in six peatlands in Alberta, Canada. Their percent N ranged from 1.2 to 2.8% – a relatively small range. The large ranges in plant N levels found in this study and the Bedford et al. (1999) study may be due to a variety of wetland types and surrounding land uses, which were not present in the Thormann and Bayley (1997) study.

In previous studies, plant nutrient levels were comparable to soil nutrient levels (Shaver and Melillo 1984). We found increasing P_{plant} was correlated with increasing P_{soil} in all samples except one collected in the wet meadow and upland, but was only correlated with two of the four samples collected in the shallow marsh. However, the 0-15 cm samples in the shallow marsh did not correlate with P_{plant} levels. This may be due to P removal by cattails (Weng et al. 2006). Thus, we found that increasing cattail biomass was correlated with increasing P_{plant} levels in the shallow marsh.

In order to explore the relationship between cattail biomass and P_{soil}, a conceptual model was created (Figure 6). In Figure 6, wetlands with high cattail biomass (between 1,000 and 7,600 kg/ha) and low P_{soil} (0-10 ppm for Olsen and 0-3 ppm for WEP) were typical of areas that were currently or had been heavily disturbed by cropping. These P_{soil} levels are similar to Olsen

P measurements in a *Typha*-choked Minnesota wetland, which were 16 and 6 ppm (Berryman et al. 2009). Cattails are effective at P_{soil} uptake, so areas containing high cattail biomass would likely have low P_{soil} (Weng et al. 2006). Additionally, low P_{soil} was found in many wetlands without cattails. These wetlands tended to be in native, undisturbed areas with high floristic quality. This is characteristic of areas that are not affected by nutrient runoff from agricultural lands (Cooper 1993). A few wetlands in Figure 6 had higher P_{soil} (>10 ppm for Olsen and >3 ppm for WEP) and no cattail biomass. These wetlands tended to be in riparian areas, which may naturally have higher P_{soil} levels, and in very recently disturbed areas, such as wetlands recently cropped around. A few wetlands also had higher P_{soil} and higher cattail biomass than other wetlands. These wetlands tended to be almost exclusively in cropped systems and may be transitioning to a "cattail-choked" state. The relationship between these variable states could be further investigated to explain cattail invasion in wetlands.

The exact thresholds and mechanisms for transitioning between the different states seen in Figure 6 need to be determined. This knowledge would assist in understanding wetland processes on a larger scale and what factors drive changes in wetland plant communities in Northern Great Plains. Our data indicate that nutrient levels, floristic quality, and land use are integrative in wetlands. Dense cattail cover affects nutrient cycling in an ecosystem that is already diminishing (Hobbie 1992, Galatowitsch et al. 1999). Therefore, further studies of the mechanism of cattail invasion as well as solutions for managing cattail-invaded wetlands are needed.

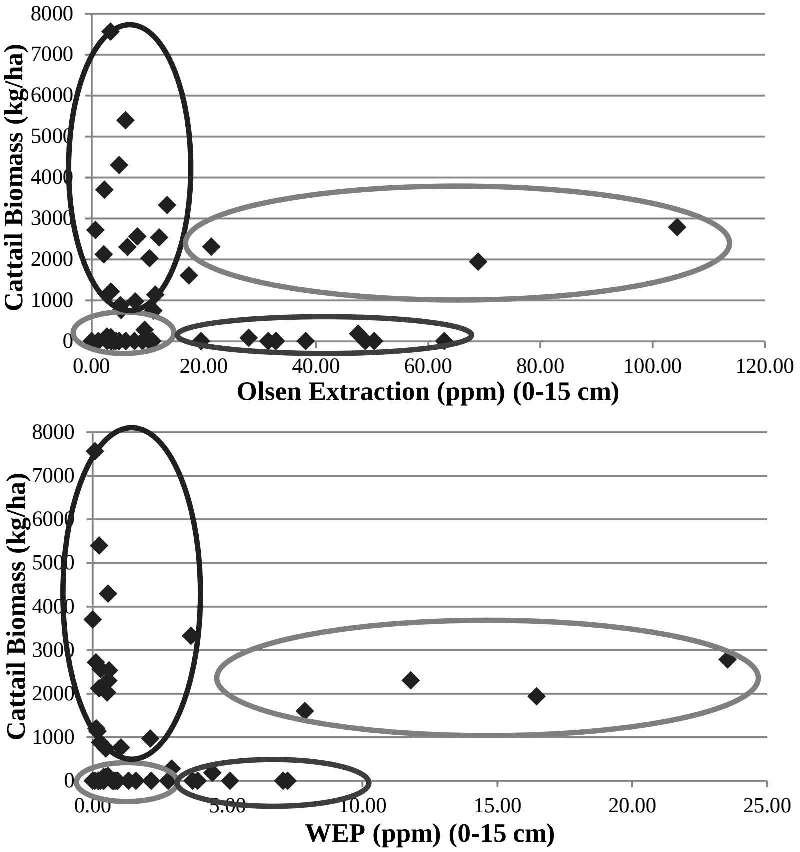

Figure 6. Cattail biomass and soil P for the Olsen extraction and WEP at 0-15 cm. Ovals represent wetlands with high cattail biomass and low soil P, low cattail biomass and low soil P, low cattail biomass and high soil P, and high cattail biomass and high soil P.

PAPER 2. PLANT PHOSPHORUS, NITROGEN, AND CARBON IN WETLANDS EXCAVATED FOR SEDIMENT REMOVAL

Introduction

Invasion of hybrid cattail (*Typha x glauca* Godr. (pro sp.)) in wetlands has become an issue across North America (Galatowisch et al. 1999). The hybridization of the narrowleaf cattail (*Typha angustifolia* L.) and broadleaf cattail (*Typha latifolia* L.) has allowed the hybrid cattail to spread into disturbed areas with altered water and soil conditions. Hybrid cattails dominate over the parents in a larger variety of habitats, nutrient levels, and water regimes (Grace and Wetzel 1981, 1982, Boers and Zedler 2008). Wetlands that are "cattail-choked" exhibit a decline in native species and modify wetland functions such as nutrient cycling (Werner and Zedler 2002, Tuchman et al. 2009).

Sedimentation can occur naturally in wetlands, but agricultural practices increase the rate of sedimentation in wetlands, which effect vegetative cover, aquatic invertebrates, wildlife, hydrologic functions, and water quality functions (Gleason and Euliss 1998). This is common in the prairie pothole region where agriculture is widespread. Sedimentation in wetlands due to agricultural practices decreases seedling emergence by burying seeds beds (Jurik et al. 1994, Wang et al. 1994). Sedimentation leads to an increase of invasive species, such as hybrid cattail, and a decline in species richness (Werner and Zedler 2002). Over time, sediment accumulation can result in decreased water depths allowing for species to colonize on new substrate in areas that may have had too deep of water levels in the past.

Sediment deposition from cultivated areas tends to be higher in nutrients than sediment in grassland areas (Martin and Hartman 1987). Angeloni et al. (2006) found that cattail invasion caused higher soluble ammonium (NH_4), nitrate (NO_3), and phosphate (PO_4) levels in sediments and a shift in denitrifying bacterial communities. Therefore, cattail invasion has the potential to affect nutrient removal in wetlands. Furthermore, cattails have been found to invade areas with higher nutrients inputs, especially phosphorus (P) (Maio and Sklar 1998, DeBusk et al. 2001, Tuchman et al. 2009).

Many studies on how cattails spread into wetlands have occurred in the Great Lakes and Everglades, but few have been completed in Northern Prairie wetlands (DeBusk et al. 2001, Wilcox et al. 2008, Farrer and Goldberg 2009). Therefore, we wanted to measure nutrient levels in Northern Prairie wetlands that had undergone sediment removal as a treatment for cattail invasion. Our goal was to study the carbon (C), nitrogen (N), and P levels of different plant types and landscape positions in wetlands that had been excavated for sediment removal. We predicted that cattails would have higher levels of P than other plant types and that the shallow marsh would be higher in nutrients than the other landscape positions (refer to Paper 1).

Methods

Eighteen wetlands were sampled in the summer of 2012 in Benson, Wells, and Towner counties in North Dakota. All wetlands had been in cropland in the past and subject to sedimentation, and had a seasonal hydrologic classification according to Stewart and Kantrud (1971). These were excavated to remove accumulated sediment. For a complete list of wetland locations and amount of sediment removed refer to Appendix F. The Benson county sites were excavated in 2007, the Wells county sites were excavated in 2003, and the Towner county sites were excavated in 2008. After excavation, the uplands were planted with native seed mixtures. Seeding was not performed within the wetlands.

At each wetland, three landscape positions – shallow marsh, wet meadow, and low prairie – were delineated based on topography and vegetation (Stewart and Kantrud 1971). The shallow marsh and wet meadow zones were located in the wetland. Shallow marsh zones contain water most of the year, and wet meadow zones hold water after spring melt and heavy rainfall events (Stewart and Kantrud 1971). The low prairie is the area immediately surrounding the wetland edge, which is only inundated during periods of unusually high water levels. For this study, the low prairie was defined as at least a 1 m elevation rise and within 50 m of the wetland edge.

At each landscape position, five 0.25 m^2 quadrats of live vegetation were clipped 2 cm from the soil surface and separated by plant type. A total of 15 quadrats were clipped per wetland. Vegetation was separated into cattails, grasses and grass-likes (includes sedges, rushes, etc.), and forbs and shrubs (current year's growth). Cattails included *Typha latifolia* L., *Typha angustifolia* L., and *Typha x glauca* Godr. Samples were stored in labelled paper bags. Several wetlands were sampled per week, so samples collected at the beginning of the week were stored in the back of trucks and laid out during the day (unless it was raining). Once all samples were collected for the week, they were transported to North Dakota State University (NDSU) and placed in a large drying oven for two weeks at 90 °C. At this time, vegetation was checked for dryness and removed if dry; otherwise they were left in the dryer for a few more days. The dried vegetation was weighed for biomass and then ground through a 2 mm screen using a Wiley Mill. Wet plant weight was not measured.

Nutrient analyses were completed by the NDSU Soil Testing Laboratory from August 2012 to March 2013 using standard methods and procedures as outlined for the North Central Region (North Central Region-13 1998). Plant C and N were analyzed using an Elementar Vario Macro Cube CNS Analyzer with a thermal conductivity detector. Plant P (P_{plant}) was analyzed using a nitric acid digestion with peroxide using a block digester (Wolf et al. 2003). For the plant P, N, and C content data refer to Appendix C.

In total, 14 wetlands contained cattails, 17 wetlands contained shallow marsh grasses and grass-likes, 9 wetlands contained shallow marsh forbs and shrubs, 18 wetlands contained wet meadow grasses and grass-likes, 15 wetlands contained wet meadow forbs and shrubs, 18 wetlands contained upland grasses and grass-likes, and 11 wetlands contained upland forbs and shrubs for a total of 102 samples for biomass and nutrient analysis. Multi-Response Permutation Procedures (MRPP) were calculated to test for differences in plant type and landscape position using PC-ORD version 6.0 software (McCune and Mefford 2011). This was completed for plant C:N ratios (C:N_{plant}) and P_{plant}. MRPP was also calculated for the biomass of different plant types. The Bonferroni correction was used to correct for multiple comparisons. A p-value of 0.05 was considered significant. Graphs were created in MS Excel 2010. In graphs and in the text, the means are reported with standard error (SE).

Results

Plant Types

The MRPP results yielded several differences. C:N_{plant} were highest in upland grasses and grass-likes at 39.5 (±1.45), which was significantly higher than shallow marsh, wet meadow, and upland forbs and shrubs (25.1 ±3.42, 21.4 ±1.24, and 25.9 ±1.79, respectively; Figure 7). C:N_{plant} in shallow marsh and wet meadow grasses and grass-likes (29.9 ±2.22 and 35.0 ±1.41, respectively) and cattails (36.5 ±2.17) were significantly higher than wet meadow forbs and shrubs only.

Phosphorus was highest in wet meadow grasses and grass-likes (11.3 ±1.26 kg/ha), which was significantly greater than shallow marsh and wet meadow forbs and shrubs (2.35 ±0.76 kg/ha and 1.51 ±0.43 kg/ha, respectively; Figure 8). Phosphorus in upland grasses and grass-likes (6.88 ±0.96 kg/ha) was also significantly greater than wet meadow forbs and shrubs.

Cattails, shallow marsh grasses and grass-likes, and upland forbs and shrubs did not have different P levels compared to other plant types (6.37 ±1.35 kg/ha, 6.11 ±0.97 kg/ha, and 5.59 ±1.74 kg/ha, respectively).

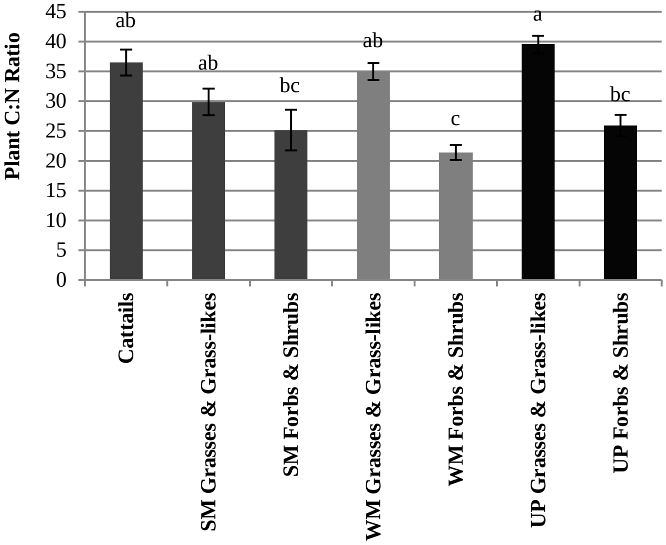

Figure 7. Mean C:N ratios for plant type. Bars represent standard errors. SM = shallow marsh, WM = wet meadow, and UP = upland. For cattails n = 14, shallow marsh grasses and grass-likes n =17, shallow marsh forbs and shrubs n = 9, wet meadow grasses and grass-likes n = 18, wet meadow forbs and shrubs n = 15, upland grasses and grass-likes n = 18, and upland forbs and shrubs n = 11. Different letters denote significant differences ($p < 0.05$).

Biomass was highest in wet meadow grasses and grass-likes (5860 ±433 kg/ha), which was significantly higher than all other plant types (Figure 9). Shallow marsh and upland grasses and grass-likes and cattails were significantly higher in biomass than wet meadow forbs and shrubs (2740 ±431 kg/ha, 3950 ±442 kg/ha, 3030 ±696 kg/ha, and 468 ±143 kg/ha, respectively). Upland grasses and grass-likes were also significantly greater than shallow marsh forbs and shrubs (693 ±231 kg/ha). The biomass of upland forbs and shrubs (2290 ±757 kg/ha) were significantly higher than wet meadow grasses and grass-likes.

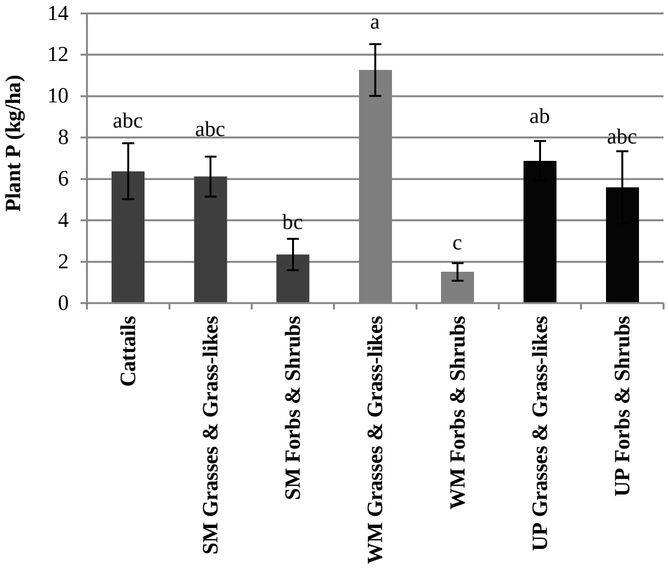

Figure 8. Mean P (kg/ha) for plant type. Bars represent standard errors. SM = shallow marsh, WM = wet meadow, and UP = upland. For cattails n = 14, shallow marsh grasses and grass-likes n =17, shallow marsh forbs and shrubs n = 9, wet meadow grasses and grass-likes n = 18, wet meadow forbs and shrubs n = 15, upland grasses and grass-likes n = 18, and upland forbs and shrubs n = 11. Different letters denote significant differences ($p < 0.05$).

Landscape Position

There were significant differences for landscape position in C:N$_{plant}$ (Figure 10). Shallow marsh C:N$_{plant}$ was significantly greater than wet meadow C:N$_{plant}$ (69.2 ±6.95 and 51.6 ±2.75, respectively). Upland C:N$_{plant}$ at 55.3 (±3.13) was not different than the shallow marsh or wet meadow. P$_{plant}$ did not show any significant differences between landscape positions with an overall mean of 34.7 kg/ha (±3.97, data not shown).

Discussion

A previous study on these sites showed significantly lower cattail cover and vegetation structure compared to sites that did not have sediment removed (Smith 2011). Smith (2011) also found that wetland vegetation in the wetlands with sediment removal tended to have native perennial species and invasive weeds present. This differed from undisturbed wetlands that had never been in cropland, which were dominated by native perennial species. Wetlands that were converted from cropland to prairie, but had never had sediment removed, were dominated by cattails and dense cover. The sediment removal effectively opened up the shallow marsh for new species (Jurek et al. 1994). In our study, cattail biomass was not significantly different from grasses and grass-likes and forbs and shrubs in the shallow marsh. This indicates several plant functional groups were present in the shallow marsh as opposed to only cattails.

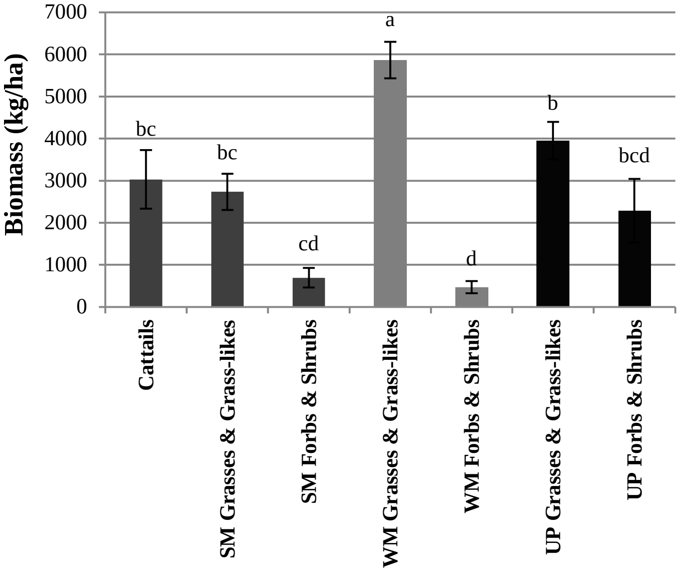

Figure 9. Mean biomass (kg/ha) for plant type. Bars represent standard errors. SM = shallow marsh, WM = wet meadow, and UP = upland. For cattails n = 14, shallow marsh grasses and grass-likes n =17, shallow marsh forbs and shrubs n = 9, wet meadow grasses and grass-likes n = 18, wet meadow forbs and shrubs n = 15, upland grasses and grass-likes n = 18, and upland forbs and shrubs n = 11. Different letters denote significant differences ($p < 0.05$).

Our results show most of the biomass is contained in the wet meadow grass and grass-likes in excavated wetlands. Grasses and grass-likes and cattails also had higher levels of P and C:N than forbs and shrubs. This differs from a statewide study of P, N, and C in wetland plants presented in Paper 1, where the highest P_{plant} levels were in cattails. However, this study of excavated wetlands has much higher mean biomass of grasses and grass-likes and cattails ranging from 2740 to 5860 kg/ha than compared to Paper 1 ranging from 1070 to 2020 kg/ha. Therefore, P levels in the grasses and grass-likes and cattails ranged from 6.11 to 11.3 kg/ha and were much higher than compared to the results of Paper 1 ranging from 1.90 to 3.97 kg/ha. This may be due to high nutrient availability, which could increase plant biomass (Vermeer and Berendse 1983). Furthermore, Mitsch et al. (2012) measured productivity on planted and unplanted created wetlands and found that the unplanted wetland had significantly higher biomass than the planted wetland, and both wetlands greatly increased in biomass (up to 7,000 kg/ha) in the first 5 years of creation. A similar phenomenon may be occurring in the wetlands with sediment removal – the openned up canopy due to excavation has allowed for plant establishement resulting in high biomass levels. If high P levels and biomass remain in these wetlands, seasonal changes would allow for the P_{plant} to return to the soil and water, potentially creating conditions for cattail reinvasion.

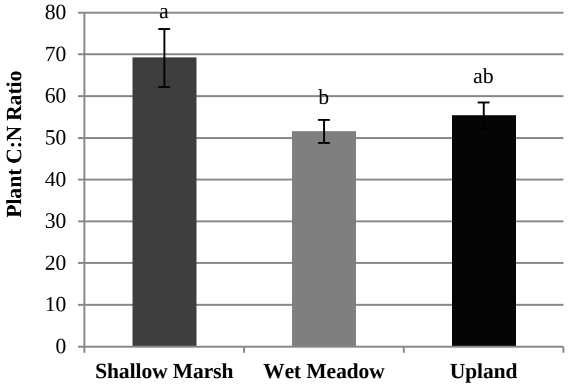

Figure 10. Mean plant C:N ratios for landscape position. Bars represent standard errors. Different letters denote significant differences ($p < 0.05$).

The continued presence of cattails in these wetlands as well as surrounding wetlands may allow for reinvasion over time unless there is sufficient cover of native perennial species (Mitsch et al. 2012) or a reduction in P levels (Newman et al. 1998, DeBusk et al. 2001). These sites need to continue to be monitored to determine if the reduction in cattail cover and increase in native perennial species is a long-term or short-term change. Paper 1 identified four possible states for cattails and soil P in wetlands, but the conditions for the existence for these states are unknown. Further study of the conditions leading to specific wetland states are needed to make predictions as to how successful sediment excavation is for reducing cattail cover over time. The specific conditions that promote cattail invasion in Northern Prairie wetlands need to be studied as well as what management is useful for long-term reduction in cattail invasion.

PAPER 3. RELATIONSHIP BETWEEN THE NATURAL ABUNDANCE OF STABLE NITROGEN AND CARBON SOIL ISOTOPES AND CONDITION

Introduction

The global nitrogen (N) and carbon (C) cycles have important implications for human well-being (Millennium Ecosystem Assessment 2005). Anthropogenic impacts to wetlands, whether through agriculture or urban development, have dramatically altered nutrient cycling with increased nutrient loads and new sources (Galloway and Cowling 2002). Other effects that can alter nutrient cycling include shifts in plant communities, disruption of soil/sediment, introductions of invasive species, and pollution. Northern prairie wetlands are important for water quality, climate regulation, and habitat, but are threatened by agriculture (Johnston 2013). Due to human impact on natural wetland systems, wetland condition assessments have been created to measure changes in wetlands (U.S. Environmental Protection Agency 2011).

Studies have shown that anthropogenic impacts to natural systems have elevated nutrient levels, which can be measured using stable isotopes (Elliott and Brush 2006). N and C both have two stable isotopes: ^{14}N, ^{15}N, ^{12}C, and ^{13}C. The lighter isotope is preferentially used during chemical reactions (such as denitrification, respiration, or methanogenesis) creating distinct $^{14}N/^{15}N$ and $^{12}C/^{13}C$ ratios. Because of these distinct signatures, isotopes can provide valuable information on biogeochemical cycling and nutrient sources (Peterson and Fry 1987). For example, soil $\delta^{15}N$ values may be an indicator of denitrification, as denitrification results in an enrichment of soil $\delta^{15}N$ values (Blackmer and Bremner 1977, Billy et al. 2010). Soil $\delta^{13}C$ values in terrestrial systems largely reflect the photosynthetic pathway (C_3, C_4, or CAM) of the dominant plant community, while peat in freshwater wetlands usually reflects the $\delta^{13}C$ values of

C_3 plants, around -27‰ (Boutton 1991). Furthermore, soil $\delta^{13}C$ values in wetlands can be affected by decomposition, methanogenesis release, and respiration of aquatic plants.

Historically, the sources of N in wetlands have included biological fixation, mainly from plant and bacteria symbiosis, with some from lightening and wildfires (Viousek et al. 2002). Under natural conditions, the source of N is atmospheric, which has an isotope value of 0‰ (Elliott and Brush 2006). Thus, $\delta^{15}N$ ranges from 0 to +2‰ when derived from biological fixation. N sources from human inputs have distinct $\delta^{15}N$ values as well. Fertilizer ranges from -2‰ to +4‰ (Vitòria et al. 2004), atmospheric deposition ranges from -11‰ to +3‰ (Elliott and Brush 2006), and manure and human wastewater ranges from +8‰ to +22‰ (Aravena et al. 1993). The increased N from human activities has resulted in an increase in $\delta^{15}N$ values worldwide; urban ecosystems have reported higher $\delta^{15}N$ values than natural ecosystems (Elliott and Brush 2006). Elevated $\delta^{15}N$ values can remain up to a century or more after human disturbance has ceased (Koerner et al. 1999).

The anaerobic and carbon-rich environment typical of wetlands promotes denitrification and is important in the N cycle. Sutherland et al. (1993) found that $\delta^{15}N$ values and denitrification were greater in wetter, depressional areas than in more elevated, drier landscape positions. However, cropped ecosystems exhibited random spatial patterns of $\delta^{15}N$ values; thus altered denitrification patterns may occur in cropped ecosystems (van Kessel et al. 1994). Additionally, soil $\delta^{13}C$ values may be highly influenced by topography and plant residues with more elevated landscape positions exhibiting higher (less negative) $\delta^{13}C$ values than lower landscape positions. Depressional areas tend to accumulate plant residues, so soil $\delta^{13}C$ may be affected by decomposition.

