Changes in Wetland Conditions and Wetland Plant Communities in the Prairie Pothole Region After 50 Years

Ryann Cressey
South Dakota State University

CHANGES IN WETLAND CONDITIONS AND WETLAND PLANT COMMUNITIES IN THE PRAIRIE POTHOLE REGION AFTER 50 YEARS

BY

RYANN CRESSEY

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Wildlife and Fisheries Science

Specialization in Wildlife Science

South Dakota State University

2016

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Wildlife and Fisheries Sciences degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidates are necessarily the conclusions of the major department.

Joshua D. Stafford, Ph.D. Date
Thesis Co-advisor

Jane E. Austin, Ph.D. Date
Thesis Co-advisor

Michele R. Dudash, Ph.D. Date
Head, Department of Natural
Resource Management

Dean, Graduate School Date

This thesis is dedicated to the journey I've been on
to get me to this point in my life and my career
and to those who experienced it with me.

ACKNOWLEDGEMENTS

First of all, I want to thank my co-advisors Dr. Joshua Stafford and Dr. Jane Austin for all their help and guidance throughout this process. Thanks to Dr. Carol Johnston for additional guidance with sampling design and plant community analyses. I can't say thank you enough to my technicians Beth Harmsen and Alyse Homola for fighting with cattails and putting up with the intense field work conditions of North Dakota. Neil Shook and Cami Dixon from Chase Lake Wetland Management District were pivotal part of this project and much gratitude is owed to them for providing housing and logistical support during field season as well as plant identification help and much more. This project could not have been completed without the land owners providing access to the wetlands within the Crystal Springs study area. Thank you to Dr. Gary Larson for additional plant identification help.

A special thanks to Hal Kantrud for coming out in the field and sharing his knowledge with me about the study wetlands and changes of study areas. This project was funded by the U.S. Geological Survey Northern Prairie Wildlife Research Center in Jamestown, ND. Robert Gleason, Mark Shefy, Dave Mushet, Deborah Buhl, Raymond Finocchiaro, Mark Wiltermuth, and Charles Dahl at Northern Prairie Wildlife Research Center provided helpful comments for research design, interpretation, and equipment maintenance. Additional thanks is in order to Northern Prairie for access to equipment, Stewart and Kantrud's original data, and herbarium specimens.

Many people at South Dakota State University helped me throughout my graduate career. Adam Janke, Jarrett Pfrimmer, Fred Oslund, and Neal Martorelli provided much support and helpful comments on my research along the way, thanks guys. Thank to Emily Ulrich for her help with plant identification. My fellow grad students got me through a lot of difficult times, taught me a lot, and helped me make some unforgettable memories while at South Dakota State University.

Most of all, I want to thank my family and friends for supporting and encouraging me through everything. Mom, I wouldn't be here without you sharing your constant curiosity of nature with me and your willingness to hang onto to me as I look over the edge of cliffs. Dad, we wouldn't have the pics to prove it without you.

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ABSTRACT

CHANGES IN WETLAND CONDITIONS AND WETLAND PLANT COMMUNITIES IN THE PRAIRIE POTHOLE REGION AFTER 50 YEARS

RYANN CRESSEY

2016

Wetlands in Stutsman County, North Dakota were revisited after 50