Changes in land use have affected wetlands and nutrient cycling globally (Millennium Ecosystem Assessment 2005, Elliott and Brush 2006). Natural abundances of stable isotopes have been used as an indicator of anthropogenic inputs into ecosystems (Hoffman et al. 2012, Xu and Zhang 2012), and elevated nutrient levels have been correlated with high human impact (Elliott and Brush 2006). Therefore, stable isotope levels in wetland soils can be used to indicate changes in land use and nutrient inputs into natural systems (Chang et al. 2002, Elliott and Brush 2006). The objective of this study was to explore the relationship between the natural abundance of N and C stable isotopes associated with wetland soils and wetland condition, using the Index of Plant Community Integrity (IPCI) and North Dakota Rapid Assessment Method (NDRAM), in Northern Prairie Wetlands. Specifically, we hypothesized that 1) δ^{15}N and δ^{13}C would correlate with wetland condition and plant quality; 2) δ^{15}N isotope values would be higher in wetlands located in cropland compared with natural ecosystems (Elliott and Brush 2006); 3) because wetland soils typically promote denitrification, δ^{15}N samples collected in the upland would be lower than those collected in the wetland, and samples collected in soil pits with hydric soil indicators would have higher δ^{15}N values than samples from soil pits without hydric soil indicators (Sutherland et al. 1993, Billy et al. 2010); and 4) δ^{13}C samples would be higher (less negative) in the upland than in the wetland (van Kessel et al. 1994).

Methods

Study Sites

This study was conducted in conjunction with the National Wetland Condition Assessment (NWCA) during the summer of 2011 across the state of North Dakota (U.S. Environmental Protection Agency 2011). Soils, land use, vegetation, condition, and buffer data collected during the NWCA project were used to compare with the isotope data and determine if correlations existed. Fifty-one wetlands were sampled that were randomly pre-selected from the Fish and Wildlife Service's Status and Trends Plots as an intensification of and to contribute to the nationwide NWCA survey (Dahl 2011, Figure 11). A hydrogeomorphic (HGM) class was assigned to each wetland (Brinson 1993, Smith et al. 1995). Of the 52 wetlands, 32 were closed depressions (CD), 5 were open depressions (OD), 5 were upper perennial riverine (UPR), 4 were lacustrine fringe (LF), 3 were organic soil flats (OSF), and 2 were topographic slopes (TS).

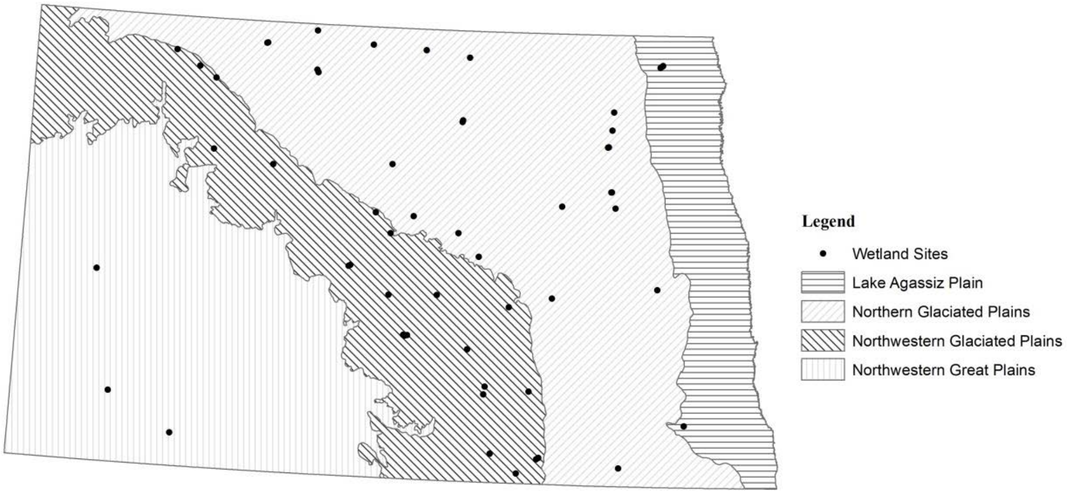

Figure 11. Location of 51 wetland sites across North Dakota sampled in the summer of 2011. The legend indicates the labels of the four main ecoregions in the state: Lake Agassiz Plain, Northern Glaciated Plains, Northwestern Glaciated Plains, and Northwestern Great Plains. For a description of the ecoregions see Bryce et al. (1998).

Additionally, the IPCI and NDRAM were performed at each wetland as regional-specific assessments to evaluate the condition of the wetland (Hargiss et al. 2008, Hargiss 2009). The IPCI was utilized to assess the vegetation, and the NDRAM was used to rapidly assess wetland characteristics, such as wetland buffer, hydrology, vegetation, soils, habitat, management, wetland potential, and overall condition. For the NDRAM, we defined surrounding land use as cropped, idle, or grazed/hayed. Cropped wetlands were cropped through or up to the wetland or were surrounded by cropland and had a very narrow (i.e., less than 1000 m) buffer. Idle wetlands did not have an active management practice in or around the wetland. Wetlands with a very large buffer (i.e., more than 1000 m) before cropping began were considered idle. Grazed/hayed wetlands were wetlands that were managed with vegetation removal by domestic grazing and/or haying. Fourteen wetlands were cropped, 18 wetlands were idle, and 19 wetlands were grazed/hayed.

National Wetland Condition Assessment

At each wetland, a full field survey for the NWCA was conducted, which included surveying and data collection of the wetland buffer, flora, water chemistry, and soils, among other components (see U.S. Environmental Protection Agency 2011 for details). Due to variable sizes in wetlands from hundreds of hectares to a fraction of a hectare, only a specified area was sampled. An assessment area (AA) was set up within each wetland with less than 10% of the AA in upland or in water over 1 m deep. The standard AA was a 0.50 ha circle; otherwise the AA was adjusted to fit the shape of the wetland. The minimum size of the AA was 0.10 ha. Average buffer width for a 100 m wide buffer was estimated using aerial photography and visual observation at the wetland. The buffer width in 8 equidistant directions was estimated and averaged to provide an average width. Five vegetation plots were set up at prescribed distances within the AA – one in each cardinal direction – and one near the center. Soil pits were excavated immediately outside the southeast corner of the outer four vegetation plots. Of the four soil pits, one was chosen as the “most representative” for the wetland using best professional judgment. The representative pit was sampled for hydric soil indicators, water level, soil nitrate (NO_3-N), soil pH, and soil isotopes.

To collect the soil isotope samples, a standard steel soil probe (2.25 cm diameter) was used to core three samples of 10-cm-deep (from the surface) soil in the representative pit and one sample of 10-cm-deep soil in the adjacent upland of each wetland. Thick root mats and rhizomes were avoided, as living plant material has different isotope ratios than the expected range for soils. Samples were placed on ice until sent to the U.S. Environmental Protection Agency (USEPA) Western Ecology Division (WED) in Corvallis, Oregon for isotopic analysis in the ISIRF (Integrated Stable Isotope Research Facility) laboratory. Soil NO_3-N, pH, and OM samples were collected from each horizon greater than 5 cm in the representative pit. Samples were stored on ice and analyzed at the NDSU Soil Testing Laboratory in Fargo, North Dakota. Samples from the top horizon were used for comparisons with the soil isotope samples.

Regional Wetland Assessment Methods

Vegetation was assessed using the IPCI method (Hargiss et al. 2008). According to the Stewart and Kantrud (1971) classification, wetlands were assessed as temporary, seasonal, or semi-permanent wetlands. Temporary wetlands contained low prairie and wet meadow zones; seasonal wetlands contained low prairie, wet meadow, and shallow marsh zones; and semi-permanent wetlands contained low prairie, wet meadow, shallow marsh, and deep marsh zones. Vegetation cover was measured within 1 m^2 quadrats, and additional species were identified between quadrats. Eight quadrats were completed in the low prairie, 7 in the wet meadow, 5 in the shallow marsh, and 5 in the deep marsh, when present. Using the species recorded, c-values were assigned according to The Northern Great Plains Quality Assessment Panel (2001). Species with higher c-values are more sensitive to disturbance and have higher fidelity to a specific habitat. Introduced species were not assigned c-values. Then the Floristic Quality Index (FQI) for each wetland was calculated using the average c-value multiplied by the square root of the total number of species (Wilhelm and Ladd 1988). The FQI and 8 other vegetation calculations were used to calculate the IPCI condition score for each wetland (see Hargiss et al. (2008) for the specific calculations).

The NDRAM is used to rapidly assess wetlands (Hargiss 2009). Wetlands are scored on average buffer width, intensity of surrounding land use, soil/substrate disturbance, plant community and habitat development, habitat alteration and recovery, management, modifications to natural hydrologic regime, potential of wetland to reach reference, invasive species, and overall condition (see Hargiss (2009) for the specific calculations).

Laboratory Analysis

Upon arrival to the USEPA WED laboratory, soil samples were stored at 4°C until they underwent a 144-hour freeze-drying process in a VirTis Genesis freezer dryer equipped with a Wizard 2.0 Data Center. After removing the wetland soils from the freeze dryer, any large debris, roots, and vegetation were separated from the soil matrix using a 2 mm sieve. On rare occasions (4 of the total 108 soil samples), the dried soil samples were too recalcitrant to break apart and sieve; therefore, they were coarsely ground using a Wiley Mill before fine grinding. The remaining soil matrix of each of the samples, whether sieved or coarsely ground, was finely ground in a glass jar using 1-inch stainless steel rods and a roller grinder for 24 hours or until the soil reached the consistency of fine flour. Finely ground soils were stored in tightly-lidded glass jars until isotope analysis at ISIRF.

Soil isotope analyses for $\delta^{15}N$ and $\delta^{13}C$ were determined by dry combustion in a Costech ECS4010 Elemental Analyzer equipped with a zero-blank autosampler and a Thermo Finnigan Delta XP Isotope Ratio Mass Spectrometer (IRMS) with a Conflow 3 interface. Data are reported as $\delta^{15}N$ or $\delta^{13}C$ values and expressed relative to atmospheric N_2 (for $\delta^{15}N$) or Pee Dee Blemnite (PDB; for $\delta^{13}C$) in ‰:

$$\delta^{15}\mathrm{N} \text{ or } \delta^{13}\mathrm{C} = \left(\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1\right)1000$$

where *R* is the ratio of ^{14}N to ^{15}N or ^{12}C to ^{13}C atoms of the sample and atmospheric N_2 or PDB. Measurement precision of the elemental analyzer was 0.11 and 0.8 for $\delta^{15}N$ and $\delta^{13}C$, respectively.

Statistical Analysis

Multi-Response Permutation Procedures (MRPP) were calculated to test differences between groups using PC-ORD version 6.0 software (McCune and Mefford 2011). The Bonferroni correction was used to correct for multiple comparisons. MRPP tested the differences between the upland and wetland for the $\delta^{15}N$ values. This was also performed for the upland and wetland $\delta^{13}C$ values. The rest of the analyses were performed using the wetland samples. MRPP was performed to evaluate differences among land use types: wetlands in cropland, idle grasslands, and grazed/hayed grasslands. MRPP tested $\delta^{15}N$ values between wetlands with and without hydric soil indicators.

Linear regressions were performed to test correlations between wetland $\delta^{15}N$ and $\delta^{13}C$ values and FQI scores, IPCI scores, NDRAM scores, soil pH, and average 100 m buffer width. Linear regression was also performed on soil $\delta^{15}N$ values and soil NO_3-N. Significant differences indicate $p < 0.05$ for all statistical analyses. Graphs were created in MS Excel 2010 and different letters indicate significant differences. In graphs and in the text, the means are reported with standard error (SE).

Results

N Isotopes

The MRPP analysis showed no differences between the upland and wetland samples for the $\delta^{15}N$ data (means of 5.33 ±0.75‰ and 5.56 ±0.76‰, respectively, data not shown). However, there were significant differences in soil $\delta^{15}N$ among differing land uses (Figure 12). Wetlands in cropland averaged 6.24 ±1.14‰ and were significantly higher than idle or grazed/hayed grasslands (means of 5.03 ±0.84‰ and 5.21 ±0.84‰ for idle and grazed/hayed wetlands, respectively). Wetlands containing one or more hydric soil indicators in the representative pit were not significantly different than wetlands with no hydric soil indicators (with n=45, without n=6, data not shown). Soil $\delta^{15}N$ values in CD wetlands were 39% lower than TS wetlands (means of 5.96 ±1.05‰ and 9.79 ±6.92‰, respectively; $p<0.05$, Figure 13). OD, UPR, LF, and OSF wetlands were not significantly different from each other or CD and TS wetland types (means of 4.35 ±1.94‰, 5.05 ±2.26‰, 4.21 ±2.10‰, and 3.16 ±1.83‰, respectively).

The linear regression analysis for the soil $\delta^{15}N$ values and FQI scores showed a decrease in $\delta^{15}N$ as FQI scores increased (R=0.49, $p<0.001$, Figure 14). Similarly, decreasing soil $\delta^{15}N$ values were significantly correlated with increasing IPCI and NDRAM scores (IPCI: $R^2=0.46$, $p<0.001$, Figure 15; NDRAM: R=0.49, $p<0.001$, Figure 16). However, soil $\delta^{15}N$ values and soil NO_3-N did not show a significant relationship, nor did soil $\delta^{15}N$ values and soil pH (R=0.15, p=0.294 and R=0.03, p=0.824 for NO_3-N and pH, respectively; data not shown). Soil $\delta^{15}N$ values decreased as average 100 m buffer width increased (R=0.33, p=0.019, Figure 17).

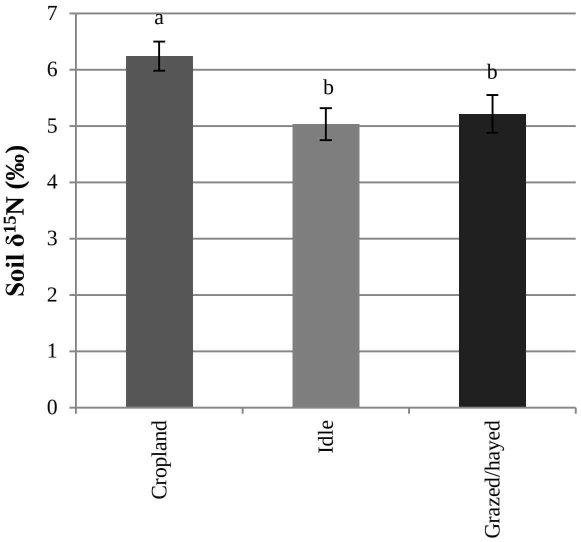

Figure 12. Mean values for soil δ^{15}N for different land uses. For cropland n=14, idle n=18, and grazed/hayed n=19. Different letters denote significant differences, and error bars represent SE.

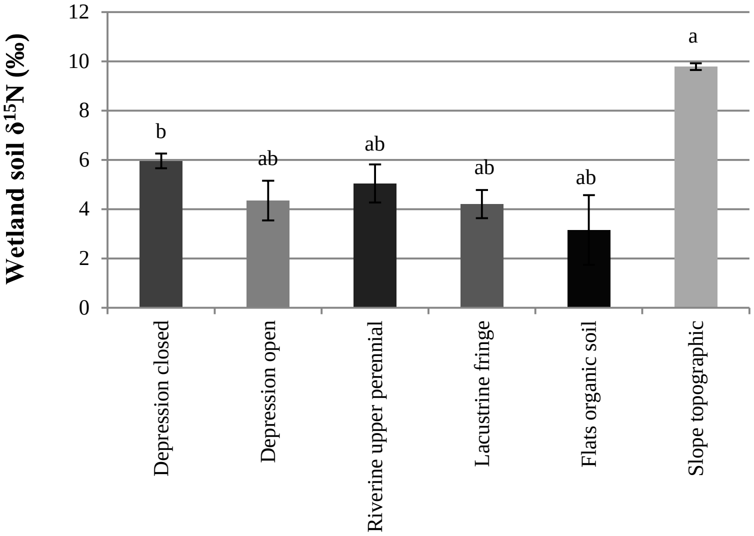

Figure 13. Mean values for wetland soil δ^{15}N of different hydrogeomorphic (HGM) classes. For depression closed n=32, depression open n=5, riverine upper perennial n=5, lacustrine fringe n=4, flats organic soil n=3, and slope topographic n=2. Different letters denote significant differences, and error bars represent SE.

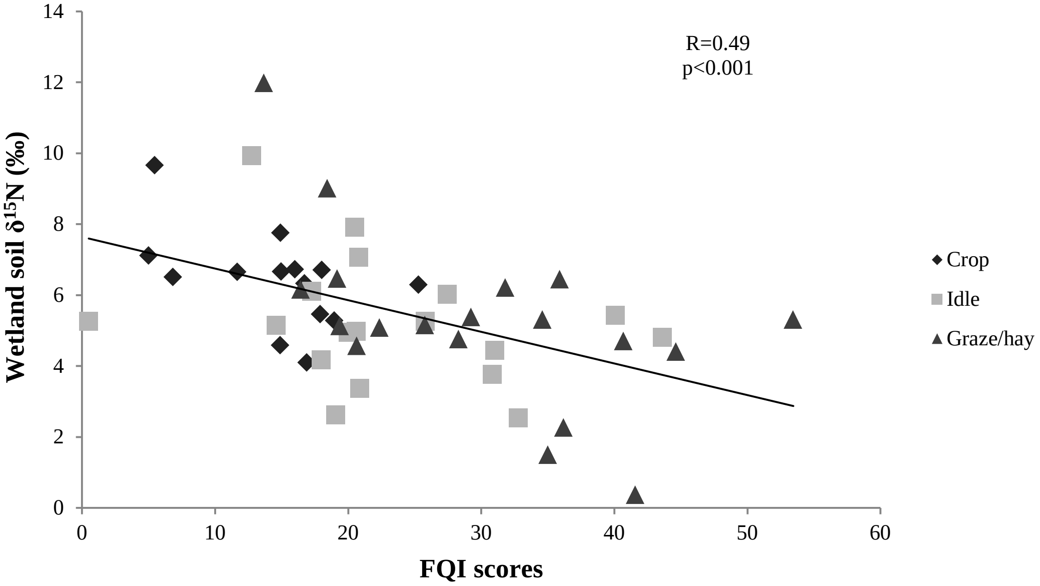

Figure 14. Linear regression for the wetland soil δ^{15}N values (‰) and FQI scores. Different land uses were represented by different symbols.

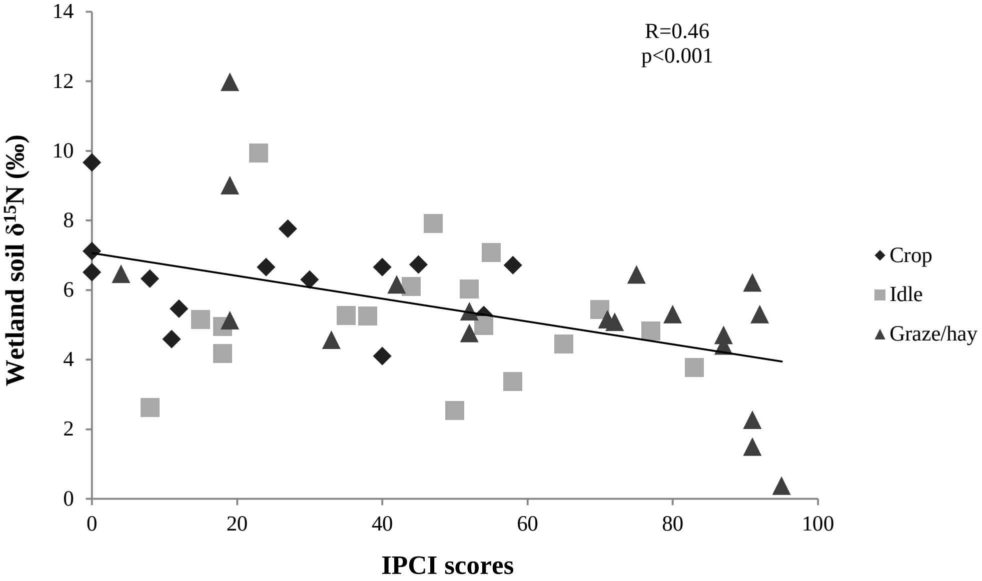

Figure 15. Linear regression of wetland soil δ^{15}N (‰) and IPCI scores. Different land uses were represented by different symbols.

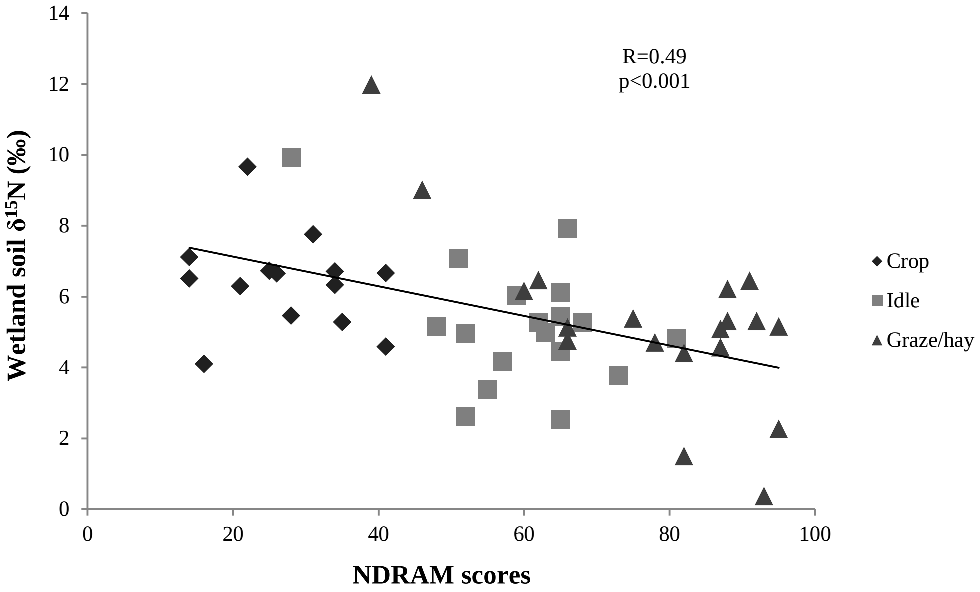

Figure 16. Linear regression of wetland soil $\delta^{15}N$ (‰) and NDRAM scores. Different land uses were represented by different symbols.

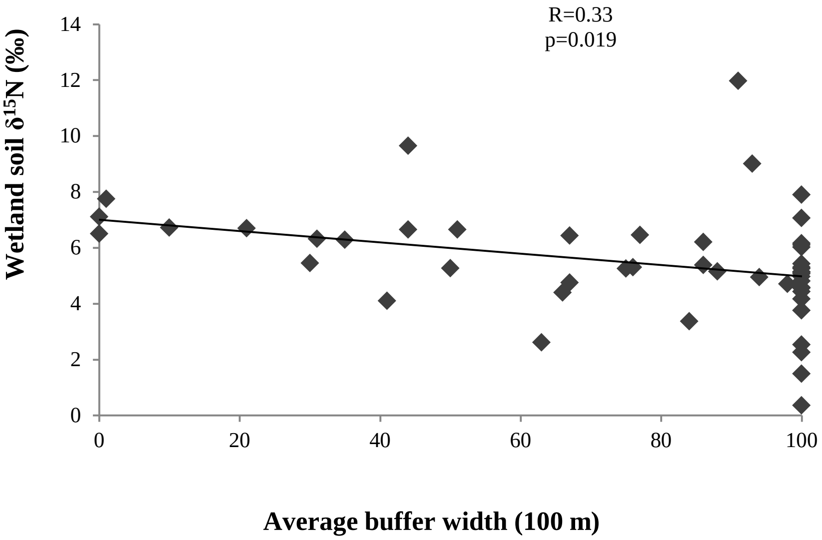

Figure 17. Linear regression of wetland soil $\delta^{15}N$ (‰) and average buffer width out of 100 m.

C Isotopes

The MRPP analysis for the $\delta^{13}C$ data was significantly higher in the wetland compared to the upland (means of -20.87 ±2.87‰ and -22.04 ±3.09‰, respectively, Figure 18). The MRPP comparing land use did not show differences for the $\delta^{13}C$ data with mean cropland at -21.24 ±3.88‰, idle grassland at -21.46 ±3.58‰, and grazed/hayed grassland at -21.58 ±3.50‰ (data not shown). Soil $\delta^{13}C$ values for CD wetlands were significantly lower than OD and UPR wetlands by 24% for OD and 22% for UPR wetlands (means of -21.66 ±3.83‰, -16.36 ±7.31‰, and -16.84 ±7.53‰, respectively; Figure 19).

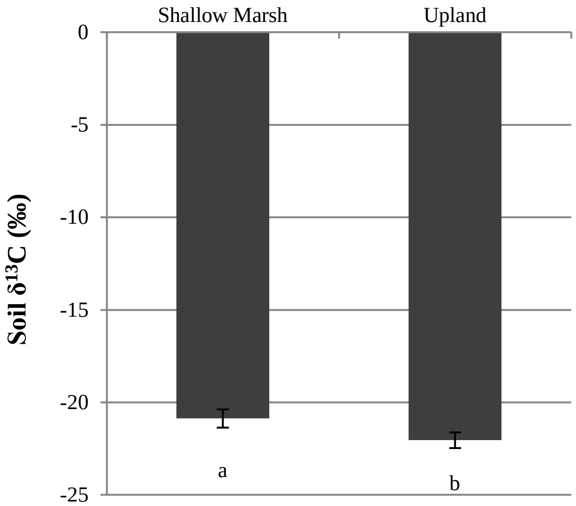

Figure 18. Mean values for the soil $\delta^{13}C$ data for different landscape positions (upland and wetland, both n=51). Different letters denote significant differences, and error bars represent SE.

Linear regression analysis for the wetland $\delta^{13}C$ values and the FQI scores showed a trend of increasing $\delta^{13}C$ with increasing FQI scores (R=0.26, p=0.068, data not shown). Soil $\delta^{13}C$ values and IPCI scores showed a slight increase in $\delta^{13}C$ as IPCI scores increased (R=0.30, p=0.031, data not shown). Although this correlation was significant, it was not a strong correlation due to the high amount of variability not explained. Wetland soil $\delta^{13}C$ values and NDRAM scores did not show a significant correlation (R=0.20, p=0.148, data not shown). Increasing wetland soil $\delta^{13}C$ values were significantly correlated with increasing soil pH (R=0.65, p<0.001, Figure 20). Soil $\delta^{13}C$ values were not significantly correlated with average 100 m buffer width (R=0.12, p=0.386, data not shown).

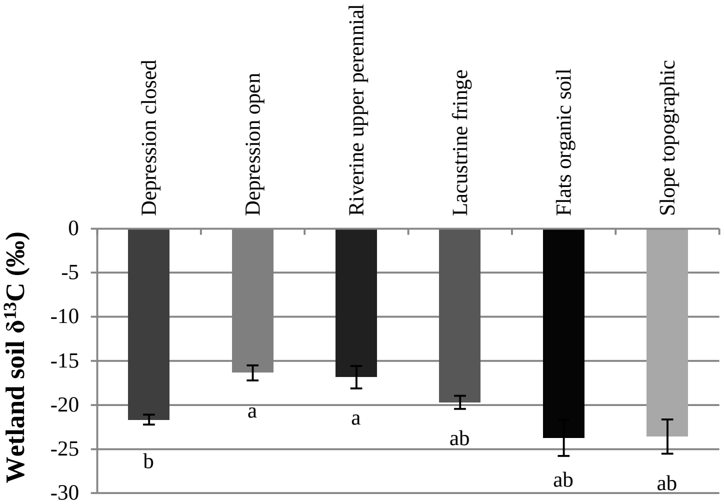

Figure 19. Mean values for wetland soil $\delta^{13}C$ of different hydrogeomorphic (HGM) classes. For depression closed n=32, depression open n=5, riverine upper perennial n=5, lacustrine fringe n=4, flats organic soil n=3, and slope topographic n=2. Different letters denote significant differences, and error bars represent SE.

Discussion

N Isotopes

We expected higher $\delta^{15}N$ values in wetlands compared to uplands because we hypothesized there would be higher denitrification rates in the wetlands as shown in previous studies (Blackmer and Bremner 1977, Billy et al. 2010). However, wetland $\delta^{15}N$ values did not differ in the wetland and the upland landscape positions. This could be due to differences in denitrification rates for different plant species (Bachand and Horne 2000) or due to the variety of wetland types and ecological conditions present in this study. Although upland and wetland mean $\delta^{15}N$ values were not significantly different, more controlled measurements testing denitrification in wetlands may provide more useful results. Additionally, since wetland $\delta^{15}N$ samples collected from soil pits with indicators were not different than soil pits without indicators, denitrification may not override the differences resulting from different wetland types or ecological condition.

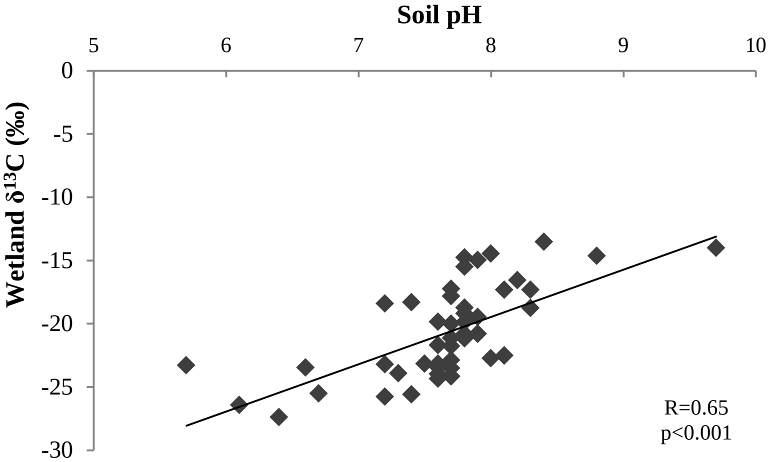

Figure 20. Linear regression of wetland soil $\delta^{13}C$ (‰) and soil pH.

We found some differences in wetland type, with CD wetlands different than TS wetlands. Both of the TS wetlands had lower wetland condition scores for the IPCI and NDRAM and higher $\delta^{15}N$ levels at 9.93 and 9.66‰. This reflects the trend of higher disturbance and lower wetland quality correlating with higher $\delta^{15}N$ values (Elliott and Brush 2006). Additionally, wetland condition scores from the IPCI and NDRAM were moderately correlated with $\delta^{15}N$ values, which could be a reason we did not find differences in landscape position. $\delta^{15}N$ values were correlated with wetland condition; higher $\delta^{15}N$ values were indicative of lower wetland condition and greater human impact (Koerner et al. 1999, Galloway and Cowling 2002, Elliott and Brush 2006).

Wetlands in cropland were enriched in $\delta^{15}N$ compared to wetlands in non-cropped grasslands (Koerner et al. 1999). Soil $\delta^{15}N$ enrichment is common in ecosystems that have been heavily impacted by human and animal wastes (Aravena et al. 1993, Elliott and Brush 2006), however, the differences are small in this study (approximately 1‰). We expected animal waste may also increase $\delta^{15}N$ values; therefore, it was surprising that $\delta^{15}N$ values in grazed/hayed wetlands were not significantly higher than idle wetlands. Soil $\delta^{15}N$ levels adjust to changing conditions slowly, so the values may be reflective of idle wetlands being disturbed in the past (Koerner et al. 1999, Kriszan et al. 2009). The mean $\delta^{15}N$ was above 5‰ for all wetlands, indicating multiple sources of N. This also indicates that all wetlands in this study, even in different land uses, may be impacted by human and animal waste to some degree (Aravena et al. 1993).

Increasing FQI scores were correlated with decreasing $\delta^{15}N$ values, which is related to land use and wetland condition. Floristic quality is significantly lower in wetlands in cropland compared to wetlands in idle or grazed/hayed landscapes (refer to Paper 1). Therefore, land use affects floristic quality as well as $\delta^{15}N$ values (Elliott and Brush 2006). Likewise, lower $\delta^{15}N$ values were indicative of higher wetland condition, higher floristic quality, and more native areas. This was reflected in the regression graphs; grazed/hay wetlands tended to cluster separate from the wetlands in cropland and idle wetlands tended to spread throughout. Similarly, larger buffer areas around wetlands are important to wetland condition (Castelle et al. 1994, Brown and Vivas 2005). Smaller buffer areas occurred in wetlands in cropped areas, thus, smaller buffer width was correlated with higher $\delta^{15}N$ values.

C Isotopes

Soil $\delta^{13}C$ isotope values associated with surface soil largely reflect the photosynthetic pathway of the dominant plant community; soils in freshwater wetlands usually reflect C_3 vegetation (Boutton 1991, Choi et al. 2001). The $\delta^{13}C$ values for C_3 plants range from -32 to -20‰ with an average of -27‰ and C_4 plants range from -17 to -9‰ with an average of -13‰ (Boutton 1991). The vast majority of plant species in this study were C_3, and the mean $\delta^{13}C$ values fall within this range. Because $\delta^{13}C$ values are heavily influenced by vegetative composition, the $\delta^{13}C$ values may not vary due to land use since the most common crops in North Dakota are wheat, sugar beets, and soybeans which are all C_3 plants. Recently, more corn is being planted in North Dakota due to high corn prices, which is accelerating wetland losses (Johnston 2013). If cropland cover continues to change to corn, the $\delta^{13}C$ values could increase since corn has a C_4 photosynthetic pathway.

Soil $\delta^{13}C$ values did not have a significant correlation with FQI or NDRAM scores. Increasing $\delta^{13}C$ values were slightly correlated with increasing IPCI scores, but with a low R-value (0.30). Therefore, our results are inconclusive regarding $\delta^{13}C$ values and wetland condition. Since the photosynthetic pathway of the plant community did not differ based on land use, the $\delta^{13}C$ values did not either (Boutton 1991, Choi et al. 2001, Staddon 2004). However, increasing soil pH was correlated with increasing $\delta^{13}C$ values. Low soil pH can decrease methane production under certain conditions (Nazaries et al. 2013), so we would expect $\delta^{13}C$ values to be lower in acidic soil. The influence of methanogenesis and $\delta^{13}C$ values in prairie wetlands needs to be further explored.

Conclusion

Natural abundance soil isotope values in wetlands need to be explored further. The results of this project will be a baseline for future study of wetland soil isotopes and condition. A number of studies have highlighted the usefulness of stable isotope natural abundance values, although there is still much to learn about applying stable isotope techniques in wetland ecosystems (Bachand and Horne 2000, Bernot et al. 2008, Aelion et al. 2010). This study is the first step in applying stable isotope natural abundance techniques in Northern Prairie wetlands. Soil natural abundance $\delta^{15}N$ values can be applied to reflect land use, wetland condition, and floristic quality. Therefore, natural abundance isotopes may be useful in wetland assessment, tracking denitrification, and studying long-term changes in land use and N sources (Chang et al. 2002, Elliot and Brush 2006, Billy et al. 2010). Additionally, $\delta^{13}C$ values reflect the plant community and can measure past changes in plant communities (Choi et al. 2001). Further studies to develop stable isotopes as indicators of wetland nutrient sources, land use changes, and nutrient cycling need to be developed, as the rapid sampling methods and low analysis cost makes stable isotopes a prime candidate for use in large-scale studies.

PAPER 4. USING CART ANALYSIS TO EVALUATE WETLAND CONDITION

Introduction

Vegetation assessment is important for determining wetland condition (Wilhelm and Ladd 1988). Plant communities are affected by a variety of biotic and abiotic components including soil type, hydrology, anthropogenic disturbances, and plant-animal interactions. Vegetative assessments and floristic quality indexes (FQIs) have been developed across the U.S. (Wilhelm and Ladd 1988, Hargiss et al. 2008). The premise is that floristic quality is representative of the condition or quality of an area. Therefore, certain species are linked to natural and native areas and certain species are linked to disturbed and stressed areas. Additionally, FQIs are region-specific. Plant species are assigned a coefficient of conservatism, or c-value, based on the tolerance of the species to disturbance in a specific region (Wilhelm and Ladd 1988, Swink and Wilhelm 1994, Taft et al. 1997). Higher c-values are assigned to species that are more sensitive to disturbance and, therefore, tend to be found in native, unaltered habitats.

Floristic Quality Indexes (FQIs) can be incorporated into vegetation-based assessments, such as the Index of Plant Community Integrity (IPCI, Hargiss et al. 2008). This assessment is based on the level of disturbance at a wetland and multiple measurements of the plant community. This assessment requires a thorough knowledge of plant species. Other methods of assessment include rapid assessments, which are developed for ease of use and minimal sample time (Fennessy et al. 2007). Many metrics of rapid assessment methods are scored based on the level of stress to an aspect of the wetland such as alteration of the hydrologic regime through ditching or draining, level of soil disturbance, and degree of alteration and development of the wetland buffer. How assessment methods relate to water, soil, and plant chemistry have not been determined. Thus, relationships between nutrient levels in wetlands and assessment methods have yet to be established.

Classification and regression trees (CART) are a tool for interpreting complex environmental data (Breiman et al. 1984, De’ath and Fabricius 2000). CART is a nonparametric method that provides linkages with environmental variables to identify patterns and processes in data. CART can be applied to large data sets, nonlinear relationships, missing values, high-order interactions, and numerical and categorical variables. Linear models can fail to find patterns identified by CART. CART has been applied to wetland studies to identify multiple states of succession in Florida everglades (Zweig and Kitchens 2009), to establish biological condition relative to human disturbance (Lougheed et al. 2007, Johnston et al. 2009), and predict seasonal wetland abundance in northern Minnesota forests (Palik et al. 2003).

Our goal was to intensify the NWCA study and establish data for statewide wetland assessment by expanding the sample size from 11 to 53 wetlands. A broad assortment of wetland data was collected during the study including soils, land use, vegetation, condition, buffer, and stressor data. Our objective was to model the data collected in order to identify distinguishing wetland characteristics. Thus, we related the vegetation data to environmental variables (including wetland location, type, size, hydrology, stressors, surrounding land use, water and soil attributes and chemical analyses, and plant nutrients) utilizing CART analysis and compared this with wetland condition. The results of this study will be a baseline for future studies of wetland assessment and condition.

Methods

Study Sites

The National Wetland Condition Assessment (NWCA) was the first ever assessment of our nation's wetlands and was completed in the summer of 2011 by the U.S. Environmental Protection Agency (USEPA, U.S. Environmental Protection Agency 2011). This assessment addresses the need for data to evaluate wetland quality. For the NWCA, a variety of data was collected about the wetland buffer, soils, vegetation, algae, water quality, hydrology, and a rapid assessment. As part of this nationwide study, North Dakota added additional sites as an intensification of the NWCA and performed three additional regional wetland assessments at each site. Thus, North Dakota was able to perform several statewide wetland studies as well as a statewide assessment of wetland condition.

During the summer of 2011, the NWCA was completed across North Dakota on 53 wetlands randomly pre-selected from the Fish and Wildlife Service's Status and Trends Plots (Dahl 2011). Thirty-six of the wetlands contained water greater than 15 cm deep, allowing for water sample collection. These 36 wetlands were selected for modeling in this study (Figure 21). Of the wetlands included in this study, 26 were closed depressions, 3 were open depressions, 3 were upper perennial riverine, 3 were lacustrine fringe, and 1 was organic soil flats based on hydrogeomorphic (HGM) classes (Smith et al. 1995).

At each wetland, the NWCA methods were performed (see U.S. Environmental Protection Agency 2011 for details). Data was collected for the wetland buffer, flora, water chemistry, soils, and a rapid assessment, among other components. In addition to the NWCA field survey, the IPCI, North Dakota Rapid Assessment Method (NDRAM), and Hydrogeomorphic (HGM) Model were completed at each wetland (Gilbert et al. 2006, Hargiss et al. 2008, Hargiss 2009). These regional wetland assessments were performed to provide comparisons to the NWCA and data for modeling. Additional live plant samples were collected for nutrient analysis.

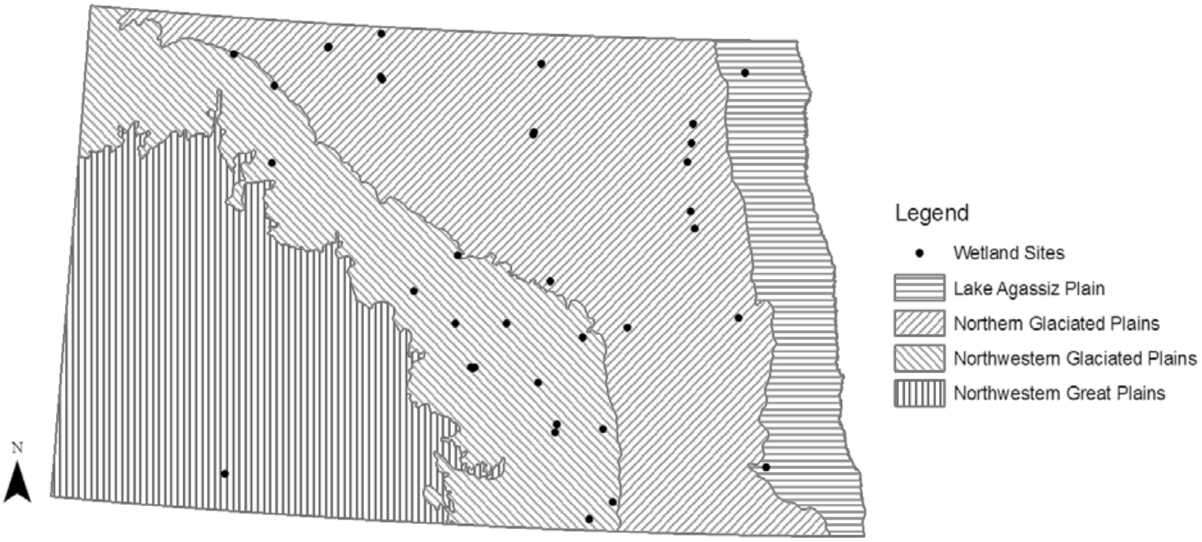

Figure 21. Location of the 36 wetland sites across North Dakota. The legend indicates the labels of the four main ecoregions in the state: Lake Agassiz Plain, Northern Glaciated Plains, Northwestern Glaciated Plains, and Northwestern Great Plains. For a description of the ecoregions see Bryce et al. (1998). Refer to Appendix A for a list of wetland locations.

National Wetland Condition Assessment

At each wetland, an assessment area (AA) was set up within the wetland with less than 10% of the AA in upland or in water over 1 m deep for the NWCA methods (U.S. Environmental Protection Agency 2011). The standard AA was a 0.50 ha circle; otherwise the AA was adjusted to fit the shape of the wetland. The minimum size of the AA was 0.10 ha. Three buffer plots were characterized in each of the four cardinal directions and one buffer plot was located at the center of the assessment area for a total of 13 plots. The first of the outer buffer plots were located 5 m from the edge of the assessment area. The next two were located 45 and 90 m from the first buffer plot. Each buffer plot was 100 m^2 and natural cover, stressors, and alien species were recorded for each plot.

Five 100 m^2 (10 m x 10 m) vegetation plots were set up at prescribed distances within the AA; one was in each cardinal direction and one was near the center (the center vegetation plot was the same as the center buffer plot). Vegetation was characterized in several ways using nested plots (1 m^2 and 10 m^2 plots were nested in the northeast and southwest corners of the large plot). Percent cover for each vascular plant species in the 100 m^2 plot was recorded as well as the height class for each species (≤ 0.5 m, 0.5 to 2 m, 2 to 5 m, 5 to 15 m, 15 to 30 m, > 30 m, and liana/vine/epiphyte). The smallest plot a species was found in was recorded. The percent cover of submerged aquatic vegetation; floating aquatic vegetation; and lianas, vines, and epiphytes was recorded for each of the 5 large plots. Cover of non-vascular plants, open water, bareground, vegetative litter, and downed dead woody material were also recorded in the 5 large plots. Last, snag, tree counts, and tree cover by species were recorded for the 5 large plots. However, the vegetation data from this assessment was not included as environmental variables in the CART model since the response variables were based on vegetation data from the IPCI.

Soil pits were dug immediately outside the southeast corner of the outer four vegetation plots. Soil pits where water was greater than 0.25 m deep were discarded. One of the soil pits was chosen as the most representative for the wetland. The representative pit was sampled for hydric soil indicators, water level, and soil chemistry. Water levels were measured as positive for standing water above soil pit and negative for water depth from the soil surface. Mercury (Hg), nitrate (NO_3-N), phosphorus (P), potassium (K), sulfate (SO_4-S), zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), chlorine (Cl), electrical conductivity (EC), percent organic matter (OM), calcium carbonate equivalent (CCE), and particle size analysis (PSA) were analyzed for each horizon in the representative pit at the NDSU Soil Testing Laboratory in Fargo, North Dakota. Data from the first soil horizon greater than 4 cm wide was used for the environmental variables.

Within the AA, water quality samples were collected. The water clarity was described as clear, turbid, stained, or milky. Surface water dissolved oxygen (DO), pH, and conductivity was recorded using a YSI probe. Water chemistry samples were collected and analyzed by the North Dakota Department of Health Laboratory in Bismarck, North Dakota. Water P, N, ammonia (NH_3-N), and nitrate-nitrite (NO_3-NO_2-N) were determined from water samples.

The wetland buffer, topography, patch complexity, plant community, water quality, hydrology alterations, and substrate stressors were rapidly assessed using the U.S.A. Rapid Assessment Method (USA-RAM). Average buffer width for a 100 m wide buffer was estimated using aerial photography and visual observation at the wetland. The buffer width in 8 equidistant directions was estimated and averaged to provide an average width. The percent of the AA adjoining buffer area was recorded as either <25%, 26-50%, 51-75%, and >75%. An overall buffer stressor score was calculated by adding up the total number of stressors present in the buffer plots. Similarly, the total number of water quality, hydrology, and substrate stressors were each calculated for the AA.

Regional Wetland Assessment Methods

Vegetation was assessed using the IPCI (Hargiss et al. 2008). Each plant species was recorded within each wetland zone based on Stewart and Kantrud (1971) using 1 m^2 quadrats. Eight quadrats were completed in the low prairie zone, seven in the wet meadow zone, five in the shallow marsh zone, and five in the deep marsh zone, and additional species were identified between quadrats. Wetland condition was scored using 9 condition metrics on a scale of 0 to 99 (see Hargiss et al. (2008) for specific calculations). The NDRAM was used to rapidly assess the buffer, soil, habitat, vegetation, hydrology, overall condition, and potential of the wetland to reach reference condition. The presence or absence of grazing, cropping, or herbicide use in and around the wetland was recorded in the NDRAM. Wetlands were scored on a scale of 0 to 100 (see Hargiss (2009) for specific calculations). As part of the HGM Model, the area of the wetland and wetland catchment, as well as the percent of catchment in cropland, native cover, and urban cover was collected using GPS and GIS information.

Vegetation Nutrient Levels

Vegetation samples were collected within each landscape position of the wetland. Samples were not collected in low prairie landscape positions that were actively cropped. At each landscape position, five 0.25 m^2 quadrats of live vegetation were clipped 2 cm from the soil surface and separated by plant type. The plant types were cool season grasses, warm season grasses, grass-likes (sedges, rushes, etc.), forbs and shrubs (current year's growth), and cattails. Cattails included *Typha latifolia* L., *Typha angustifolia* L., and *Typha x glauca* Godr. Most cattails were *Typha x glauca* Godr. This resulted in a total of 15 quadrats clipped per wetland. Samples were stored in labelled paper bags. Several wetlands were sampled per week, so samples collected at the beginning of the week were stored in the back of trucks and laid out during the day (unless it was raining). Once all samples were collected for the week, they were transported to North Dakota State University (NDSU) and placed in a large drying oven for two weeks at 90 °C. At this time, vegetation was checked for dryness and removed if dry; otherwise they were left in the dryer for a few more days. The dried vegetation was weighed for biomass and then ground through a 2 mm screen using a Wiley Mill.

Biomass measurements were calculated according to dry plant weight; wet weight was not measured. Biomass measurements were adjusted according to time of collection, plant type, and if the zone had been grazed to represent maximum plant growth. This was accomplished using plant growth curves and visual estimation of grazing severity (Sedivec et al. 2009, Sedivec et al. 2010). Based on recommendations by Sedivec et al. (2009) and Sedivec et al. (2010) and professional judgment, plant functional groups were adjusted according to time of harvest: cool season grasses, sedges and rushes, cattails, and forbs were considered at 70% growth from June 13th through June 17th, 80% growth from June 20th through June 24th, and 95% growth from June 27th through June 30th. Only seven sites had warm season grasses. The growth adjustments were as follows: 60% on June 21st and 90% from July 13th through 20th.

Nutrient analysis of vegetation samples was completed by the NDSU Soil Testing Laboratory from October of 2011 to August of 2012 using standard methods and procedures as outlined for the North Central Region (North Central Region-13 1998). Plant C and N were analyzed using an Elementar Vario Macro Cube CNS Analyzer with a thermal conductivity detector. Plant P was analyzed using a nitric acid digestion with peroxide using a block digester (Wolf et al. 2003).

Statistical Methods

Floristic Quality Index scores were calculated using the plant species list for each wetland generated by the IPCI. C-values from The Northern Great Plains Quality Assessment Panel (2001) were assigned to each species. The FQI score for each wetland was the average c-value multiplied by the square root of the total number of species (Wilhelm and Ladd 1988). Additionally, a data matrix of plant species cover was created using the IPCI species data. Data were arcsine square-root transformed. Nonmetric multidimensional scaling (NMS) was used with the relative Sørensen distance measure to ordinate plant species data using PC-ORD version 6.0 software (McCune and Mefford 2011). The ordination utilized a random starting point, 50 runs with real data, and 500 runs with randomized data. The best solution was selected based on 1) the highest dimensions with a reduction of 5 or more in the stress of real data, 2) a $p \leq 0.05$ for the Monte Carlo test comparing stress for the real data to a randomized data set, and 3) final solutions with stress < 20, number of iterations < 150, and instability < 0.0005. Species proportions were correlated with axis scores ($r < -0.40$ or $r > 0.40$ were considered significant scores, McCune and Grace 2002). A graph of the ordination was created in PC-ORD and was varimax rotated.

CART models were constructed using the FQI and NMS Axis 1 scores as the response variables (Johnston et al. 2009). The environmental variables collected from the assessment study in Table 2 were used as potential predictor variables for both CART models. We used SAS Enterprise Miner 12.1 to complete the analysis, which has a built in pruning method to determine optimal splits (SAS Institute Inc., Cary, NC, USA 2012). Greater details on using CART models for ecological data can be found in De'ath and Fabricius (2000). Linear regressions were calculated to determine if soil OM and average buffer width were correlated with the IPCI and NDRAM scores using MS Excel 2010.

Table 2. Environmental variables used in the CART model of 36 wetland sites across North Dakota.

Parameter	**Units of measure**	**Continuous or categorical (# categories)**	**Survey**
Latitude	decimal degree	continuous	NWCA
Longitude	decimal degree	continuous	NWCA
County	unitless	categorical (23)	NWCA
FWS Status & Trends class	unitless	categorical (3)	NWCA
Hydrogeomorphic class	unitless	categorical (5)	NWCA

Table 2. Environmental variables used in the CART model of 36 wetland sites across North Dakota (continued).

Parameter	**Units of measure**	**Continuous or categorical (# categories)**	**Survey**
Wetland catchment	ha	continuous	HGM Model
Percent of catchment in cropland	ha	continuous	HGM Model
Percent of catchment in native cover	ha	continuous	HGM Model
Percent of catchment in urban cover	ha	continuous	HGM Model
Percent buffer adjacent to AA	unitless	categorical (4)	NWCA
Mean buffer width up to 100 m	m	continuous	NWCA
Buffer stressor score	unitless	continuous	NWCA
Water clarity	unitless	categorical (4)	NWCA
Hydrology stressor score	unitless	continuous	NWCA
Number of water quality stressors	unitless	continuous	NWCA
DO	mg/L	continuous	NWCA
Water pH	unitless	continuous	NWCA
Water conductivity	µS/cm	continuous	NWCA
Water P	mg/L	continuous	NWCA
Water N	mg/L	continuous	NWCA
Water NH_3-N	mg/L	continuous	NWCA
Water NO_3-NO_2-N	mg/L	continuous	NWCA
Plant P	kg/ha	continuous	Additional data
Plant N	kg/ha	continuous	Additional data
Plant C	kg/ha	continuous	Additional data
Grazing presence	unitless	categorical (2)	NDRAM
Cropping presence	unitless	categorical (2)	NDRAM
Herbicide presence	unitless	categorical (2)	NDRAM
Substrate stressor score	unitless	continuous	NWCA
Soil Hg	mg/kg	continuous	NWCA
Soil NO_3-N	ppm	continuous	NWCA
Soil P	ppm	continuous	NWCA
Soil K	ppm	continuous	NWCA
Soil pH	unitless	continuous	NWCA

Table 2. Environmental variables used in the CART model of 36 wetland sites across North Dakota (continued).

Parameter	**Units of measure**	**Continuous or categorical (# categories)**	**Survey**
Soil EC	mmhos/cm	continuous	NWCA
Percent soil OM	unitless	continuous	NWCA
Soil SO_4-S	ppm	continuous	NWCA
Soil Zn	ppm	continuous	NWCA
Soil Fe	ppm	continuous	NWCA
Soil Mn	ppm	continuous	NWCA
Soil Cu	ppm	continuous	NWCA
Soil Cl	ppm	continuous	NWCA
CCE	unitless	continuous	NWCA
Sand PSA	unitless	continuous	NWCA
Silt PSA	unitless	continuous	NWCA
Clay PSA	unitless	continuous	NWCA
Histisol presence	unitless	categorical (2)	NWCA
Hydrogen sulfide odor in soil pit	unitless	categorical (2)	NWCA
Over 1 cm of muck	unitless	categorical (2)	NWCA
Depleted below dark surface	unitless	categorical (2)	NWCA
Thick dark surface	unitless	categorical (2)	NWCA
Loamy mucky mineral soil	unitless	categorical (2)	NWCA
Depleted matrix	unitless	categorical (2)	NWCA
Redox dark surface	unitless	categorical (2)	NWCA
Water level in soil pit	cm	continuous	NWCA

Results

The best solution to the NMS ordination had two dimensions, Axis 1 and Axis 2 (Figure 22). Axis 1 explained 55% of the variance in the data and Axis 2 explained 26% variance in the data for a total of 81%. Seventeen plant species were significant to the positive end of Axis 1, 2 species were significant to the negative end of Axis 1, 1 species was significant to the positive end of Axis 2, and 47 species were significant to the negative end of Axis 2 (Table 3). The species at the positive end of Axis 1 tended to be annual and weedy species. The species significant at the negative end of Axis 1 and the positive end of Axis 2 both were cool season grasses. There were many species significant to the negative end of Axis 2. Most were native, perennial forbs with a few sedges and trees.

The CART model that used the FQI scores as the response variable had 6 terminal nodes and an R^2 of 0.767 (Figure 23). The first split utilized percent soil OM, splitting the data at above and below 13.1%. Wetlands with greater than 13.1% soil OM resulted in a terminal node with an average FQI score of 37.1 (the highest of all of the terminal nodes, n=5). Soil OM was significantly positively correlated with IPCI (R^2 = 0.25, p = 0.002) and NDRAM (R^2 = 0.20, p = 0.007) assessment scores (Figure 24).

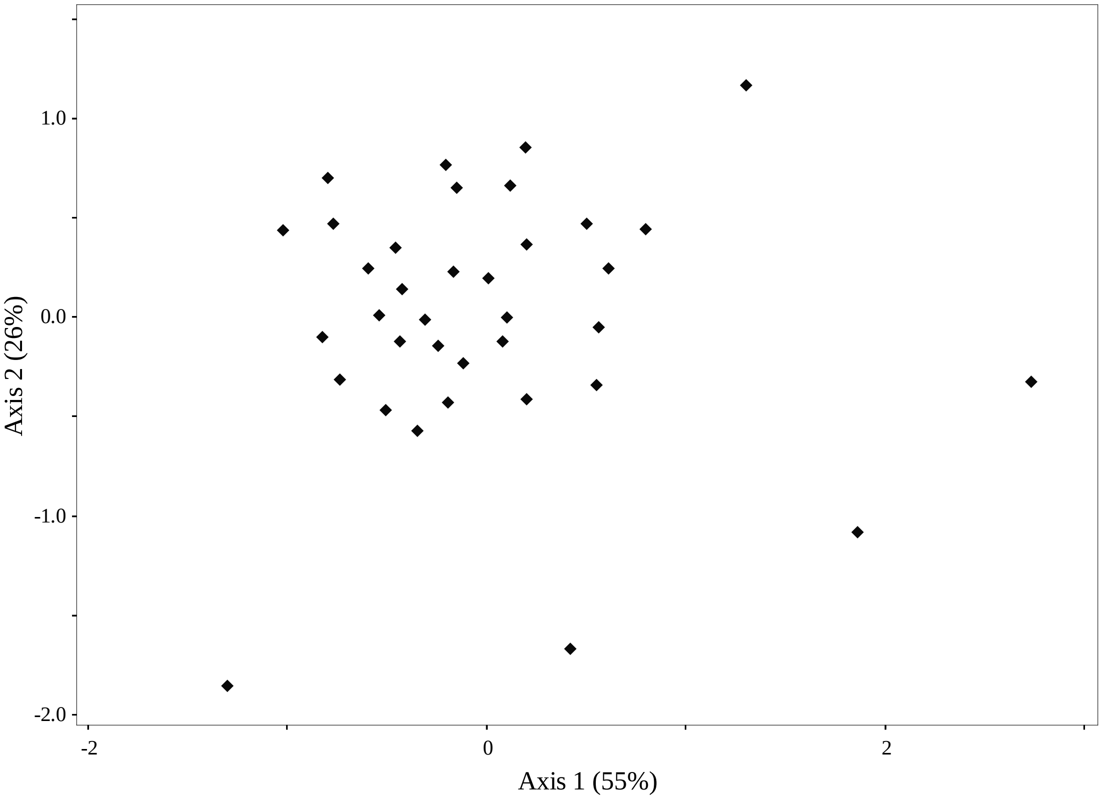

Figure 22. NMS ordination with Axis 1 and Axis 2. The percent of variance explained by each axis is listed in parenthesis.

Table 3. Species associated with the end of each NMS axis. Scientific names of plant species are according to the USDA Plants Database (USDA, NRCS 2012). Life-forms: N = native and I = introduced. Origin: P = perennial, A = annual, and B = biennial.

Scientific name	**Life**	**Origin**	**Scientific name**	**Life**	**Origin**
Axis 1 – positive			**Axis 2 – negative (cont.)**		
Alisma subcordatum	N	P	Carex interior	N	P
Anthemis arvensis	I	A	Carex retrorsa	N	P
Artemisia biennis	I	B	Carex rosea	N	P
Avena fatua	I	A	Carex rostrata	N	P
Beckmannia syzigachne	N	A	Carex stipata	N	P
Callitriche palustris	N	P	Cicuta maculata	N	P
Eleocharis engelmannii	N	A	Cornus sericea	N	P
Epilobium ciliatum	N	P	Cyclachaena xanthifolia	N	A
Euphorbia glyptosperma	N	A	Elymus hystrix	N	P
Gratiola neglecta	N	A	Equisetum arvense	N	P
Juncus bufonius	N	A	Fragaria virginiana	N	P
Lemna minor	N	P	Fraxinus pennsylvanica	N	P
Limosella aquatica	N	P	Galium aparine	N	A
Polygonum aviculare	N	A	Heracleum maximum	N	P
Rorippa palustris	N	A	Heuchera richardsonii	N	P
Typha x glauca	I	P	Lolium perenne	I	P
Veronica peregrina	N	A	Maianthemum canadense	N	P
Axis 1 – negative			Maianthemum stellatum	N	P
Calamagrostis stricta	N	P	Osmorhiza claytonii	N	P
Poa pratensis	I	P	Platanthera aquilonis	N	P
Axis 2 – positive			Poa sandbergii	N	P
Elymus repens	I	P	Polygonum ramosissimum	N	A
Axis 2 – negative			Prenanthes alba	N	P
Amphicarpaea bracteata	N	A	Quercus macrocarpa	N	P
Aquilegia canadensis	N	P	Ranunculus longirostris	N	P
Aralia nudicaulis	N	P	Rubus idaeus	N	P
Artemisia frigida	N	P	Rudbeckia laciniata	N	P
Asarum canadense	N	P	Sagittaria cuneata	N	P
Aster ciliolatus	N	P	Salicornia rubra	N	A
Atriplex subspicata	N	A	Sisymbrium altissimum	I	A
Bassia scoparia	I	A	Solidago gigantea	N	P
Bromus japanicus	I	A	Thalictrum venulosum	N	P
Calamagrostis canadensis	N	P	Trillium cernuum	N	P
Calla palustris	N	P	Triticum aestivum	I	A
Carex formosa	N	P	Ulmus americana	N	P

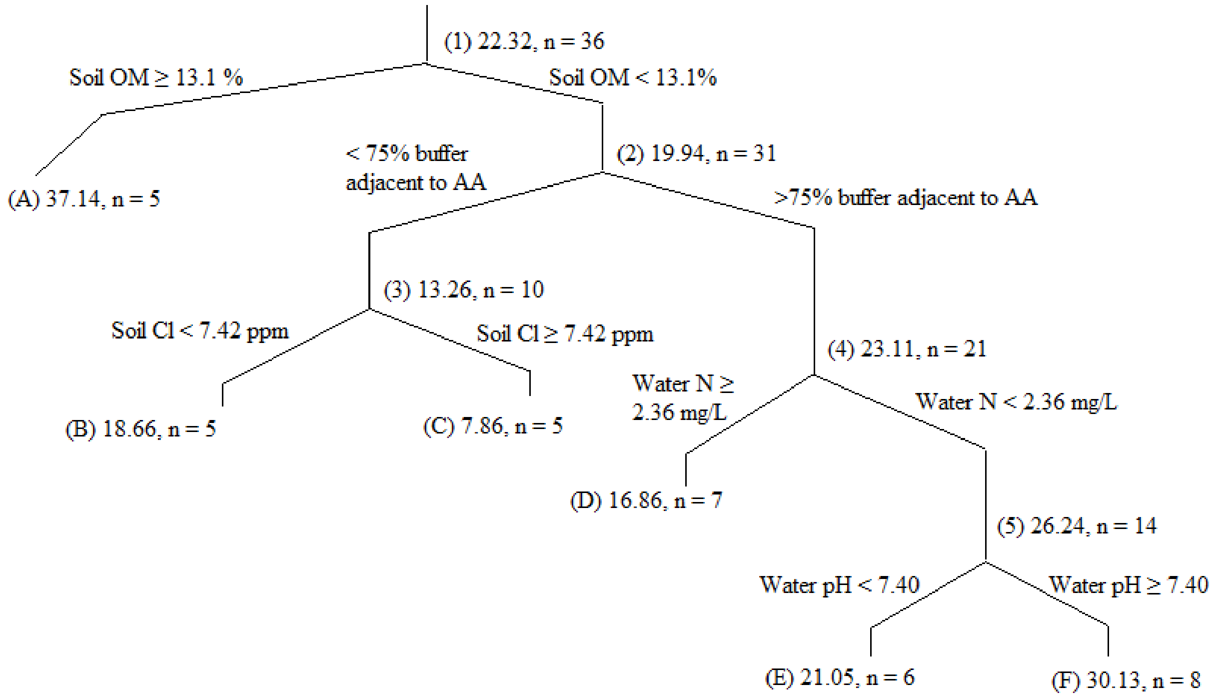

Figure 23. Classification and regression tree between FQI scores and environmental variables. Split nodes are identified by the number in parenthesis followed by the average FQI scores and n = number of wetlands. Terminal nodes are identified by a letter in parenthesis and are followed by the average FQI scores and n = number of wetlands.

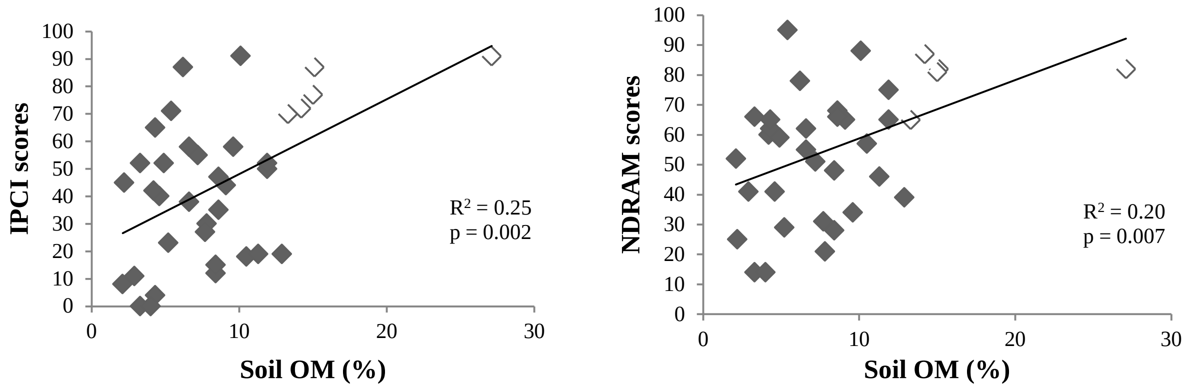

Figure 24. Linear regressions of soil OM (%) and IPCI and NDRAM scores. Wetlands in terminal node A of the FQI CART model (soil OM > 13.1) are represented by open diamonds.

Node 2 of the FQI CART model split the data based on the percent of buffer adjacent to the AA into wetlands with >75% adjacent buffer or wetlands with <25%, 26-50%, and 51-75% adjacent buffer. Figure 25 displays the average IPCI and NDRAM condition scores for each category of buffer continuity and shows a trend of increasing conditions scores with increasing continuity. Node 3 split the data by soil Cl greater than or less than 7.42 ppm resulting in 2 terminal nodes. Wetlands in the node with soil Cl less than 7.42 ppm had an average FQI score of 18.7 (n=5), and wetlands in the node with soil Cl greater than 7.42 had an average FQI score of 7.86 (the lowest of all terminal nodes, n = 5). Node 4 was split by water N as above or below 2.36 ppm. Water N less than 2.36 ppm resulted in a terminal node with an average FQI score of 16.9 (n = 7). Node 5 split wetlands by water pH as above or below 7.40 into 2 terminal nodes. The terminal node with water pH less than 7.4 had an average FQI score of 21.0 (n = 6), and the terminal node with water pH greater than 7.4 had an average FQI score of 30.1 (n = 8). Average IPCI and NDRAM condition scores for the terminal nodes are listed in Table 4.

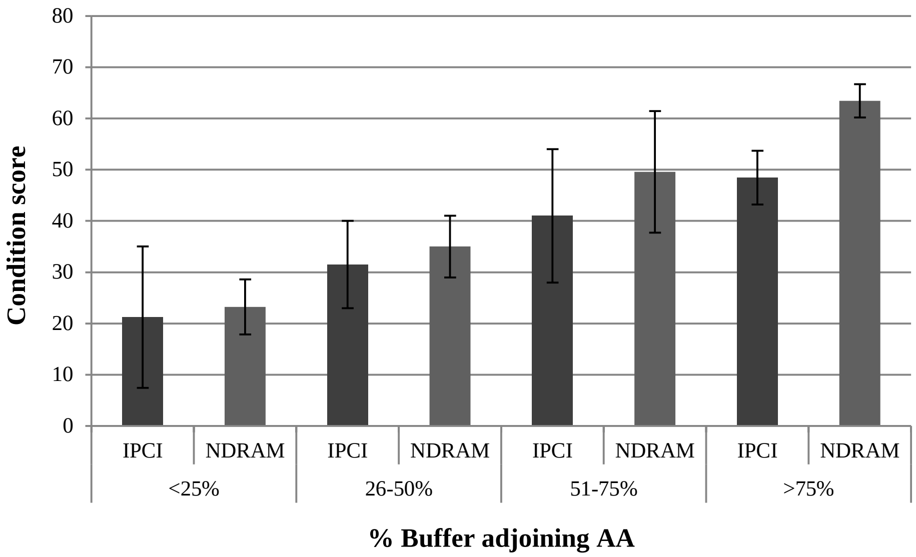

Figure 25. Average IPCI and NDRAM conditions scores of each category of buffer continuity adjoining the AA. Error bars represent standard error.

Table 4. Mean IPCI and NDRAM scores for the terminal nodes of the FQI and NMS Axis 1 CART models. See Figures 22 and 25 for the CART models. Standard errors are given in parenthesis.

Terminal node	IPCI	NDRAM
FQI – A	79.4 (±4.13)	79.4 (±3.75)
FQI – B	33.6 (±8.48)	32.6 (±5.35)
FQI – C	19.6 (±8.47)	33.2 (±10.1)
FQI – D	21.7 (±6.38)	49.9 (±5.60)
FQI – E	47.2 (±11.2)	59.5 (±6.04)
FQI – F	58.4 (±5.39)	70.6 (±4.14)
NMS – A	23.6 (±8.31)	25.0 (±3.02)
NMS – B	68.7 (±8.55)	71.0 (±4.83)
NMS – C	43.4 (±6.99)	59.5 (±7.30)
NMS – D	28.3 (±7.45)	55.2 (±5.33)
NMS – E	44.2 (±9.29)	62.7 (±6.73)

The CART model that used the NMS Axis 1 scores as the response variable had 5 terminal nodes and an R^2 of 0.678 (Figure 26). The first split utilized average buffer width, splitting the data at above and below 32.5 m. Wetlands with less than 32.5 m average buffer width resulted in a terminal node with an average NMS Axis 1 score of 1.14 (the highest of all terminal nodes, n = 7). Buffer width was slightly positively correlated with IPCI scores – the R^2 value was low and explains very little of the variation in the data ($R^2 = 0.17$, $p = 0.012$, Figure 27). The NDRAM scores also showed a positive correlation with buffer width and had a higher R^2 score ($R^2 = 0.55$, $p < 0.001$). Node 2 of the CART model split the data based on water P into wetlands with greater than or less than 0.32 ppm. Node 3 split the data by soil NO_3-N greater than or less than 10 ppm resulting in 2 terminal nodes. Wetlands in the node with soil NO_3-N less than 10 ppm had an average NMS Axis 1 score of -0.707 (the lowest of all terminal nodes, n=9), and wetlands in the node with soil NO_3-N greater than 10 had an average NMS Axis 1 score of -0.260 (n = 8). Node 4 was split by soil Fe as above or below 57.5 ppm and resulted in 2 terminal nodes. Soil Fe less than 57.5 ppm resulted in a terminal node with an average NMS

Axis 1 score of -0.202 (n = 6). The terminal node with soil Fe greater than 57.5 ppm had an average NMS Axis 1 score of 0.279 (n = 6). Average IPCI and NDRAM condition scores for the terminal nodes are listed in Table 4.

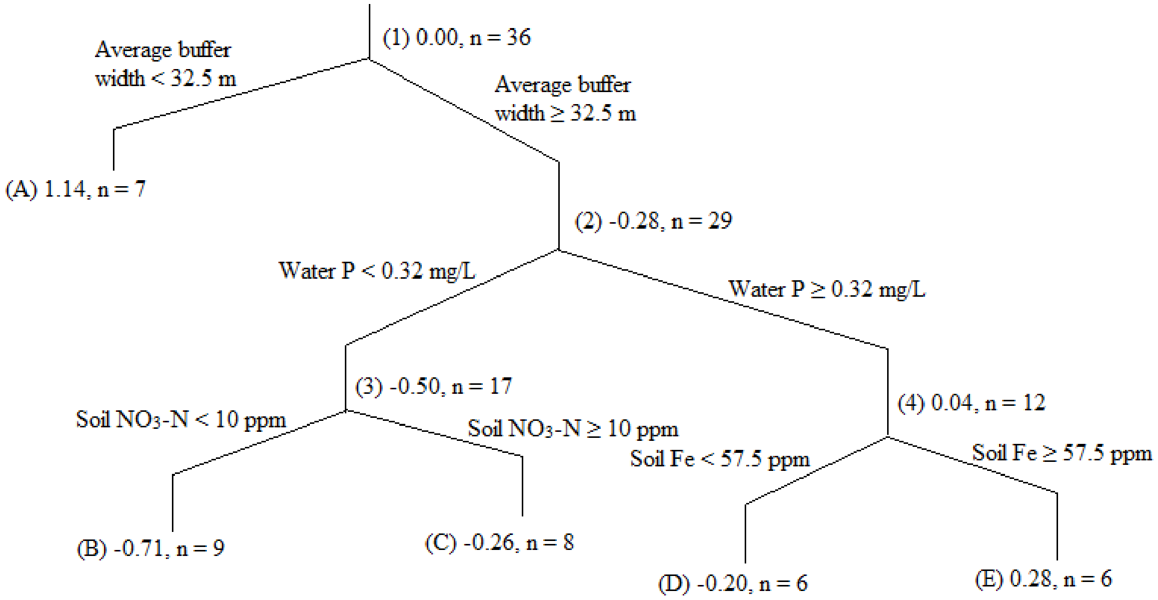

Figure 26. Classification and regression tree between NMS Axis 1 scores and environmental variables. Split nodes are identified by the number in parenthesis followed by the average NMS Axis 1 scores and n = number of wetlands. Terminal nodes are identified by a letter in parenthesis and are followed by the average NMS Axis 1 scores and n = number of wetlands.

Discussion

The results of the CART analysis allowed us to identify patterns in the data related to wetland floristic quality and condition (Johnston et al. 2009). The model utilizing the FQI scores was slightly more explanatory than the model using the NMS Axis 1 scores ($R^2 = 0.767$ vs. 0.678), but both explained most of the variability in the data. Both models relied on physical variables related to soils, buffer, and water and dismissed variables related to location, wetland type, land use, stressors, plants, and hydric soil indicators.

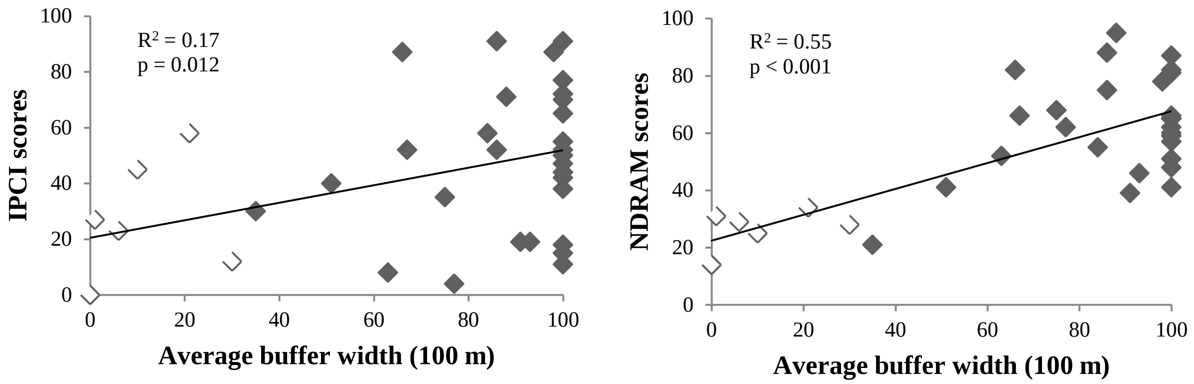

Figure 27. Linear regressions of average buffer width of a 100 m buffer and IPCI and NDRAM scores. Wetlands in terminal node A of the NMS Axis 1 CART model (average buffer width < 32.5 m) are represented by open diamonds.

FQI CART Model

The first split in the FQI model was by soil OM, separating 5 sites containing high soil OM from the rest of the sites. These sites tended to have higher IPCI and NDRAM condition scores. Linear regressions of the IPCI and NDRAM scores against the soil OM show slight correlations of increasing soil OM significantly correlated with increasing wetland condition. Furthermore, soil OM has been found to be higher in naturally occurring wetlands than mitigation wetlands (Shaffer and Ernst 1999) and in undisturbed grasslands than cultivated grasslands (Cambardella and Elliott 1992). Therefore, the first split indicates wetlands with higher soil OM may also have greater wetland condition and less substrate disturbance. The next split in the model was by the percent of the buffer adjacent to the AA. Buffer areas that are disturbed or invaded tend to have less continuity, soil porosity, and soil OM (DeKeyser et al. 2009). Therefore, the continuity of the buffer zone, so that it is free of cropland and roads and ditches, greatly affects wetland quality (Castelle et al. 1994).

The remaining wetlands in the FQI model were split into leaves that tended to have more buffer continuity and higher condition and less buffer continuity and lower condition (DeKeyser et al. 2009). Further splits in the model were determined by soil and water variables. Soil chloride was the last split for wetlands with less buffer continuity. Chloride salts are very soluble and can vary due to soil EC, CEC, and saturation of other salts in the soil (Arndt and Richardson 1989). Additionally, the source of water (precipitation vs. groundwater) and cycling of water levels can affect soil salinity. The wetlands in the high soil Cl leaf tended to be cropped around with a seasonal hydrologic classification (Stewart and Kantrud 1971). At least one wetland showed visible salinity effects (noted in the NDRAM).

For the leaf of wetlands with higher buffer continuity, total N in the water was the next split. Wetlands with high water N were grouped into a terminal node. These wetlands tended to have low to fair condition (mean IPCI = 21.7 and NDRAM = 49.9). The wetlands were in a variety of landscape settings: cropland, grazed rangeland, hayed prairie, and idle areas. We can hypothesize that the condition of these wetlands tended to be low because of present or past disturbance and nonpoint pollution of N. Agricultural drainage water can be high in NO_3-N; the effectiveness of wetlands to be a sink for N depends on the N load and the capacity of wetlands to remove N through denitrification (Crumpton and Goldsborough 1998, Woltemade 2000). Plant uptake can also affect N levels, although is not permanently removed from the wetland by this process. Additional nonpoint sources include runoff from pasture and range, urban runoff, septic tank leachate, constructions sites, abandoned mines, atmospheric deposition (Carpenter et al. 1998).

The last two terminal nodes of the FQI model were split by acidic and alkaline water pH. Wetlands can be naturally acidic or alkaline depending on hydrology and soil parent material or pH can be affected by heavy metal discharge from mining or construction activities or acid deposition (Sheoran and Sheoran 2006). However, the pH range for wetlands in this study was

6.70 to 8.59 indicating some wetlands may have slight acidification. Most Northern Prairie wetlands are generally calcareous and have alkaline water with a pH level greater than 7.4 (LaBaugh 1989).

NMS Axis 1 CART Model

The first split in the NMS Axis 1 model was the average buffer width of a 100 m buffer. Wetlands with an average buffer width less than 32.5 m resulted in a terminal node. The wetlands in this group tended to be cropped within, up to or near the wetland and had a smaller seasonal hydrologic classification (Stewart and Kantrud 1971). Often smaller wetlands are most affected by agricultural practices as they are easier to crop through during dry years or crop up to during wet years (Stewart and Kantrud 1973, Voldseth et al. 2007). Cultivation removes the native plant community providing ideal habitat for invasive, annual, and weedy species. Buffer areas are important for floristic quality as well as wetland function (DeKeyser et al. 2009, Hargiss 2009). Therefore, buffer characteristics were significant variables in both CART models.

Total water P was the significant variable for the second split in the model. Agriculture and urban activities contribute as nonpoint pollution sources of P (Carpernter et al. 1998). Excess levels of P in wetlands can lead to eutrophication and increase species invasion, specifically of *Typha* species (Newman et al. 1998, Tuchman et al. 2009). Water P in wetlands ranged from 0.018 to 4.42 mg/L with a mean of 0.703 mg/L in this study. One study in North Dakota seasonal prairie pothole wetlands have identified water P levels to range from 0.09 to 2.63 mg/L in native prairie and 0.07 to 3.90 mg/L in cropland (Detenbeck et al. 2002). Furthermore, LaBaugh et al. (1987) found a range in water P concentrations of two seasonal and two semi-permanent wetlands to be 0 to 3.06 mg/L. The mean water P for this study is well within ranges of previous studies. However, the high end of our range is outside the ranges of the other studies. Wetlands in the branch of the CART model with P levels above 0.32 mg/L may be impacted by high P levels since condition scores tended to be lower in this branch than the other. The last two splits in the model were soil NO_3-N (on the branch with low water P) and soil Fe (on the branch with high water P). The terminal node of the model with low water P and low soil NO_3-N contained wetlands with the highest condition scores (average IPCI = 68.67 and NDRAM = 71.00). This group of wetlands contained high average buffer width and low nutrient levels.

The other 3 terminal nodes contained wetlands with mid to low condition scores. High soil NO_3-N can indicate high inputs of N from agriculture, urban areas, or atmospheric deposition exceeding denitrification rates (Carpenter et al. 1998, Woltemade 2000). Freeland et al. (1999) found mean nitrate levels to be similar in the soil surface of North Dakota wetlands surrounded by agriculture and grassland. However, higher subsoil NO_3-N levels were found in the wet meadow zones of wetlands surrounded by agriculture. Boundary levels for soil NO_3-N levels related to wetland condition in Northern Prairie wetlands need to be determined. The terminal nodes D and E containing high and low soil Fe had similar condition scores for the NDRAM, but nodes D showed low IPCI scores with an average of 28.33. This variable may have been significant since the presence of Fe in wetlands may indicate groundwater chemistry has been unaltered by human activities (Smolders et al. 2010). If Fe inputs are decreased in groundwater-fed wetlands (which is common in agricultural settings), P may be mobilized in the system leading to eutrophication.

Conclusion

The specific environmental variables selected varied between the FQI and NMS models. However, both identified buffer, soil, and water data as the significant variables for the models. The CART models were able to group wetlands of similar condition. This demonstrates potential applicability of CART models and condition assessment. The CART models selected soil OM and average buffer width as the first splits in the data, and indicated high soil OM as a predictor of high wetland condition and small buffer width as a predictor of low wetland condition. Wetland buffers have been linked to wetland condition by many studies (Castelle et al. 1994, DeKeyser et al. 2009). The results of the CART analysis strengthen this conclusion. The CART models also identified soil and water characteristics – soil Cl, Fe, and NO_3-N and water N, P, and pH – that have not previously been considered as predictors of floristic quality or wetland condition. Overall, this study highlighted the different levels of wetland condition across North Dakota and identified areas of future study related to wetland condition and assessment and soil, water, and buffer data.

GENERAL CONCLUSION

The studies in this dissertation address important issues in Northern Prairie wetlands – wetland condition and nutrient levels. As humans continue to alter natural landscapes for agriculture and urban expansion, wetlands are at risk for degradation and high nutrient loads (Millennium Ecosystem Assessment 2005). These issues are reflected in the results of this dissertation. Wetlands surrounded by cropland had lower floristic quality than wetlands surrounded by other land uses. Additionally, cattails may affect nutrient cycling of phosphorus (P), and may be able to invade wetlands that have been disturbed due to agriculture. Methods to mitigate cattail invasion, such as sediment removal, require long-term study. Linkages between nutrient loading, species composition, and surrounding land use need to be determined to provide further understanding of wetland processes and aid in proper wetland management.

A new tool for measuring nutrients in wetlands – natural abundance of stable isotopes for nitrogen (N) and carbon (C) – was investigated in this dissertation and showed some promising results. Soil $\delta^{15}N$ values were able to reflect surrounding land use and were significantly correlated with floristic quality and wetland condition. Both soil $\delta^{15}N$ and $\delta^{13}C$ were able to detect differences in wetland type, and soil $\delta^{13}C$ was significantly different for landscape position. Stable isotopes may be useful for measurements in land use and wetland condition and can potentially measure nutrient processes in wetlands. Applications for stable isotopes need to be further developed for use in Northern Prairie wetlands.

The Classification and Regression Tree (CART) models presented in this dissertation may guide future research. Significant variables in the models were able to separate wetlands based on biological condition. In both models, wetland buffer was significant, which is consistent with previous studies. The other significant variables – soil organic matter (OM), soil chloride (Cl), water N, water pH, water P, soil nitrate (NO_3-N), and soil iron (Fe) – may be important characteristics of wetlands that affect wetland condition, higher trophic levels, or wetland processes and warrant further investigation.

The results of this dissertation are important to guide future studies of wetlands. As data and scoring methods become available for the National Wetland Condition Assessment (NWCA), a comparison of wetland condition in the state of North Dakota to national wetland condition may be completed with the data collected from these studies. Additionally, a comparison of the NWCA scores with the results of the regional assessment methods – Index of Plant Community Integrity (IPCI), North Dakota Rapid Assessment Method (NDRAM), and Hydrogeomorphic (HGM) Model – would be possible. The next NWCA is scheduled for the summer of 2016.

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APPENDIX A. TABLE OF GPS LOCATION, SUB-ECOREGION, WETLAND TYPE, AND LAND USE FOR 2011 STUDY SITES

Site[1]	GPS Location of Wetland	Sub-Ecoregion	Wetland Type	Land Use
Reference 1	Lat: 48.858 Long: -100.1277	Turtle Mountains	Forested Seasonal	Idle
Reference 2	Lat: 48.668477 Long: -102.403441	Northern Missouri Coteau	Semi-Permanent	Idle
5001*	Lat: 47.199866 Long: -98.787754	End Moraine Complex	Seasonal	Cropped
5003*	Lat: 47.602358 Long: -100.408356	Missouri Coteau	Semi-Permanent	Cropped
5004	Lat: 48.879718 Long: -100.663489	Glacial Lake Basins	Temporary	Idle
5006	Lat: 47.825361 Long: -98.173759	Glacial Outwash	Semi-Permanent	Idle
5007	Lat: 47.244844 Long: -103.289167	Little Missouri Badlands	Riparian Temporary	Grazed/hayed
5008*	Lat: 48.853747 Long: -101.734305	Northern Black Prairie	Seasonal	Cropped
5010*	Lat: 46.354189 Long: -97.468212	Sand Deltas and Beach Ridges	Seasonal	Cropped
5011*	Lat: 47.184499 Long: -100.401375	Missouri Coteau	Semi-Permanent	Idle
5012*	Lat: 48.769736 Long: -102.644221	Northern Missouri Coteau	Semi-Permanent	Idle
5013*	Lat: 48.38973 Long: -99.730017	End Moraine Complex	Semi-Permanent	Grazed/hayed
5015*	Lat: 46.168993 Long: -102.465416	Missouri Plateau	Riparian Seasonal	Cropped
5016*	Lat: 48.798334 Long: -97.733043	Sand Deltas and Beach Ridges	Riparian Seasonal	Idle
5017*	Lat: 48.351826 Long: -98.228343	Drift Plains	Seasonal	Grazed/hayed
5018*	Lat: 48.955488 Long: -101.23654	Northern Black Prairie	Seasonal	Grazed/hayed
5019*	Lat: 47.931093 Long: -98.221209	Drift Plains	Semi-Permanent	Idle
5021	Lat: 46.108727 Long: -98.896921	Missouri Coteau	Semi-Permanent	Grazed/hayed
5023*	Lat: 46.915981 Long: -100.200047	Missouri Coteau	Semi-Permanent	Idle

Site[1]	GPS Location of Wetland	Sub-Ecoregion	Wetland Type	Land Use
5027	Lat: 46.426751 Long: -103.089604	Missouri Plateau	Seasonal	Cropped
5030*	Lat: 48.236622 Long: -98.262384	Drift Plains	Seasonal	Idle
5032*	Lat: 48.688003 Long: -101.220021	Northern Black Prairie	Seasonal	Grazed/hayed
5034*	Lat: 47.273933 Long: -97.749742	Drift Plains	Seasonal	Idle
5037*	Lat: 47.367658 Long: -100.80623	Missouri Coteau	Semi-Permanent	Idle
5040*	Lat: 48.817798 Long: -99.685235	Northern Black Prairie	Semi-Permanent	Cropped
5042	Lat: 48.071318 Long: -100.419674	Drift Plains	Seasonal	Idle
5043*	Lat: 46.536591 Long: -99.429962	Missouri Coteau	Semi-Permanent	Idle
5046*	Lat: 46.917062 Long: -100.237146	Missouri Coteau	Seasonal	Grazed/hayed
5048	Lat: 48.029477 Long: -101.611066	Missouri Coteau	Semi-Permanent	Grazed/hayed
5049*	Lat: 46.008085 Long: -99.087701	Missouri Coteau	Semi-Permanent	Grazed/hayed
5052*	Lat: 46.118288 Long: -98.876435	Missouri Coteau	Semi-Permanent	Idle
5055*	Lat: 48.378733 Long: -99.737211	End Moraine Complex	Semi-Permanent	Grazed/hayed
5056*	Lat: 46.589206 Long: -99.42079	Collapsed Glacial Outwash	Semi-Permanent	Grazed/hayed
5059*	Lat: 48.475155 Long: -98.217563	Drift Plains	Seasonal	Cropped
5062*	Lat: 48.592716 Long: -102.23213	Northern Missouri Coteau	Semi-Permanent	Grazed/hayed
5065*	Lat: 47.197185 Long: -99.924721	Missouri Coteau	Semi-Permanent	Idle
5066*	Lat: 48.851731 Long: -101.740764	Northern Black Prairie	Seasonal	Cropped
5067	Lat: 46.137029 Long: -99.34873	Missouri Coteau	Semi-Permanent	Grazed/hayed
5068	Lat: 48.78548 Long: -97.757942	Sand Deltas and Beach Ridges	Fen (Temporary)	Grazed/hayed
5069*	Lat: 47.131597 Long: -99.208903	Missouri Coteau	Seasonal	Grazed/hayed

Site[1]	GPS Location of Wetland	Sub-Ecoregion	Wetland Type	Land Use
5072*	Lat: 48.110772 Long: -102.209249	Glaciated Dark Brown Prairie	Semi-Permanent	Grazed/hayed
5073*	Lat: 46.912737 Long: -100.223631	Missouri Coteau	Seasonal	Idle
5075*	Lat: 46.565028 Long: -98.989472	Missouri Coteau	Semi-Permanent	Idle
5077	Lat: 46.060652 Long: -98.099341	Glacial Lake Deltas	Seasonal	Cropped
5078*	Lat: 48.672473 Long: -101.207191	Northern Black Prairie	Seasonal	Cropped
5079*	Lat: 47.466397 Long: -99.524628	Drift Plains	Seasonal	Idle
5082	Lat: 48.797818 Long: -97.736775	Sand Deltas and Beach Ridges	Riparian Seasonal	Grazed/hayed
5083*	Lat: 47.822517 Long: -98.17961	Drift Plains	Semi-Permanent	Cropped
5084*	Lat: 46.83646 Long: -99.60636	Collapsed Glacial Outwash	Seasonal	Grazed/hayed
5085	Lat: 47.739127 Long: -100.563759	Missouri Coteau	Semi-Permanent	Cropped
5089	Lat: 47.374251 Long: -100.79192	Missouri Coteau	Seasonal	Idle
5091	Lat: 47.621626 Long: -99.735634	Drift Plains	Seasonal	Cropped
5093	Lat: 47.930465 Long: -98.226496	Drift Plains	Semi-Permanent	Idle
5094	Lat: 47.724992 Long: -100.185961	Drift Plains	Seasonal	Cropped
5095	Lat: 48.235145 Long: -98.269298	Drift Plains	Semi-Permanent	Grazed/hayed

[1] All sites were included in the stable isotope analysis except for Reference 1 and 2, 5006, and 5010

*These sites were included in the CART analysis

APPENDIX B. COMPREHENSIVE PLANT SPECIES LIST FOR 2011 STUDY SITES

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Acer negundo	Box Elder	1	N	P	FAC
Achillea millefolium	Yarrow	3	N	P	UPL
Agoseris glauca	False Dandelion	8	N	P	FAC
Agrimonia striata	Striate Agrimony	5	N	P	FACU
Agropyron cristatum	Crested Wheatgrass	*	I	P	UPL
Agrostis hyemalis	Ticklegrass	1	N	P	FACW
Agrostis stolonifera	Redtop, Creeping Bentgrass	*	I	P	FACW
Alisma gramineum	Narrowleaf Water Plantain	2	N	P	OBL
Alisma subcordatum	Common Water Plantain	2	N	P	OBL
Allium geyeri	N/A	10	N	P	FACU
Allium stellatum	Pink Wild Onion	7	N	P	UPL
Alnus incana	Speckled Alder	9	N	P	FACW
Alopecurus aequalis	Shortawn Foxtail	2	N	P	OBL
Amaranthus albus	Tumbleweed	0	N	A	FACU
Amaranthus retroflexus	Rough Pigweed, Redroot Amaranth	0	N	A	FACU
Ambrosia artemisifolia	Common Ragweed, Short Ragweed	0	N	A	FACU
Ambrosia psilostachya	Western Ragweed	2	N	P	FAC
Amorpha canescens	Lead Plant	9	N	P	UPL
Amorpha fruticosa	False Indigo	4	N	P	FACW
Amphicarpaea bracteata	Hog Peanut	8	N	A	FACU
Andropogon gerardii	Big Bluestem	5	N	P	FACU
Anemone canadensis	Meadow Anemone, Candian Anemone	4	N	P	FACW
Anemone cylindrica	Candle Anemone	7	N	P	UPL
Antennaria microphylla	Pink Pussy-toes, Littleleaf Pussy-toes	7	N	P	UPL
Antennaria neglecta	Field Pussy-toes	5	N	P	UPL
Anthemis arvensis	Corn Chamomile	*	I	A	UPL
Apocynum cannabinum	Indian Hemp Dogbane, Prairie Dogbane	4	N	P	FAC
Aquilegia canadensis	Wild Columbine, Red Columbine	8	N	P	FAC
Arabis hirsuta	Rock Cress, Creamflower Rockcress	7	N	B	UPL
Arabis holboellii	Rock Cress, Collins' Rockcress	5	N	B	UPL
Aralia nudicaulis	Wild Sarsaparilla	10	N	P	FACU

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Argentina anserina	Silverweed	2	N	P	OBL
Artemisia absinthium	Wormwood, Absinthium	*	I	P	UPL
Artemisia biennis	Biennial Wormwood	*	I	B	FAC
Artemisia cana	Dwarf Sagebrush, Silver Sagebrush	7	N	P	FACU
Artemisia dracunculus	Silky Wormwood, Tarragon	4	N	P	UPL
Artemisia frigida	Prairie Sagewort	4	N	P	UPL
Artemisia ludoviciana	White Sage	3	N	P	UPL
Asarum canadense	Wild Ginger, Canadian Wildginger	10	N	P	UPL
Asclepias syriaca	Common Milkweed	0	N	P	UPL
Asclepias verticillata	Whorled Milkweed	3	N	P	UPL
Aster cilolatus	N/A	8	N	P	FACW
Astragalus agrestis	Field Milk-vetch, Purple Milkvetch	6	N	P	FACU
Astragalus canadensis	Canada Milk-vetch	5	N	P	FACU
Astragalus crassicarpus	Ground-plum	7	N	P	UPL
Astragalus gracilis	Slender Milk-vetch	8	N	P	UPL
Athyrium filix-femina	Lady-fern, Subarctic Ladyfern	8	N	P	FAC
Atriplex subspicata	Spearscale, Saline Saltbush	2	N	A	FAC
Avena fatua	Wild Oats	*	I	A	UPL
Avenula hookeri	Spike Oat	9	N	P	UPL
Bassia scoparia	Kochia, Fire-weed	*	I	A	FAC
Beckmannia syzigachne	American Sloughgrass	1	N	A	OBL
Berteroa incana	Hoary False Alyssum	*	I	A	UPL
Betula papyrifera	Paper Birch, Canoe Birch	8	N	P	FACU
Betula pumila	Bog Birch	10	N	P	OBL
Bidens frondosa	Beggar-ticks, Devil's Beggartick	1	N	A	FACW
Bidens vulgata	Beggar-ticks, Big Devil's Beggartick	1	N	A	FACW
Botrychium multifidum	Leathery Grape-fern	10	N	P	FAC
Botrychium virginianum	Rattlesnake Fern	7	N	P	FACU
Bouteloua gracilis	Blue Grama	7	N	P	UPL
Bouteloua hirsuta	Hairy Grama	7	N	P	UPL
Brassica napus	Canola	*	I	A	UPL
Brassica rapa	Field Mustard	*	I	A	UPL
Bromus inermis	Smooth Brome	*	I	P	UPL

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Bromus japanicus	Japanese Brome	*	I	A	FACU
Bromus tectorum	Downy Brome, Cheatgrass	*	I	A	UPL
Calamagrostis canadensis	Bluejoint	5	N	P	FACW+
Calamagrostis stricta	N/A	5	N	P	FACW+
Calamovilfa longifolia	Prairie Sandreed	5	N	P	UPL
Calla palustris	Wild Calla, Water Arum	10	N	P	OBL
Callitriche palustris	N/A	7	N	P	OBL
Calylophus serrulatus	Plains Yellow Primrose, yellow subdrops	7	N	P	UPL
Calystegia sepium	Hedge Bindweed	0	N	P	UPL
Camelina microcarpa	Small-seeded False Flax, Littlepod False Flax	*	I	A	FACU
Campanula rotundifolia	Harebell, Bluebell Bellflower	7	N	P	FAC
Capsella bursa-pastoris	Shepherd's Purse	*	I	A	FACU
Cardamine pensylvanica	Bitter Cress	6	N	A	OBL
Carex aquatilis	Water Sedge	10	N	P	OBL
Carex atherodes	Slough Sedge, Wheat Sedge	4	N	P	OBL
Carex aurea	Golden Sedge	8	N	P	FACW
Carex brevior	Fescue Sedge, Shortbeak Sedge	4	N	P	FACU
Carex deweyana	N/A	10	N	P	FACU
Carex disperma	N/A	9	N	P	FACW
Carex formosa	N/A	10	N	P	FACW
Carex granularis	Meadow Sedge	6	N	P	FACW
Carex hallii	N/A	10	N	P	FACW-
Carex interior	Interior Sedge	10	N	P	OBL
Carex laeviconica	Smoothcone Sedge	6	N	P	OBL
Carex obtusata	N/A	8	N	P	FACW
Carex pellita	Woolly Sedge	4	N	P	OBL
Carex praegracilis	Clustered-field Sedge	5	N	P	FACW
Carex prairea	N/A	10	N	P	OBL
Carex retrorsa	N/A	6	N	P	OBL
Carex rosea	N/A	8	N	P	FAC
Carex rostrata	N/A	8	N	P	OBL
Carex sartwellii	N/A	5	N	P	FACW
Carex stipata	Saw-beak Sedge	7	N	P	OBL
Carex tenera	N/A	7	N	P	FACW
Carex vulpinoidea	Fox Sedge	2	N	P	OBL

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Cerastium arvense	Prairie Chickweed	2	N	P	FACU
Ceratophyllum demersum	Hornwort, Coontail	4	N	P	OBL
Chenopodium album	Lamb's Quarters	*	I	A	UPL
Chenopodium glaucum	Oak-leaved Goosefoot	*	I	A	FACW
Chenopodium rubrum	Alkali Blite	2	N	A	OBL
Chorispora tenella	Blue Mustard, Crossflower	*	I	A	UPL
Cicuta maculata	Common Water Hemlock	4	N	P	OBL
Cirsium arvense	Canada Thistle, Field Thistle	*	I	P	FACU
Cirsium flodmanii	Flodman's Thistle	5	N	P	FAC
Cirsium vulgare	Bull Thistle	*	I	B	UPL
Comandra umbellata	Bastard Toadflax	8	N	P	UPL
Conium maculatum	Poison Hemlock	*	I	B	FAC
Convolvulus arvensis	Field Bindweed	*	I	P	UPL
Conyza canadensis	Horseweed	0	N	A	FACU
Corallorhiza maculata	Spotted Coral-root	8	N	P	FACU-
Cornus canadensis	Bunchberry	10	N	P	FAC
Cornus sericea	Redosier Dogwood	5	N	P	FAC
Corylus cornuta	Beaked Hazelnut	8	N	P	UPL
Crataegus chrysocarpa	Northern Hawthorn, Red Hawthorn	6	N	P	FACU
Crepis runcinata	Hawk's-beard	8	N	P	FAC
Cyclachaena xanthifolia	Marsh Elder	0	N	A	FACU
Cynoglossum officinale	Hound's Tongue	*	I	B	UPL
Cyperus acuminatus	Tapeleaf Flatsedge	2	N	A	OBL
Cypripedium parviflorum	Yellow Lady's-slipper	10	N	P	FACW
Dalea purpurea	Purple Prairie Clover	8	N	P	UPL
Deschampsia cespitosa	Tufted Hairgrass	9	N	P	FACW
Descurainia pinnata	Tansy Mustard	1	N	A	UPL
Descurainia sophia	Flixweed	*	I	A	UPL
Dichanthelium leibergii	Leiberg Dichanthelium	8	N	P	FACU
Distichlis spicata	Inland Saltgrass	2	N	P	FACW
Draba nemorosa	Yellow Whitlowort, Woodland Draba	1	N	A	UPL
Dryopteris carthusiana	Spinulose Wood Fern	10	N	P	FACW
Dryopteris cristata	Crested Shield Fern	10	N	P	OBL
Echinacea angustifolia	Purple Coneflower	7	N	P	UPL
Echinochloa crusgalli	Barnyard Grass	*	I	A	FACW
Elaeagnus commutata	Silverberry	5	N	P	FAC
Eleocharis acicularis	Needle Spikesedge	3	N	P	OBL

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Eleocharis compressa	Flatstem Spikesedge	8	N	P	FACW
Eleocharis macrostachya	Spike Rush	4	N	P	OBL
Eleocharis engelmannii	Blunt Spikesedge	2	N	A	OBL
Elymus canadensis	Canada Wild Rye	3	N	P	FACU
Elymus hystrix	Bottlebrush Grass	8	N	P	UPL
Elymus repens	Quackgrass	*	I	P	FAC
Elymus trachycaulus	Slender Wheatgrass	6	N	P	FAC-
Epilobium ciliatum	Willow-herb	3	N	P	OBL
Epilobium leptophyllum	Narrow-leaved Willow-herb	6	N	P	OBL
Equisetum arvense	Field Horsetail	4	N	P	FAC
Equisetum fluviatile	Water Horsetail	8	N	P	OBL
Equisetum laevigatum	Smooth Scouring Rush	3	N	P	FAC
Erigeron glabellus	N/A	7	N	B	FACW
Erigeron philadelphicus	Philadelphia Fleabane	2	N	B	FACW
Erigeron strigosus	Daisy Fleabane	3	N	A	FACU
Erysimum asperum	Western Wallflower	3	N	B	UPL
Erysimum cheiranthoides	Wormseed Wallflower	*	I	A	FACU
Erysimum inconspicuum	Smallflower Wallflower	7	N	P	UPL
Euphorbia esula	Leafy Spurge	*	I	P	UPL
Euphorbia glyptosperma	Ridge-seeded Spurge	0	N	A	FACU
Euphorbia spathulata	N/A	5	N	A	UPL
Euthamia graminifolia	N/A	6	N	P	FACW
Festuca subverticillata	Nodding Fescue	10	N	P	FACU
Fragaria virginiana	Wild Strawberry	4	N	P	FACU
Fraxinus pennsylvanica	Red Ash, Green Ash	5	N	P	FAC
Gaillardia aristata	Blanket flower	5	N	P	UPL
Galium aparine	Catchweed Bedstraw, Stickywilly	0	N	A	FACU
Galium boreale	Northern Bedstraw	4	N	P	FACU
Galium trifidum	Small Bedstraw	8	N	P	OBL
Geum aleppicum	Yellow Avens	4	N	P	FACU
Geum triflorum	Torch Flower, Maidenhair	8	N	P	FACU
Gleditsia triacanthos	Honey Locust	6	N	P	FACU
Glyceria grandis	Tall Mannagrass	4	N	P	OBL
Glyceria striata	Fowl Mannagrass	6	N	P	OBL
Glycine max	Soybean	*	I	P	UPL
Glycyrrhiza lepidota	Wild Licorice	2	N	P	FACU
Gratiola neglecta	Hedge Hyssop	0	N	A	OBL
Grindelia squarrosa	Curly-top Gumweed	1	N	B	UPL
Hedeoma hispida	Rough False Pennyroyal	2	N	A	UPL

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Helianthus annuus	Common Sunflower	0	N	A	FACU
Helianthus maximiliani	Maximilian Sunflower	5	N	P	FACU
Helianthus nuttallii	Nuttall's Sunflower	8	N	P	FAC
Helianthus pauciflorus	Stiff Sunflower	8	N	P	UPL
Heliopsis helianthoides	False Sunflower, Ox-eye	5	N	P	UPL
Heracleum maximum	Cow Parsnip, Eltrot	3	N	P	FAC
Hesperostipa comata	Needle-and-thread	6	N	P	UPL
Hesperostipa spartea	Porcupine-grass	8	N	P	UPL
Heuchera richardsonii	Alumroot	8	N	P	FACU
Hierochloe odorata	Sweetgrass	10	N	P	FACW
Hippuris vulgaris	Mare's Tail	5	N	P	OBL
Hordeum jubatum	Foxtail Barley	0	N	P	FACW
Humulus lupulus	Common Hops	3	N	P	FACU
Hypoxis hirsuta	Yellow Stargrass	8	N	P	FACW
Impatiens capensis	Spotted Touch-me-not, Jewel Weed	4	N	A	FACW
Ipomoea purpurea	Common Morning-glory	*	I	A	FAC
Iva annua	Marsh Elder	*	I	A	FAC
Juncus arcticus	Baltic Rush	5	N	P	FACW
Juncus bufonius	Toad Rush	1	N	A	OBL
Juncus interior	Inland Rush	5	N	P	FACW
Juncus longistylis	N/A	10	N	P	FACW
Juncus torreyi	Torrey's Rush	2	N	P	FACW
Juniperus horizontalis	Creeping Juniper	6	N	P	FACU
Koeleria macrantha	Junegrass	7	N	P	UPL
Lactuca serriola	Prickly Lettuce	*	I	A	FACU
Lactuca tatarica	Blue Lettuce	1	N	P	FACU
Lathyrus venosus	Bushy Vetchling	8	N	P	FACW
Lemna trisulca	Star Duckweed	2	N	P	OBL
Lemna turionifera	N/A	1	N	P	OBL
Leonurus cardiaca	Motherwort	*	I	P	FACU
Lepidium densiflorum	Peppergrass	0	N	A	FACU
Liatris ligulistylis	Gay-feather	10	N	P	FAC
Liatris punctata	Blazing Star	7	N	P	UPL
Lilium philadelphicum	Wild Lily, Wood Lily	8	N	P	FAC
Limosella aquatica	Mudwort	2	N	P	OBL
Linaria vulgaris	Butter-and-eggs	*	I	P	UPL
Linum lewisii	Blue Flax	6	N	P	UPL
Linum rigidum	Stiffstem Flax	5	N	A	UPL
Lithospermum canescens	Hoary Puccoon	7	N	P	UPL
Lithospermum incisum	Narrow-leaved Puccoon	7	N	P	UPL
Lobelia spicata	Palespike Lobelia	6	N	P	FAC

Scientific Name[1]	**Common Name**	**C-Val[2]**	**Life[3]**	**Origin[4]**	**Indicator[5]**
Lolium perenne	Perennial Ryegrass	*	I	P	FACU
Lotus corniculatus	Bird's-foot Trefoil	*	I	P	FACU
Lotus unifoliolatus	Prairie Trefoil, Deer Vetch	3	N	A	UPL
Lycopus americanus	American Bugleweed	4	N	P	OBL
Lycopus asper	Rough Bugleweed	4	N	P	OBL
Lycopus uniflorus	One Flower Horehound	8	N	P	OBL
Lysimachia hybrida	Loosestrife	5	N	P	OBL
Lysimachia thyrsiflora	Tufted Loosestrife	7	N	P	OBL
Maianthemum canadense	Wild Lily-of-the-valley	8	N	P	FACU
Maianthemum stellatum	Spikenard, Starry False Lily of the Valley	5	N	P	FACU
Malva pusilla	Common Mallow	*	I	A	UPL
Matricaria discoidea	Pineapple Weed, Disc Mayweed	*	I	A	UPL
Medicago lupulina	Black Medick	*	I	P	FACU
Medicago sativa	Alfalfa	*	I	P	UPL
Melilotus officinalis	Sweet Clover	*	I	A	UPL
Mentha arvensis	Field Mint	3	N	P	FACW
Mertensia lanceolata	Wild Forget-me-not, Prairie Bluebells	9	N	P	UPL
Monarda fistulosa	Wild Bergamot	5	N	P	UPL
Muhlenbergia asperifolia	Scratchgrass	2	N	P	FACW
Muhlenbergia richardsonis	Mat Muhly	10	N	P	FAC
Myriophyllum sibiricum	Shortspike Watermilfoil	3	N	P	OBL
Nassella viridula	Green Needlegrass	5	N	P	UPL
Nepeta cataria	Catnip	*	I	P	FACU
Oenothera albicaulis	Prairie Evening Primrose	5	N	A	UPL
Oenothera biennis	Common Evening Primrose	0	N	B	FACU
Oligoneuron rigidum	Rigid Goldenrod, Stiff Goldenrod	4	N	P	FACU-
Onosmodium bejariense	False Gromwell, Western Marbleseed	7	N	P	UPL
Orthocarpus luteus	Owl Clover	6	N	A	FACU
Osmorhiza claytonii	Sweet Jarvil, Sweetroot	10	N	P	FACU
Oxalis stricta	Yellow Wood Sorrel	0	N	P	FACU
Oxytropis splendens	Showy Locoweed	9	N	P	FACU
Packera plattensis	Prairie Ragwort, Prairie Groundsel	6	N	B	FACU-
Panicum virgatum	Switchgrass	5	N	P	FAC

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Parthenocissus vitacea	Woodbine, Thicket Creeper	2	N	P	FACU
Pascopyrum smithii	Western Wheatgrass	4	N	P	UPL
Pediomelum argophyllum	Silver-leaf Scurf-pea	4	N	P	UPL
Pediomelum esculentum	Breadroot Scurf-pea	9	N	P	UPL
Penstemon gracilis	Slender Beardtongue	6	N	P	FACU
Phalaris arundinacea	Reed Canarygrass	0	N	P	FACW+
Phleum pratense	Timothy	*	I	P	FACU
Phragmites australis	Common Reed	0	N	P	FACW
Physalis virginiana	Virginia Ground Cherry	4	N	P	UPL
Plantago major	Common Plantain	*	I	P	FAC
Plantago patagonica	Patagonian Plantain, Woolly Plantain	1	N	A	UPL
Platanthera aquilonis	Northern Green Orchid	9	N	P	OBL
Poa compressa	Canada Bluegrass	*	I	P	FACU
Poa palustris	Fowl Bluegrass	4	N	P	FACW
Poa pratensis	Kentucky Bluegrass	*	I	P	FACU
Poa secunda	Canby's Bluegrass, Sandberg’s Bluegrass	8	N	P	FACU
Polygala alba	White Milkwort	5	N	P	UPL
Polygala verticillata	Whorled Milkwort	8	N	A	UPL
Polygonum amphibium var. emersum	Swamp Smartweed	0	N	P	OBL
Polygonum amphibian var.stipulaceum	Water Smartweed	6	P	N	FACW
Polygonum arenastrum	Knotweed	0	N	A	UPL
Polygonum aviculare	Knotweed	0	N	A	FACU
Polygonum convolvulus	Wild Buckwheat, Black Bindweed	*	I	A	FAC
Polygonum lapathifolium	Pale Smartweed, Curly-top Knotweed	1	N	A	OBL
Polygonum ramosissimum	Bushy Knotweed	3	N	A	FACU
Populus balsamifera	Balsam poplar	6	N	P	FACW
Populus deltoides	Cottonwood	3	N	P	FAC
Populus tremuloides	Quaking aspen	4	N	P	FAC
Potamogeton gramineus	Variable Pondweed	6	N	P	OBL
Potamogeton pusillus	Baby Pondweed	2	N	P	OBL
Potentilla arguta	Tall Cinquefoil	8	N	P	FACU
Potentilla concinna	N/A	8	N	P	UPL
Potentilla norvegica	Norwegian Cinquefoil	0	N	A	FAC
Prenanthes alba	White Rattlesnake-root	10	N	P	FACU
Prunus americana	Wild Plum	4	N	P	UPL

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Prunus virginiana	Choke Cherry	4	N	P	FACU-
Puccinellia nuttalliana	Alkali-grass	4	N	P	OBL
Pulsatilla patens	Pasque flower	9	N	P	UPL
Quercus macrocarpa	Bur Oak	6	N	P	FACU
Ranunculus cymbalaria	Shore Buttercup	3	N	P	OBL
Ranunculus longirostris	White Water Crowfoot, Longbeak Buttercup	3	N	P	OBL
Ranunculus pensylvanicus	Bristly Crowfoot, Pennsylvania Buttercup	4	N	A	FACW+
Ranunculus sceleratus	Cursed Crowfoot, Cursed Buttercup	3	N	A	OBL
Ratibida columnifera	Prairie Coneflower	3	N	P	UPL
Rhus aromatica	Fragrant Sumac, Polecat Bush	7	N	P	UPL
Ribes americanum	Wild Black Currant	7	N	P	FACW
Ribes oxyacanthoides	Bristly Gooseberry	5	N	P	FAC
Ribes triste	Swamp Currant, Red Currant	10	N	P	OBL
Rorippa palustris	Bog Yellow Cress	2	N	A	OBL
Rosa arkansana	Prairie Wild Rose	3	N	P	FACU
Rosa blanda	Smooth Wild Rose	8	N	P	FACU
Rosa woodsii	Western Wild Rose	5	N	P	FACU
Rubus idaeus	Red Raspberry	5	N	P	UPL
Rudbeckia hirta	Black-eyed Susan	5	N	B	FACU
Rudbeckia laciniata	Golden Glow	6	N	P	FACU
Rumex aquaticus	Western Dock	7	N	P	OBL
Rumex crispus	Curly Dock	*	I	P	FACW
Rumex maritimus	Golden Dock	1	N	A	FACW
Rumex orbiculatus	Great Water Dock	9	N	P	OBL
Sagittaria cuneata	Arrowhead	6	N	P	OBL
Sagittaria latifolia	Arrowhead	6	N	P	OBL
Salicornia rubra	Saltwort	0	N	A	OBL
Salix alba	Yellowstem White Willow	*	I	P	FACW
Salix amygdaloides	Peachleaf Willow	3	N	P	FACW
Salix bebbiana	Beaked Willow	8	N	P	FACW
Salix discolor	Pussy Willow	7	N	P	FACW
Salix eriocephala	Diamond Willow	5	N	P	FACW
Salix interior	Sandbar Willow	3	N	P	FACW+
Salix lutea	Yellow Willow	5	N	P	FACW
Salsola tragus	Russian Thistle, Tumbleweed	*	I	A	UPL

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Sanicula marilandica	Black Snakeroot	7	N	P	FACU
Schedonorus pratensis	Meadow Fescue	*	I	P	FAC
Schizachyrium scoparium	Little Bluestem	6	N	P	UPL
Schoenoplectus acutus	Hard-stem Bulrush	5	N	P	OBL
Schoenoplectus fluviatilis	River Bulrush	2	N	P	OBL
Schoenoplectus maritimus	Prairie Bulrush, Cosmopolitan Bulrush	4	N	P	OBL
Schoenoplectus pungens	N/A	4	N	P	OBL
Schoenoplectus tabernaemontani	Soft-stem Bulrush	3	N	P	OBL
Scirpus atrovirens	Darkgreen Bulrush	5	N	P	OBL
Scirpus pallidus	N/A	5	N	P	OBL
Scolochloa festucacea	Sprangletop	6	N	P	OBL
Setaria pumila	Yellow Foxtail	*	I	A	FACU
Setaria viridis	Green Foxtail, Gren Bristlegrass	*	I	A	UPL
Shepherdia argentea	Buffaloberry	5	N	P	UPL
Shepherdia canadensis	Rabbitberry	6	N	P	FACU
Silene antirrhina	Sleepy Catchfly	3	N	A	UPL
Silene noctiflora	Night-flowering Catchfly, Sticky Cockle	*	I	A	UPL
Sinapis arvensis	Charlock, Wild Mustard	*	I	A	UPL
Sisymbrium altissimum	Tumbling Mustard	*	I	A	UPL
Sisyrinchium campestre	White-eyed Grass, Prairie Blue-Eyed Grass	10	N	P	UPL
Sium suave	Water Parsnip, Hemlock	3	N	P	OBL
Solanum ptycanthum	Black Nightshade	0	N	A	FACU
Solidago canadensis	Canada Goldenrod	1	N	P	FACU
Solidago gigantea	Late Goldenrod, Giant Goldenrod	4	N	P	FACW
Solidago missouriensis	Prairie Goldenrod	5	N	P	UPL
Solidago mollis	Soft Goldenrod	6	N	P	UPL
Solidago nemoralis	Gray Goldenrod	6	N	P	UPL
Sonchus arvensis	Field Sow Thistle	*	I	P	FAC
Sonchus oleraceus	Common Sow Thistle	*	I	A	FACU
Sparganium eurycarpum	Giant Burreed	4	N	P	OBL
Spartina gracilis	Alkali Cordgrass	6	N	P	FACW
Spartina pectinata	Prairie Cordgrass	5	N	P	FACW
Sphaeralcea coccinea	Red False Mallow, Scarlet Globemallow	4	N	P	UPL
Sphenopholis obtusata	Prairie Wedgegrass	7	N	A	FAC
Spiraea alba	Meadow-sweet	7	N	P	FACW

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Sporobolus heterolepis	Prairie Dropseed	10	N	P	UPL
Stachys pilosa	Hedge-nettle, Marsh Betony	3	N	P	FACW
Stuckenia pectinata	Sago Pondweed	0	N	P	OBL
Suaeda calceoliformis	Sea Blite	2	N	A	UPL
Symphoricarpos occidentalis	Western Snowberry	3	N	P	UPL
Symphyotrichum ciliatum	Rayless Aster	0	N	A	FACW
Symphyotrichum ciliolatum	N/A	8	N	P	FACW
Symphyotrichum ericoides	White Aster	2	N	P	FACU
Symphyotrichum falcatum	N/A	4	N	P	FACU
Symphyotrichum laeve	Smooth Blue Aster	5	N	P	UPL
Symphyotrichum lanceolatum ssp. hesperium	Panicled Aster	4	N	P	OBL
Symphyotrichum lanceolatum ssp. lanceolatum	Panicled Aster	3	N	P	FACW
Taraxacum officinale	Common Dandelion	*	I	P	FACU
Teucrium canadense	American Germander, Wood Sage	3	N	P	FACW
Thalictrum dasycarpum	Purple Meadow Rue	7	N	P	FAC
Thalictrum venulosum	Early Meadow Rue	6	N	P	FACW
Thinopyrum intermedium	Intermediate Wheatgrass	*	I	P	UPL
Thinopyrum ponticum	Tall Wheatgrass	*	I	P	UPL
Thlaspi arvense	Field Pennycress	*	I	A	FACU
Toxicodendron rydbergii	Poison Ivy	3	N	P	FACU
Tragopogon dubius	Goat's Beard, Yellow Salisfy	*	I	B	UPL
Trifolium pratense	Red Clover	*	I	P	FACU
Trifolium repens	White Clover, Ladino Clover	*	I	P	FACU
Triglochin maritima	Arrowgrass	5	N	P	OBL
Trillium cernuum	Nodding Trillium, Whip-poor-will Flower	10	N	P	FAC
Triticum aestivum	Wheat	*	I	A	UPL
Typha angustifolia	Narrow-leaved Cattail	*	I	P	OBL
Typha latifolia	Broad-leaved Cattail	2	N	P	OBL
Typha x glauca	Hybrid Cattail	*	I	P	OBL
Ulmus americana	American Elm	3	N	P	FAC
Ulmus pumila	Siberian Elm	*	I	P	UPL
Urtica dioica	Stinging Nettle	0	N	P	FACW
Utricularia macrorhiza	Common Bladderwort	2	N	P	OBL

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Verbena bracteata	Prostrate Vervain, Bigbract Verbena	0	N	A	FACU
Verbena stricta	Hoary Vervain	2	N	P	UPL
Veronica peregrina	Purslane Speedwell	0	N	A	FACW
Viburnum opulus	Highbush Cranberry	10	N	P	FAC
Vicia americana	American Vetch	6	N	P	UPL
Viola nephrophylla	Northern Bog Violet	8	N	P	FACW
Viola nuttallii	Nuttall's Violet, Yellow Prairie Violet	8	N	P	UPL
Viola pedatifida	Prairie Violet, Larkspur-violet	8	N	P	FACU
Xanthium strumarium	Cocklebur	0	N	A	FAC
xElyhordeum macounii	N/A	3	N	P	FAC
Zea mays	Corn	*	I	A	UPL
Zigadenus elegans	White Camass	8	N	P	FACU
Zizia aptera	Meadow Parsnip	8	N	P	UPL
Zizia aurea	Golden Alexanders	8	N	P	FAC-

*C-values not assigned to introduced species.

[1] Scientific names of plant species are according to the USDA Plants Database (USDA, NRCS 2012).

[2] C-values (coefficient of conservatism) assigned by The Northern Great Plains Floristic Quality Assessment Panel (2001).

[3] Life-forms: N = native and I = introduced.

[4] Origin: P = perennial, A = annual, and B = biennial.

[5] Indicator categories are according to the National List of Plant Species that Occur in Wetlands: Northern Plains (Region 4) (Reed 1988).

APPENDIX C. PLANT CARBON, NITROGEN, AND PHOSPHORUS CONTENT AND BIOMASS FOR THE 2011 WETLAND SITES

Site	Landscape Position	Plant Type*	%N	%P	%C
5001	Shallow marsh	Forbs & shrubs	2.07	0.45	45.6
5001	Shallow marsh	Cool grasses	1.76	0.20	46.2
5001	Wet meadow	Cool grasses	1.56	0.26	45.4
5001	Wet meadow	Forbs & shrubs	3.10	0.58	43.3
5003	Shallow marsh	Forbs & shrubs	1.74	0.30	41.3
5003	Shallow marsh	Cool grasses	1.76	0.33	41.3
5003	Shallow marsh	Sedges & rushes	1.74	0.24	41.1
5003	Wet meadow	Forbs & shrubs	2.01	0.32	37.8
5003	Wet meadow	Cool grasses	1.57	0.21	41.4
5004	Wet meadow	Forbs & shrubs	1.52	0.24	38.8
5004	Wet meadow	Cool grasses	0.93	0.13	40.3
5006	Shallow marsh	Sedges & rushes	1.87	0.25	38.2
5006	Shallow marsh	Cattails	1.59	0.13	41.0
5006	Upland	Cool grasses	0.96	0.07	41.3
5006	Upland	Forbs & shrubs	1.55	0.15	38.1
5006	Wet meadow	Cool grasses	1.23	0.11	42.9
5006	Wet meadow	Sedges & rushes	2.06	0.32	38.1
5007	Upland	Warm grasses	1.47	0.10	44.3
5007	Upland	Forbs & shrubs	1.62	0.09	41.0
5007	Upland	Cool grasses	1.32	0.07	43.4
5007	Upland	Sedges & rushes	1.70	0.07	42.0
5007	Wet meadow	Cool grasses	1.41	0.10	42.5
5007	Wet meadow	Forbs & shrubs	2.23	0.14	38.4
5008	Shallow marsh	Cattails	1.80	0.36	40.1
5008	Upland	Forbs & shrubs	7.55	0.33	38.5
5008	Upland	Cool grasses	7.61	0.35	37.3
5008	Wet meadow	Forbs & shrubs	4.56	0.72	37.7
5008	Wet meadow	Cattails	5.09	0.64	39.6
5010	Shallow marsh	Cattails	2.10	0.20	44.3
5010	Shallow marsh	Forbs & shrubs	2.53	0.38	39.8
5010	Shallow marsh	Cool grasses	1.25	0.23	44.5
5010	Upland	Forbs & shrubs	1.47	0.25	43.9
5010	Upland	Cool grasses	1.44	0.21	43.3
5010	Wet meadow	Cool grasses	1.90	0.22	44.9
5010	Wet meadow	Forbs & shrubs	1.85	0.24	44.3
5011	Shallow marsh	Cool grasses	1.79	0.21	42.3

Site	**Landscape Position**	**Plant Type***	**%N**	**%P**	**%C**
5011	Shallow marsh	Sedges & rushes	2.08	0.36	41.1
5011	Upland	Forbs & shrubs	3.28	0.40	40.4
5011	Upland	Cool grasses	1.47	0.17	42.3
5011	Wet meadow	Cool grasses	2.47	0.34	42.6
5011	Wet meadow	Forbs & shrubs	2.65	0.33	41.9
5012	Shallow marsh	Sedges & rushes	2.02	0.35	40.4
5012	Upland	Cool grasses	1.05	0.09	43.9
5012	Upland	Forbs & shrubs	1.59	0.18	40.0
5012	Wet meadow	Cool grasses	2.81	0.23	43.7
5012	Wet meadow	Sedges & rushes	2.42	0.21	43.3
5013	Shallow marsh	Forbs & shrubs	1.72	0.20	41.8
5013	Shallow marsh	Sedges & rushes	1.56	0.15	38.5
5013	Upland	Forbs & shrubs	1.72	0.15	41.3
5013	Upland	Cool grasses	1.05	0.09	41.4
5013	Wet meadow	Forbs & shrubs	1.59	0.28	36.9
5013	Wet meadow	Cool grasses	1.31	0.15	42.7
5013	Wet meadow	Sedges & rushes	1.34	0.13	43.1
5015	Shallow marsh	Cool grasses	1.53	0.15	43.6
5015	Shallow marsh	Forbs & shrubs	2.59	0.47	36.2
5015	Shallow marsh	Sedges & rushes	2.73	0.23	42.9
5015	Upland	Cool grasses	1.39	0.23	40.0
5015	Upland	Forbs & shrubs	2.16	0.48	38.9
5015	Wet meadow	Cool grasses	0.90	0.11	43.6
5015	Wet meadow	Warm grasses	1.43	0.12	43.0
5016	Shallow marsh	Sedges & rushes	1.88	0.26	41.2
5016	Shallow marsh	Forbs & shrubs	2.17	0.35	37.5
5016	Upland	Forbs & shrubs	2.31	0.23	37.6
5016	Upland	Cool grasses	1.89	0.25	39.0
5016	Upland	Sedges & rushes	1.89	0.20	41.4
5016	Wet meadow	Forbs & shrubs	2.05	0.30	37.5
5016	Wet meadow	Sedges & rushes	1.89	0.23	41.8
5016	Wet meadow	Cool grasses	1.92	0.37	39.0
5017	Shallow marsh	Cattails	1.44	0.23	45.0
5017	Upland	Cool grasses	1.06	0.10	42.4
5017	Wet meadow	Cool grasses	1.41	0.20	42.8
5017	Wet meadow	Forbs & shrubs	1.57	0.28	42.3
5018	Shallow marsh	Cool grasses	1.33	0.16	43.0
5018	Shallow marsh	Forbs & shrubs	1.72	0.39	41.5
5018	Shallow marsh	Cattails	1.77	0.38	41.0
5018	Upland	Forbs & shrubs	1.95	0.37	38.7

Site	Landscape Position	Plant Type*	%N	%P	%C
5018	Upland	Cool grasses	1.16	0.16	41.7
5018	Wet meadow	Forbs & shrubs	1.61	0.28	40.9
5018	Wet meadow	Cool grasses	1.25	0.21	42.6
5019	Shallow marsh	Cool grasses	1.77	0.13	41.9
5019	Shallow marsh	Cattails	2.18	0.12	42.2
5019	Upland	Cool grasses	2.24	0.17	40.0
5019	Upland	Forbs & shrubs	2.22	0.24	38.8
5019	Wet meadow	Forbs & shrubs	1.67	0.27	37.0
5019	Wet meadow	Cool grasses	2.07	0.15	40.0
5021	Shallow marsh	Cattails	2.51	0.24	43.6
5021	Shallow marsh	Forbs & shrubs	3.53	0.22	43.4
5021	Upland	Cool grasses	1.88	0.14	45.3
5021	Upland	Forbs & shrubs	3.58	0.28	46.5
5021	Wet meadow	Cool grasses	1.87	0.17	44.2
5021	Wet meadow	Forbs & shrubs	2.85	0.24	43.7
5023	Shallow marsh	Sedges & rushes	5.98	0.16	40.7
5023	Upland	Cool grasses	2.06	0.07	41.6
5023	Upland	Forbs & shrubs	3.08	0.12	42.1
5023	Wet meadow	Cool grasses	3.28	0.05	40.8
5023	Wet meadow	Forbs & shrubs	3.93	0.12	41.4
5027	Shallow marsh	Cool grasses	1.66	0.19	43.0
5027	Upland	Cool grasses	1.08	0.15	43.0
5027	Upland	Forbs & shrubs	1.42	0.21	44.1
5027	Wet meadow	Cool grasses	1.06	0.17	42.9
5030	Shallow marsh	Cattails	1.13	0.17	44.5
5030	Upland	Cool grasses	1.14	0.07	41.2
5030	Upland	Forbs & shrubs	1.50	0.15	40.7
5030	Wet meadow	Cool grasses	1.04	0.07	41.1
5030	Wet meadow	Forbs & shrubs	1.62	0.16	42.6
5030	Wet meadow	Sedges & rushes	1.30	0.09	40.0
5032	Shallow marsh	Cool grasses	2.54	0.30	42.2
5032	Shallow marsh	Sedges & rushes	2.93	0.41	38.9
5032	Shallow marsh	Forbs & shrubs	2.49	0.20	41.9
5032	Upland	Cool grasses	1.32	0.09	43.0
5032	Upland	Forbs & shrubs	2.09	0.21	42.3
5032	Wet meadow	Cool grasses	2.29	0.22	43.6
5032	Wet meadow	Sedges & rushes	2.17	0.25	41.9
5034	Shallow marsh	Sedges & rushes	3.26	0.38	42.7
5034	Shallow marsh	Cool grasses	2.45	0.26	45.3
5034	Shallow marsh	Forbs & shrubs	2.42	0.32	45.5

Site	Landscape Position	Plant Type*	%N	%P	%C
5034	Upland	Forbs & shrubs	1.88	0.12	44.0
5034	Upland	Cool grasses	1.52	0.10	43.0
5034	Wet meadow	Sedges & rushes	2.16	0.20	43.7
5034	Wet meadow	Cool grasses	1.78	0.17	44.9
5034	Wet meadow	Forbs & shrubs	2.17	0.21	42.2
5037	Shallow marsh	Cattails	1.82	0.19	40.9
5037	Upland	Forbs & shrubs	2.11	0.17	42.5
5037	Upland	Cool grasses	1.08	0.08	41.2
5037	Wet meadow	Cool grasses	1.17	0.10	41.7
5037	Wet meadow	Forbs & shrubs	1.43	0.12	42.3
5040	Shallow marsh	Cattails	2.18	0.28	42.2
5040	Shallow marsh	Cool grasses	2.02	0.19	43.3
5040	Shallow marsh	Forbs & shrubs	2.48	0.34	36.7
5040	Upland	Cool grasses	3.32	0.21	40.0
5040	Upland	Forbs & shrubs	2.78	0.27	41.8
5040	Wet meadow	Cattails	2.20	0.33	40.2
5040	Wet meadow	Forbs & shrubs	2.47	0.14	41.2
5040	Wet meadow	Cool grasses	1.63	0.16	42.3
5040	Wet meadow	Sedges & rushes	2.35	0.22	43.2
5042	Shallow marsh	Sedges & rushes	3.00	0.10	42.9
5042	Upland	Cool grasses	2.95	0.12	41.3
5042	Upland	Forbs & shrubs	3.34	0.19	40.1
5042	Wet meadow	Cool grasses	2.92	0.10	43.1
5043	Shallow marsh	Sedges & rushes	3.29	0.30	39.8
5043	Shallow marsh	Cool grasses	3.12	0.24	42.8
5043	Shallow marsh	Cattails	2.60	0.19	42.2
5043	Upland	Cool grasses	5.54	0.07	40.6
5043	Upland	Forbs & shrubs	5.72	0.10	40.6
5043	Wet meadow	Forbs & shrubs	3.03	0.13	41.9
5043	Wet meadow	Sedges & rushes	5.47	0.15	37.7
5043	Wet meadow	Cool grasses	2.29	0.08	42.4
5043	Wet meadow	Warm grasses	4.54	0.13	42.4
5046	Shallow marsh	Cool grasses	3.18	0.35	41.3
5046	Shallow marsh	Forbs & shrubs	4.29	0.40	42.8
5046	Upland	Cool grasses	2.12	0.15	41.4
5046	Upland	Forbs & shrubs	3.05	0.20	41.7
5046	Wet meadow	Cool grasses	3.40	0.37	41.6
5046	Wet meadow	Sedges & rushes	2.93	0.25	42.9
5046	Wet meadow	Forbs & shrubs	3.65	0.50	42.7
5048	Upland	Warm grasses	1.90	0.24	43.5

Site	Landscape Position	Plant Type*	%N	%P	%C
5048	Upland	Cool grasses	1.68	0.19	44.6
5048	Upland	Forbs & shrubs	2.45	0.28	41.7
5048	Wet meadow	Forbs & shrubs	2.36	0.27	41.1
5048	Wet meadow	Cool grasses	2.08	0.18	45.1
5049	Shallow marsh	Sedges & rushes	2.66	0.31	42.9
5049	Shallow marsh	Cattails	2.74	0.34	43.5
5049	Upland	Cool grasses	1.53	0.15	41.7
5049	Upland	Forbs & shrubs	3.30	0.30	41.6
5049	Wet meadow	Cool grasses	1.88	0.16	42.3
5049	Wet meadow	Forbs & shrubs	2.28	0.21	39.8
5049	Wet meadow	Sedges & rushes	1.97	0.15	42.9
5052	Shallow marsh	Forbs & shrubs	2.65	0.27	39.9
5052	Shallow marsh	Sedges & rushes	2.29	0.28	41.7
5052	Shallow marsh	Cool grasses	2.17	0.26	41.7
5052	Upland	Cool grasses	1.43	0.07	41.6
5052	Upland	Forbs & shrubs	2.90	0.15	41.6
5052	Wet meadow	Forbs & shrubs	2.00	0.17	39.0
5052	Wet meadow	Cool grasses	1.47	0.10	41.9
5052	Wet meadow	Sedges & rushes	2.10	0.18	41.7
5055	Shallow marsh	Cattails	1.40	0.11	43.0
5055	Upland	Cool grasses	1.64	0.11	42.0
5055	Wet meadow	Sedges & rushes	1.57	0.09	41.9
5055	Wet meadow	Cool grasses	1.34	0.08	43.4
5056	Shallow marsh	Cool grasses	2.94	0.39	42.8
5056	Shallow marsh	Forbs & shrubs	4.38	0.53	41.2
5056	Upland	Cool grasses	2.69	0.35	41.8
5056	Upland	Forbs & shrubs	4.54	0.50	36.3
5056	Wet meadow	Cool grasses	1.95	0.27	42.1
5056	Wet meadow	Forbs & shrubs	2.81	0.49	39.1
5059	Shallow marsh	Cattails	1.13	0.20	43.3
5059	Shallow marsh	Sedges & rushes	1.45	0.24	41.4
5059	Shallow marsh	Cool grasses	0.76	0.18	41.4
5059	Wet meadow	Cool grasses	0.90	0.17	41.0
5059	Wet meadow	Sedges & rushes	1.64	0.21	40.6
5059	Wet meadow	Forbs & shrubs	1.23	0.27	42.8
5062	Shallow marsh	Cool grasses	6.87	0.19	41.1
5062	Shallow marsh	Sedges & rushes	5.48	0.29	41.4
5062	Upland	Cool grasses	3.56	0.15	40.0
5062	Upland	Forbs & shrubs	4.87	0.24	41.9
5062	Wet meadow	Forbs & shrubs	3.65	0.13	40.8

Site	Landscape Position	Plant Type*	%N	%P	%C
5062	Wet meadow	Cool grasses	4.32	0.12	39.7
5065	Shallow marsh	Cool grasses	5.16	0.26	39.5
5065	Upland	Forbs & shrubs	11.80	0.20	33.9
5065	Upland	Cool grasses	8.81	0.10	34.9
5065	Wet meadow	Cool grasses	13.22	0.09	33.1
5065	Wet meadow	Forbs & shrubs	12.13	0.17	34.2
5066	Shallow marsh	Forbs & shrubs	4.38	0.57	40.9
5066	Shallow marsh	Cattails	3.52	0.65	40.2
5066	Shallow marsh	Sedges & rushes	3.61	0.67	37.5
5066	Upland	Cool grasses	4.80	0.31	39.1
5066	Upland	Forbs & shrubs	3.82	0.41	37.7
5066	Wet meadow	Cool grasses	3.39	0.48	41.3
5066	Wet meadow	Forbs & shrubs	3.41	0.41	37.5
5066	Wet meadow	Sedges & rushes	4.13	0.46	38.2
5067	Upland	Forbs & shrubs	2.42	0.18	42.5
5067	Upland	Cool grasses	1.65	0.13	42.9
5067	Upland	Warm grasses	2.08	0.19	42.9
5067	Wet meadow	Forbs & shrubs	2.16	0.28	41.0
5067	Wet meadow	Cool grasses	1.96	0.18	42.3
5067	Wet meadow	Sedges & rushes	2.06	0.16	43.5
5068	Shallow marsh	Sedges & rushes	5.39	0.24	39.7
5068	Shallow marsh	Forbs & shrubs	6.60	0.38	43.2
5068	Shallow marsh	Cattails	4.55	0.42	38.5
5068	Upland	Cool grasses	1.89	0.22	41.4
5068	Upland	Forbs & shrubs	6.02	0.36	37.9
5068	Wet meadow	Cool grasses	3.44	0.28	39.6
5068	Wet meadow	Forbs & shrubs	5.14	0.41	39.0
5068	Wet meadow	Sedges & rushes	4.42	0.26	40.6
5069	Shallow marsh	Cattails	1.51	0.24	42.0
5069	Shallow marsh	Sedges & rushes	1.93	0.23	43.8
5069	Upland	Cool grasses	1.29	0.17	41.9
5069	Upland	Forbs & shrubs	2.01	0.29	42.3
5069	Wet meadow	Sedges & rushes	1.84	0.17	43.0
5069	Wet meadow	Forbs & shrubs	1.87	0.25	40.7
5069	Wet meadow	Cool grasses	1.56	0.15	43.1
5072	Shallow marsh	Cool grasses	3.65	0.18	43.1
5072	Shallow marsh	Sedges & rushes	4.61	0.26	42.0
5072	Upland	Cool grasses	4.27	0.07	40.9
5072	Upland	Forbs & shrubs	4.32	0.12	41.7
5072	Wet meadow	Cool grasses	3.23	0.16	43.2

Site	**Landscape Position**	**Plant Type***	**%N**	**%P**	**%C**
5073	Shallow marsh	Cool grasses	3.52	0.22	42.0
5073	Shallow marsh	Cattails	3.44	0.23	41.7
5073	Upland	Cool grasses	1.52	0.10	41.8
5073	Upland	Forbs & shrubs	2.67	0.18	42.5
5073	Wet meadow	Sedges & rushes	1.89	0.14	42.5
5073	Wet meadow	Forbs & shrubs	3.55	0.11	39.6
5073	Wet meadow	Cool grasses	2.29	0.31	43.9
5075	Shallow marsh	Cool grasses	2.20	0.29	43.2
5075	Upland	Cool grasses	1.55	0.20	42.7
5075	Upland	Forbs & shrubs	3.38	0.31	42.6
5075	Wet meadow	Cool grasses	2.23	0.28	41.6
5075	Wet meadow	Forbs & shrubs	3.05	0.28	36.3
5077	Shallow marsh	Cattails	1.81	0.27	44.1
5077	Shallow marsh	Cool grasses	1.98	0.16	42.7
5077	Shallow marsh	Forbs & shrubs	2.94	0.32	44.2
5077	Shallow marsh	Sedges & rushes	2.19	0.27	42.9
5077	Wet meadow	Cool grasses	1.56	0.24	42.1
5077	Wet meadow	Forbs & shrubs	1.95	0.28	42.4
5077	Wet meadow	Sedges & rushes	1.73	0.20	43.1
5078	Shallow marsh	Cattails	1.96	0.39	41.4
5078	Shallow marsh	Forbs & shrubs	2.52	0.51	35.8
5078	Shallow marsh	Cool grasses	2.03	0.26	42.5
5078	Upland	Forbs & shrubs	1.91	0.21	39.3
5078	Upland	Cool grasses	1.52	0.20	41.9
5078	Wet meadow	Cattails	3.19	0.39	40.3
5078	Wet meadow	Forbs & shrubs	1.89	0.32	42.3
5079	Shallow marsh	Cattails	0.97	0.19	43.1
5079	Shallow marsh	Sedges & rushes	1.88	0.28	39.6
5079	Upland	Cool grasses	1.04	0.12	40.2
5079	Wet meadow	Cool grasses	1.58	0.09	42.8
5082	Shallow marsh	Forbs & shrubs	1.90	0.28	37.2
5082	Shallow marsh	Cool grasses	2.19	0.41	42.8
5082	Shallow marsh	Sedges & rushes	2.15	0.32	41.6
5082	Upland	Sedges & rushes	1.68	0.21	41.5
5082	Upland	Forbs & shrubs	2.44	0.31	40.6
5082	Upland	Cool grasses	1.71	0.25	40.0
5082	Wet meadow	Forbs & shrubs	2.41	0.33	38.7
5082	Wet meadow	Sedges & rushes	1.76	0.29	40.9
5082	Wet meadow	Cool grasses	1.93	0.23	39.9
5083	Shallow marsh	Cattails	1.75	0.28	42.6

Site	Landscape Position	Plant Type*	%N	%P	%C
5083	Shallow marsh	Cool grasses	1.04	0.13	44.5
5083	Shallow marsh	Sedges & rushes	2.27	0.28	38.8
5083	Upland	Forbs & shrubs	1.54	0.20	43.4
5083	Upland	Cool grasses	1.00	0.10	42.7
5083	Wet meadow	Forbs & shrubs	1.28	0.18	45.1
5083	Wet meadow	Cool grasses	1.04	0.11	43.6
5084	Shallow marsh	Forbs & shrubs	1.56	0.18	41.8
5084	Shallow marsh	Sedges & rushes	1.71	0.16	42.8
5084	Upland	Cool grasses	1.17	0.15	43.2
5084	Upland	Forbs & shrubs	1.90	0.23	42.6
5084	Upland	Sedges & rushes	1.90	0.19	44.2
5084	Wet meadow	Cool grasses	1.68	0.17	43.4
5084	Wet meadow	Forbs & shrubs	1.93	0.21	41.7
5084	Wet meadow	Sedges & rushes	1.78	0.17	43.8
5085	Shallow marsh	Cattails	1.78	0.21	43.2
5085	Upland	Cool grasses	1.64	0.18	41.8
5085	Wet meadow	Cool grasses	1.37	0.14	42.7
5085	Wet meadow	Forbs & shrubs	1.97	0.14	40.7
5089	Upland	Cool grasses	1.20	0.09	42.4
5089	Upland	Forbs & shrubs	1.91	0.16	43.7
5089	Wet meadow	Cool grasses	1.35	0.09	43.6
5089	Wet meadow	Forbs & shrubs	2.13	0.14	42.2
5091	Shallow marsh	Cattails	2.52	0.34	40.4
5091	Wet meadow	Sedges & rushes	3.67	0.26	41.7
5091	Wet meadow	Forbs & shrubs	3.79	0.53	43.5
5093	Shallow marsh	Forbs & shrubs	2.23	0.21	41.7
5093	Shallow marsh	Cool grasses	1.50	0.22	40.8
5093	Shallow marsh	Cattails	1.53	0.18	42.1
5093	Upland	Forbs & shrubs	1.50	0.37	37.8
5093	Upland	Cool grasses	2.14	0.23	41.3
5093	Wet meadow	Forbs & shrubs	1.56	0.17	38.9
5093	Wet meadow	Cool grasses	1.48	0.08	43.9
5093	Wet meadow	Sedges & rushes	1.61	0.09	43.6
5094	Shallow marsh	Forbs & shrubs	1.84	0.36	40.7
5094	Shallow marsh	Sedges & rushes	1.07	0.24	42.0
5094	Wet meadow	Sedges & rushes	2.02	0.21	37.2
5094	Wet meadow	Cool grasses	3.54	0.24	39.3
5094	Wet meadow	Forbs & shrubs	1.96	0.29	40.4
5095	Shallow marsh	Cattails	1.25	0.17	43.9
5095	Upland	Forbs & shrubs	1.46	0.14	44.4

Site	**Landscape Position**	**Plant Type***	**%N**	**%P**	**%C**
5095	Upland	Cool grasses	1.06	0.06	40.6
5095	Wet meadow	Cool grasses	1.05	0.09	42.3
5095	Wet meadow	Forbs & shrubs	1.83	0.15	40.8
Reference 1	Shallow marsh	Sedges & rushes	13.65	0.21	33.8
Reference 1	Shallow marsh	Cool grasses	15.55	0.14	34.1
Reference 1	Shallow marsh	Cattails	14.79	0.23	33.6
Reference 1	Upland	Forbs & shrubs	4.22	0.17	43.6
Reference 1	Upland	Cool grasses	3.17	0.10	42.0
Reference 1	Wet meadow	Sedges & rushes	4.81	0.13	41.8
Reference 1	Wet meadow	Cool grasses	9.60	0.18	39.1
Reference 1	Wet meadow	Forbs & shrubs	6.86	0.33	40.0
Reference 2	Shallow marsh	Warm grasses	1.36	0.12	42.9
Reference 2	Shallow marsh	Sedges & rushes	1.99	0.17	40.8
Reference 2	Shallow marsh	Forbs & shrubs	2.29	0.19	43.2
Reference 2	Upland	Cool grasses	1.12	0.10	43.5
Reference 2	Upland	Forbs & shrubs	1.69	0.08	43.7
Reference 2	Wet meadow	Sedges & rushes	1.57	0.11	42.1
Reference 2	Wet meadow	Cool grasses	1.22	0.07	41.5
Reference 2	Wet meadow	Forbs & shrubs	2.10	0.11	42.6

*Cool grasses = cool season grasses and Warm grasses = warm season grasses

APPENDIX D. INDEX OF PLANT COMMUNITY INTEGRITY (IPCI), FLORISTIC QUALITY INDEX (FQI), AND NORTH DATKOTA RAPID ASSESSMENT (NDRAM) SCORES FOR THE 2011 WETLAND SITES

Wetland*	IPCI Score	IPCI Condition Category	FQI Score	NDRAM Score	NDRAM Condition Category
S5001	58	Fair	18.03	34	Fair Low
S5008	0	Very Poor	6.84	14	Poor
S5010	23	Poor	12.03	29	Fair Low
S5017	19	Very Poor	13.67	39	Fair Low
S5018	42	Fair	16.44	60	Fair High
S5027	0	Very Poor	5.46	22	Poor
S5030	44	Fair	17.24	65	Fair High
S5032	71	Good	25.77	95	Good
S5034	55	Fair	20.78	51	Fair Low
S5042	83	Very Good	30.83	73	Good
S5046	72	Good	22.36	87	Good
S5059	27	Poor	14.91	31	Fair Low
S5066	0	Very Poor	5.00	14	Poor
S5069	91	Very Good	31.80	88	Good
S5073	58	Fair	20.86	55	Fair High
S5077	40	Fair	16.89	16	Poor
S5078	45	Fair	16.00	25	Poor
S5079	47	Fair	20.50	66	Fair High
S5084	91	Very Good	35.01	82	Good
S5089	54	Fair	20.62	63	Fair High
S5091	54	Fair	18.96	35	Fair Low
S5094	24	Poor	11.67	26	Poor
SRef1	95	Very Good	39.02	95	Good
SP5003	12	Poor	17.90	28	Fair Low
SP5006	23	Poor	21.47	61	Fair High
SP5011	35	Fair	0.49	68	Fair High
SP5012	70	Good	40.09	65	Fair High
SP5013	87	Good	44.64	82	Good
SP5016	77	Good	43.61	81	Good
SP5019	18	Poor	18.00	57	Fair High
SP5021	33	Fair	20.65	87	Good

Wetland*	**IPCI Score**	**IPCI Condition Category**	**FQI Score**	**NDRAM Score**	**NDRAM Condition Category**
SP5023	38	Fair	25.79	62	Fair High
SP5037	50	Fair	32.79	65	Fair High
SP5040	30	Poor	25.30	21	Poor
SP5043	8	Poor	19.06	52	Fair Low
SP5048	80	Good	34.59	92	Good
SP5049	52	Fair	28.30	66	Fair High
SP5052	52	Fair	27.45	59	Fair High
SP5055	87	Good	40.69	78	Good
SP5056	4	Poor	19.17	62	Fair High
SP5062	52	Fair	29.25	75	Fair High
SP5065	65	Fair	31.04	65	Fair High
SP5067	75	Good	35.90	91	Good
SP5072	19	Poor	18.44	46	Fair Low
SP5075	15	Poor	14.61	48	Fair Low
SP5082	92	Good	53.44	88	Good
SP5083	11	Poor	14.90	41	Fair Low
SP5085	8	Poor	16.73	34	Fair Low
SP5093	18	Poor	20.01	52	Fair Low
SP5095	19	Poor	19.37	66	Fair High
SPRef2	69	Good	31.16	95	Good
T5004	23	Poor	12.75	28	Fair Low
T5007	91	Good	36.20	95	Good
T5015	40	Fair	14.96	41	Fair Low
T5068	95	Good	19.37	93	Good

*Wetlands beginning with a S were seasonal, SP were semi-permanent, and T were temporary

APPENDIX E. HYDROGEOMORPHIC (HGM) MODEL SCORES FOR THE 2011 WETLAND SITES

Wetland*	Water Storage	Groundwater Recharge	Retain Particulates	Remove, Convert, and Sequester Dissolved Substances	Plant Community Resilience and Carbon Cycling	Provide Faunal Habitat	Provide Faunal Habitat (Alternate Formula)
S5001	0.94	0.90	0.78	0.77	0.82	0.85	0.86
S5008	0.94	0.75	0.66	0.68	0.66	0.67	0.73
S5010	0.86	0.85	0.72	0.69	0.74	0.77	0.79
S5017	0.64	0.64	0.77	0.61	0.60	0.58	0.60
S5018	0.89	0.70	0.77	0.90	0.84	0.82	0.74
S5027	0.93	0.80	0.71	0.74	0.69	0.62	0.67
S5030	0.97	0.89	0.97	0.97	0.96	0.96	0.94
S5032	0.96	0.90	0.94	0.95	0.94	0.92	0.86
S5034	0.84	0.68	0.93	0.83	0.82	0.80	0.77
S5042	0.76	0.75	0.62	0.91	0.88	0.88	0.79
S5046	0.97	0.90	0.98	0.97	0.97	0.94	0.94
S5059	0.92	0.87	0.83	0.83	0.84	0.85	0.76
S5066	0.96	0.75	0.66	0.66	0.65	0.71	0.77
S5069	0.97	0.82	0.98	0.98	0.98	0.97	0.95
S5073	0.83	0.75	0.89	0.80	0.81	0.81	0.82
S5077	0.90	0.76	0.74	0.69	0.77	0.77	0.83
S5078	0.94	0.76	0.74	0.74	0.79	0.79	0.83
S5079	0.89	0.81	0.80	0.93	0.90	0.90	0.82
S5084	0.97	0.93	0.98	0.98	0.98	0.94	0.89
S5089	0.97	0.85	0.98	0.98	0.98	0.96	0.91
S5091	0.92	0.84	0.87	0.85	0.90	0.89	0.95
S5094	0.91	0.78	0.65	0.67	0.69	0.71	0.76
SRef1	0.97	0.89	0.98	0.97	0.97	0.94	0.96
SP5003	0.94	0.83	0.76	0.75	0.79	0.81	0.88
SP5006	0.97	0.81	0.95	0.96	0.94	0.94	0.92
SP5011	0.97	0.83	0.98	0.96	0.96	0.97	0.92
SP5012	0.95	0.85	0.93	0.96	0.96	0.97	0.91
SP5013	0.86	0.74	0.75	0.94	0.93	0.94	0.93
SP5016	0.99	0.97	0.92	0.92	0.95	0.92	0.86
SP5019	0.81	0.68	0.93	0.82	0.83	0.83	0.83
SP5021	0.97	0.82	0.98	0.98	0.98	0.98	0.94

Wetland*	Water Storage	Groundwater Recharge	Retain Particulates	Remove, Convert, and Sequester Dissolved Substances	Plant Community Resilience and Carbon Cycling	Provide Faunal Habitat	Provide Faunal Habitat (Alternate Formula)
SP5023	0.94	0.80	0.91	0.90	0.92	0.85	0.85
SP5037	0.97	0.82	0.98	0.98	0.98	0.98	0.93
SP5040	0.94	0.87	0.78	0.77	0.84	0.87	0.93
SP5043	0.93	0.88	0.89	0.87	0.91	0.93	0.90
SP5048	1.00	0.91	0.99	0.99	1.00	1.00	0.95
SP5049	0.94	0.77	0.98	0.96	0.98	0.94	0.92
SP5052	0.84	0.74	0.97	0.85	0.87	0.87	0.84
SP5055	0.91	0.71	0.81	0.95	0.95	0.92	0.94
SP5056	0.80	0.76	0.92	0.82	0.82	0.82	0.73
SP5062	0.82	0.75	0.95	0.83	0.85	0.83	0.80
SP5065	0.81	0.65	0.94	0.82	0.84	0.81	0.81
SP5067	0.99	0.74	0.99	0.99	0.99	0.94	0.93
SP5072	0.78	0.76	0.91	0.79	0.81	0.81	0.75
SP5075	0.97	0.85	0.92	0.93	0.89	0.90	0.83
SP5082	1.00	0.84	1.00	0.97	0.97	0.97	0.87
SP5083	0.96	0.79	0.90	0.91	0.90	0.91	0.91
SP5085	0.95	0.75	0.84	0.84	0.86	0.84	0.91
SP5093	0.62	0.61	0.53	0.71	0.69	0.70	0.71
SP5095	0.84	0.67	0.88	0.81	0.80	0.78	0.82
SPRef2	0.97	0.84	0.98	0.99	0.99	0.97	0.93
T5004	0.48	0.43	0.69	0.41	0.41	0.39	0.39
T5007	0.77	0.82	0.53	0.89	0.87	0.87	0.75
T5015	0.94	0.90	0.75	0.74	0.77	0.78	0.76
T5068	0.75	0.63	0.36	0.89	0.87	0.84	0.82

*Wetlands beginning with a S were seasonal, SP were semi-permanent, and T were temporary

APPENDIX F. WETLAND LOCATION AND AMOUNT OF SEDIMENT REMOVAL FOR THE 2012 SITES

Site	County	Year excavated	Amount of sediment removed (cm)	Latitude	Longitude
Nik1	Towner	2008	25	48.6011111	-99.23583333
Nik3	Towner	2008	46	48.58805556	-99.2425
Nik4	Towner	2008	36	48.58777778	-99.23888889
Nik5	Towner	2008	51	48.58805556	-99.23805556
Nik6	Towner	2008	25	48.58888889	-99.23777778
Hoff1	Benson	2007	20 to 30	48.21611111	-99.45611111
Hoff2	Benson	2007	20 to 30	48.21722222	-99.45166667
Hoff5	Benson	2007	20 to 30	48.21055556	-99.46666667
CW47	Wells	2003	20	47.51027778	-99.46055556
CW48	Wells	2003	30	47.50972222	-99.46194444
CW57	Wells	2003	40	47.51166667	-99.46527778
CW58	Wells	2003	13	47.51166667	-99.46583333
CW61	Wells	2003	20	47.51166667	-99.45916667
CW62	Wells	2003	10	47.51166667	-99.45944444
CW63	Wells	2003	36	47.5125	-99.45916667
CW64	Wells	2003	10	47.51333333	-99.45944444
CW65	Wells	2003	25	47.51333333	-99.46
CW66	Wells	2003	41	47.51416667	-99.45916667

APPENDIX G. COMPREHENSIVE PLANT SPECIES LIST FOR 2012 STUDY SITES

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Agropyron caninum	N/A	6	P	N	FAC-
Agropyron elongatum	Tall Wheatgrass	*	P	I	UPL
Agropyron repens	Quackgrass	*	P	I	FAC
Agropyron smithii	Western Wheatgrass	4	P	N	UPL
Alisma subcordatum	Common Water Plantain	2	P	N	OBL
Alopecurus aequalis	Shortawn Foxtail	2	P	N	OBL
Ambrosia psilostachya	Western Ragweed	2	P	N	FAC
Andropogon gerardii	Big Bluestem	5	P	N	FACU
Anemone canadensis	Meadow Anemone	4	P	N	FACW
Apocynum cannabinum	Indian Hemp Dogbane, Prairie Dogbane	4	P	N	FAC
Artemisia absinthium	Wormwood	*	P	I	UPL
Artemisia biennis	Biennial Wormwood	*	B	I	FAC
Asclepias incarnata	Swamp Milkweed	5	P	N	OBL
Asclepias syriaca	Common Milkweed	0	P	N	UPL
Astragalus canadensis	Canada Milk-vetch	5	P	N	FACU
Atriplex subspicata	Spearscale	2	A	N	FAC
Beckmannia syzigachne	American Sloughgrass	1	A	N	OBL
Bouteloua curtipendula	Sideoats Grama	5	P	N	UPL
Brassica napus	Canola	*	A	I	UPL
Bromus inermis	Smooth Brome	*	P	I	UPL
Bromus japanicus	Japanese Brome	*	A	I	FACU
Calamovilfa longifolia	Prairie Sandreed	5	P	N	UPL
Carex atherodes	Slough Sedge	4	P	N	OBL
Carex lanuginosa	Woolly Sedge	4	P	N	OBL
Carex sychnocephala	N/A	7	P	N	FACW
Carex vulpinoidea	Fox Sedge	2	P	N	OBL
Cicuta maculata	Common Water Hemlock	4	P	N	OBL
Cirsium arvense	Canada Thistle, Field Thistle	*	P	I	FACU
Cirsium vulgare	Bull Thistle	*	B	I	UPL
Convolvulus arvensis	Field Bindweed	*	P	I	UPL
Conyza canadensis	Horseweed	0	A	N	FACU
Dalea purpurea	Purple Prairie Clover	8	P	N	UPL
Descurainia sophia	Flixweed	*	A	I	UPL
Distichlis spicata	Inland Saltgrass	2	P	N	FACW
Echinochloa crusgalli	Barnyard Grass	*	A	I	FACW
Eleocharis acicularis	Needle Spikesedge	3	P	N	OBL

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Eleocharis macrostachya	Spike Rush	4	P	N	OBL
Elymus canadensis	Canada Wild Rye	3	P	N	FACU
Epilobium ciliatum	Willow-herb	3	P	N	OBL
Equisetum laevigatum	Smooth Scouring Rush	3	P	N	FAC
Erigeron strigosus	Daisy Fleabane	3	A	N	FACU
Euphorbia esula	Leafy Spurge	*	P	I	UPL
Fraxinus pennsylvanica	Red Ash, Green Ash	5	P	N	FAC
Galium aparine	Catchweed Bedstraw	0	A	N	FACU
Glyceria grandis	Tall Mannagrass	4	P	N	OBL
Glycyrrhiza lepidota	Wild Licorice	2	P	N	FACU
Gratiola neglecta	Hedge Hyssop	0	A	N	OBL
Helianthus maximilianii	Maximilian Sunflower	5	P	N	FACU
Helianthus nuttallii	Nuttall's Sunflower	8	P	N	FAC
Helianthus pauciflorus	Stiff Sunflower	8	P	N	UPL
Hordeum jubatum	Foxtail Barley	0	P	N	FACW
Juncus balticus	Baltic Rush	5	P	N	FACW
Juncus dudleyi	Dudley Rush	4	P	N	FAC
Juncus interior	Inland Rush	5	P	N	FACW
Juncus torreyi	Torrey's Rush	2	P	N	FACW
Koeleria pyramidata	Junegrass	7	P	N	UPL
Lactuca oblongifolia	Blue Lettuce	1	P	N	FACU
Lemna turionifera	N/A	1	P	N	OBL
Lepidium densiflorum	Peppergrass	0	A	N	FACU
Lycopus americanus	American Bugleweed	4	P	N	OBL
Lycopus asper	Rough Bugleweed	4	P	N	OBL
Lysimachia thyrsiflora	Tufted Loosestrife	7	P	N	OBL
Medicago lupulina	Black Medick	*	P	I	FACU
Medicago sativa	Alfalfa	*	P	I	UPL
Melilotus alba	White Sweet Clover	*	A	I	UPL
Melilotus officinalis	Yellow Sweet Clover	*	A	I	FACU-
Mentha arvensis	Field Mint	3	P	N	FACW
Monarda fistulosa	Wild Bergamot	5	P	N	UPL
Oxalis stricta	Yellow Wood Sorrel	0	P	N	FACU
Panicum virgatum	Switchgrass	5	P	N	FAC
Phalaris arundinacea	Reed Canarygrass	0	P	N	FACW+
Phleum pratense	Timothy	*	P	I	FACU
Phragmites australis	Common Reed	0	P	N	FACW
Plantago major	Common Plantain	*	P	I	FAC
Poa palustris	Fowl Bluegrass	4	P	N	FACW
Poa pratensis	Kentucky Bluegrass	*	P	I	FACU
Polygonum amphibian var. emersum	Swamp Smartweed	0	P	N	OBL

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Polygonum amphibian var.stipulaceum	Water Smartweed	6	P	N	FACW
Polygonum lapathifolium	Pale Smartweed	1	A	N	OBL
Populus deltoides	Cottonwood	3	P	N	FAC
Potamogeton pectinatus	Sago Pondweed	0	P	N	OBL
Potamogeton pusillus	Baby Pondweed	2	P	N	OBL
Potentilla anserina	Silverweed	2	P	N	OBL
Potentilla norvegica	Norwegian Cinquefoil	0	A	N	FAC
Potentilla rivalis	Brook Conquefoil	3	A	N	OBL
Ranunculus cymbalaria	Shore Buttercup	3	P	N	OBL
Ratibida columnifera	Prairie Coneflower	3	P	N	UPL
Rorippa palustris	Bog Yellow Cress	2	A	N	OBL
Rudbeckia hirta	Black-eyed Susan	5	B	N	FACU
Rumex crispus	Curly Dock	*	P	I	FACW
Rumex maritimus	Golden Dock	1	A	N	FACW
Rumex mexicanus	Willow-leaved Dock	1	P	N	FACW
Sagittaria cuneata	Arrowhead	6	P	N	OBL
Salix lutea	Yellow Willow	5	P	N	FACW
Schedonnardus paniculatus	Tumblegrass	1	P	N	FAC
Schizachyrium scoparium	Little Bluestem	6	P	N	UPL
Schoenoplectus acutus	Hard-stem Bulrush	5	P	N	OBL
Schoenoplectus fluviatilis	River Bulrush	2	P	N	OBL
Schoenoplectus maritimus	Prairie Bulrush	4	P	N	OBL
Schoenoplectus pungens	N/A	4	P	N	OBL
Schoenoplectus tabernaemontani	Soft-stem Bulrush	3	P	N	OBL
Scolochloa festucacea	Sprangletop	6	P	N	OBL
Silene dichotomo	Forked Catchfly	*	A	I	UPL
Silene noctiflora	Night-flowering Catchfly, Sticky Cockle	*	A	I	UPL
Sium suave	Water Parsnip	3	P	N	OBL
Solidago canadensis	Canada Goldenrod	1	P	N	FACU
Solidago rigida	Rigid Goldenrod	4	P	N	FACU-
Sonchus arvensis	Field Sow Thistle	*	P	I	FAC
Sorghastrum nutans	Indian Grass	6	P	N	FACU
Spartina pectinata	Prairie Cordgrass	5	P	N	FACW
Stipa viridula	Green Needlegrass	5	P	N	UPL
Suaeda depressa	Sea Blite	2	A	N	UPL
Symphotrichum ciliatum	Rayless Aster	0	A	N	FACW
Symphotrichum ericoides	White Aster	2	P	N	FACU
Symphotrichum falcatus	N/A	4	P	N	FACU

Scientific Name[1]	Common Name	C-Val[2]	Life[3]	Origin[4]	Indicator[5]
Symphotrichum lanceolatum	Panicled Aster	3	P	N	FACW
Taraxacum officinale	Common Dandelion	*	P	I	FACU
Teucrium canadense	American Germander, Wood Sage	3	P	N	FACW
Thlaspi arvense	Field Pennycress	*	A	I	FACU
Typha angustifolia	Narrow-leaved Cattail	*	P	I	OBL
Typha latifolia	Broad-leaved Cattail	2	P	N	OBL
Typha x glauca	Hybrid Cattail	*	P	I	OBL
Urtica dioica	Stinging Nettle	0	P	N	FACW
Verbena bracteata	Prostrate Vervain	0	A	N	FACU
Verbena stricta	Hoary Vervain	2	P	N	UPL
Vernonia fasciculata	Ironweed	3	P	N	FAC
Veronica peregrina	Purslane Speedwell	0	A	N	FACW
Vicia americana	American Vetch	3	P	N	UPL
Xanthium strumarium	Cocklebur	0	A	N	FAC
xElyhordeum macounii	N/A	3	P	N	FAC
Zizia aptera	Meadow Parsnip	8	P	N	UPL

*C-values not assigned to introduced species.

[1] Scientific names of plant species are according to the USDA Plants Database (USDA, NRCS 2012).

[2] C-values (coefficient of conservatism) assigned by The Northern Great Plains Floristic Quality Assessment Panel (2001).

[3] Life-forms: N = native and I = introduced.

[4] Origin: P = perennial, A = annual, and B = biennial.

[5] Indicator categories are according to the National List of Plant Species that Occur in Wetlands: Northern Plains (Region 4) (Reed 1988).

APPENDIX H. PLANT CARBON, NITROGEN, AND PHOSPHORUS CONTENT FOR THE 2012 WETLAND SITES

Site	Landscape Position	Plant Type*	%N	%P	%C
Nik1	Shallow marsh	Cattails	1.24	0.17	43.0
Nik1	Upland	Cool grasses	0.97	0.19	41.8
Nik1	Upland	Forbs & shrubs	2.45	0.21	42.5
Nik1	Wet meadow	Cool grasses	1.26	0.20	42.1
Nik1	Wet meadow	Forbs & shrubs	1.71	0.30	40.8
Nik1	Wet meadow	Sedges & rushes	1.58	0.31	42.5
Nik3	Shallow marsh	Cattails	1.17	0.20	42.7
Nik3	Shallow marsh	Cool grasses	1.45	0.29	40.0
Nik3	Shallow marsh	Forbs & shrubs	1.66	0.32	41.4
Nik3	Shallow marsh	Sedges & rushes	1.47	0.24	41.5
Nik3	Upland	Cool grasses	1.08	0.22	41.1
Nik3	Upland	Forbs & shrubs	1.73	0.17	43.0
Nik3	Wet meadow	Cool grasses	1.53	0.24	41.5
Nik3	Wet meadow	Forbs & shrubs	2.64	0.40	35.2
Nik3	Wet meadow	Sedges & rushes	1.71	0.26	41.2
Nik4	Shallow marsh	Cattails	1.03	0.18	42.3
Nik4	Shallow marsh	Cool grasses	4.22	0.45	36.2
Nik4	Upland	Cool grasses	1.13	0.19	41.6
Nik4	Upland	Forbs & shrubs	1.47	0.23	42.3
Nik4	Wet meadow	Cool grasses	0.93	0.22	41.5
Nik4	Wet meadow	Forbs & shrubs	1.19	0.29	37.9
Nik4	Wet meadow	Sedges & rushes	1.35	0.17	42.9
Nik5	Shallow marsh	Cattails	1.49	0.19	43.7
Nik5	Shallow marsh	Sedges & rushes	1.08	0.17	43.0
Nik5	Upland	Cool grasses	1.17	0.18	40.9
Nik5	Upland	Forbs & shrubs	1.82	0.25	41.2
Nik5	Wet meadow	Cool grasses	1.06	0.23	40.9
Nik5	Wet meadow	Forbs & shrubs	1.66	0.37	36.8
Nik5	Wet meadow	Sedges & rushes	1.30	0.19	42.8
Nik6	Shallow marsh	Cattails	0.94	0.13	44.7
Nik6	Shallow marsh	Cool grasses	1.46	0.28	40.7
Nik6	Shallow marsh	Forbs & shrubs	0.95	0.23	44.7
Nik6	Shallow marsh	Sedges & rushes	1.21	0.17	40.6
Nik6	Upland	Cool grasses	1.61	0.24	39.7
Nik6	Upland	Forbs & shrubs	1.46	0.20	42.1
Nik6	Wet meadow	Cool grasses	1.10	0.22	41.2
Nik6	Wet meadow	Forbs & shrubs	1.76	0.38	34.4
Nik6	Wet meadow	Sedges & rushes	1.34	0.25	40.2
Hoff1	Shallow marsh	Cattails	1.11	0.15	44.4

Site	**Landscape Position**	**Plant Type***	**%N**	**%P**	**%C**
Hoff1	Shallow marsh	Cool grasses	1.36	0.29	42.0
Hoff1	Shallow marsh	Forbs & shrubs	1.56	0.39	42.5
Hoff1	Shallow marsh	Sedges & rushes	1.32	0.24	40.6
Hoff1	Upland	Cool grasses	1.37	0.23	42.2
Hoff1	Upland	Forbs & shrubs	1.22	0.36	37.3
Hoff1	Wet meadow	Cattails	1.42	0.09	43.9
Hoff1	Wet meadow	Cool grasses	1.09	0.21	42.0
Hoff1	Wet meadow	Forbs & shrubs	1.70	0.36	39.2
Hoff2	Shallow marsh	Cattails	1.15	0.19	43.7
Hoff2	Shallow marsh	Cool grasses	1.29	0.32	41.3
Hoff2	Shallow marsh	Forbs & shrubs	1.74	0.42	42.8
Hoff2	Shallow marsh	Sedges & rushes	1.07	0.28	31.4
Hoff2	Upland	Cool grasses	0.91	0.24	41.6
Hoff2	Upland	Forbs & shrubs	1.26	0.26	37.0
Hoff2	Upland	Warm grasses	0.87	0.23	42.1
Hoff2	Wet meadow	Cool grasses	0.94	0.17	42.1
Hoff2	Wet meadow	Forbs & shrubs	1.90	0.27	43.4
Hoff5	Shallow marsh	Cattails	0.81	0.14	44.8
Hoff5	Shallow marsh	Cool grasses	1.15	0.32	41.5
Hoff5	Shallow marsh	Forbs & shrubs	1.25	0.37	42.2
Hoff5	Shallow marsh	Sedges & rushes	1.13	0.22	41.1
Hoff5	Upland	Cool grasses	1.05	0.17	41.5
Hoff5	Upland	Forbs & shrubs	1.07	0.22	41.0
Hoff5	Upland	Warm grasses	1.00	0.27	43.0
Hoff5	Wet meadow	Cool grasses	1.28	0.32	39.8
Hoff5	Wet meadow	Forbs & shrubs	1.47	0.38	38.4
Hoff5	Wet meadow	Sedges & rushes	1.25	0.21	41.7
CW47	Shallow marsh	Sedges & rushes	1.54	0.28	40.1
CW47	Upland	Cool grasses	0.84	0.17	40.4
CW47	Upland	Warm grasses	1.65	0.27	42.7
CW47	Wet meadow	Cool grasses	1.22	0.12	43.9
CW47	Wet meadow	Forbs & shrubs	1.83	0.27	42.0
CW47	Wet meadow	Sedges & rushes	1.14	0.21	40.5
CW47	Wet meadow	Warm grasses	2.29	0.23	42.9
CW48	Shallow marsh	Sedges & rushes	1.94	0.43	40.2
CW48	Upland	Cool grasses	1.07	0.23	40.6
CW48	Upland	Forbs & shrubs	1.92	0.28	43.4
CW48	Wet meadow	Cool grasses	1.38	0.17	42.2
CW48	Wet meadow	Forbs & shrubs	1.95	0.26	38.4
CW57	Shallow marsh	Cattails	1.31	0.21	42.5
CW57	Shallow marsh	Sedges & rushes	1.24	0.18	42.1
CW57	Upland	Cool grasses	0.76	0.14	41.7
CW57	Upland	Forbs & shrubs	2.20	0.28	45.3

Site	**Landscape Position**	**Plant Type***	**%N**	**%P**	**%C**
CW57	Upland	Warm grasses	1.68	0.27	42.1
CW57	Wet meadow	Cool grasses	1.08	0.14	44.8
CW57	Wet meadow	Sedges & rushes	1.49	0.29	40.7
CW58	Shallow marsh	Cattails	1.58	0.24	43.7
CW58	Shallow marsh	Sedges & rushes	1.92	0.32	39.3
CW58	Upland	Cool grasses	0.87	0.13	41.4
CW58	Upland	Forbs & shrubs	2.15	0.28	45.2
CW58	Upland	Warm grasses	1.44	0.19	42.7
CW58	Wet meadow	Cool grasses	0.75	0.16	42.6
CW58	Wet meadow	Sedges & rushes	1.34	0.25	41.6
CW61	Shallow marsh	Cool grasses	0.98	0.15	43.6
CW61	Shallow marsh	Forbs & shrubs	1.99	0.26	43.0
CW61	Shallow marsh	Warm grasses	1.72	0.26	42.8
CW61	Upland	Cool grasses	0.87	0.12	42.0
CW61	Upland	Warm grasses	1.49	0.20	41.9
CW61	Wet meadow	Cool grasses	1.04	0.13	42.1
CW61	Wet meadow	Warm grasses	1.44	0.19	42.2
CW62	Shallow marsh	Cool grasses	0.92	0.14	42.5
CW62	Shallow marsh	Forbs & shrubs	2.80	0.33	44.3
CW62	Shallow marsh	Warm grasses	1.34	0.17	43.2
CW62	Upland	Cool grasses	0.79	0.10	41.1
CW62	Upland	Warm grasses	1.11	0.17	42.8
CW62	Wet meadow	Cool grasses	1.17	0.15	43.3
CW62	Wet meadow	Forbs & shrubs	2.15	0.23	44.6
CW62	Wet meadow	Warm grasses	1.59	0.24	43.0
CW63	Shallow marsh	Cattails	1.23	0.30	43.8
CW63	Shallow marsh	Sedges & rushes	1.38	0.32	42.2
CW63	Upland	Cool grasses	1.08	0.10	42.4
CW63	Upland	Warm grasses	1.50	0.16	42.4
CW63	Wet meadow	Cattails	1.13	0.29	43.2
CW63	Wet meadow	Cool grasses	1.18	0.22	42.4
CW63	Wet meadow	Forbs & shrubs	1.99	0.36	40.8
CW63	Wet meadow	Sedges & rushes	1.51	0.21	41.6
CW64	Shallow marsh	Cattails	1.32	0.27	42.7
CW64	Shallow marsh	Cool grasses	1.45	0.21	44.3
CW64	Shallow marsh	Forbs & shrubs	2.65	0.43	38.9
CW64	Shallow marsh	Sedges & rushes	0.72	0.30	23.0
CW64	Upland	Cool grasses	1.00	0.10	41.5
CW64	Upland	Warm grasses	1.30	0.15	43.3
CW64	Wet meadow	Cool grasses	1.10	0.10	44.0
CW64	Wet meadow	Forbs & shrubs	2.02	0.23	38.2
CW64	Wet meadow	Sedges & rushes	1.34	0.12	42.8
CW65	Shallow marsh	Cattails	1.79	0.28	41.2

Site	**Landscape Position**	**Plant Type***	**%N**	**%P**	**%C**
CW65	Shallow marsh	Forbs & shrubs	2.21	0.22	36.6
CW65	Shallow marsh	Sedges & rushes	1.60	0.14	41.7
CW65	Upland	Cool grasses	1.14	0.08	41.7
CW65	Upland	Warm grasses	1.72	0.16	43.3
CW65	Wet meadow	Cool grasses	1.00	0.09	44.1
CW65	Wet meadow	Forbs & shrubs	3.13	0.19	43.4
CW65	Wet meadow	Sedges & rushes	1.34	0.13	43.5
CW65	Wet meadow	Warm grasses	1.56	0.11	38.3
CW66	Shallow marsh	Cattails	1.18	0.12	45.6
CW66	Shallow marsh	Sedges & rushes	1.95	0.10	41.8
CW66	Upland	Cool grasses	0.90	0.12	44.0
CW66	Wet meadow	Cool grasses	1.63	0.15	47.4
CW66	Wet meadow	Sedges & rushes	1.46	0.13	43.2

*Cool grasses = cool season grasses and Warm grasses = warm season grasses

APPENDIX I. INDEX OF PLANT COMMUNITY INTEGRITY (IPCI), FLORISTIC QUALITY INDEX (FQI), AND NORTH DATKOTA RAPID ASSESSMENT (NDRAM) SCORES FOR THE 2012 WETLAND SITES

Wetland	IPCI Score	IPCI Condition Category	FQI Score	NDRAM Score	NDRAM Condition Category
Nik1	40	Fair	19.50	52	Fair low
Nik3	43	Fair	20.57	45	Fair low
Nik4	34	Poor	17.36	45	Fair low
Nik5	43	Fair	19.39	54	Fair high
Nik6	30	Poor	17.35	54	Fair high
Hoff1	70	Good	24.72	52	Fair low
Hoff2	66	Good	23.37	54	Fair high
Hoff5	69	Good	26.60	52	Fair low
CW47	51	Fair	16.52	61	Fair high
CW48	44	Fair	21.38	61	Fair high
CW57	49	Fair	21.06	64	Fair high
CW58	52	Fair	22.98	64	Fair high
CW61	48	Fair	19.87	60	Fair high
CW62	41	Fair	19.02	60	Fair high
CW63	72	Good	24.34	61	Fair high
CW64	73	Good	24.38	63	Fair high
CW65	52	Fair	20.59	61	Fair high
CW66	45	Fair	20.06	63	Fair high

APPENDIX J. HYDROGEOMORPHIC (HGM) MODEL SCORES FOR THE 2012 WETLAND SITES

Wetland	Water Storage	Groundwater Recharge	Retain Particulates	Remove, Convert, and Sequester Dissolved Substances	Plant Community Resilience and Carbon Cycling	Provide Faunal Habitat	Provide Faunal Habitat (Alternate Formula)
Nik1	0.97	0.83	0.94	0.95	0.92	0.91	0.88
Nik3	0.95	0.75	0.90	0.91	0.89	0.85	0.88
Nik4	0.91	0.84	0.86	0.88	0.87	0.83	0.85
Nik5	0.97	0.76	0.94	0.96	0.93	0.90	0.91
Nik6	0.97	0.79	0.94	0.95	0.92	0.88	0.89
Hoff1	0.97	0.81	0.98	0.98	0.98	0.94	0.97
Hoff2	0.97	0.82	0.95	0.96	0.94	0.88	0.93
Hoff5	0.97	0.86	0.96	0.95	0.93	0.92	0.92
CW47	0.97	0.86	0.95	0.94	0.92	0.90	0.90
CW48	0.97	0.80	0.94	0.92	0.89	0.87	0.88
CW57	0.94	0.77	0.96	0.95	0.95	0.92	0.91
CW58	0.94	0.79	0.93	0.93	0.91	0.88	0.86
CW61	0.97	0.80	0.95	0.96	0.94	0.91	0.91
CW62	0.97	0.82	0.96	0.97	0.95	0.91	0.91
CW63	0.97	0.75	0.95	0.96	0.94	0.91	0.90
CW64	0.97	0.80	0.96	0.96	0.95	0.93	0.91
CW65	0.97	0.78	0.94	0.94	0.91	0.88	0.87
CW66	0.97	0.84	0.94	0.94	0.91	0.89	0.87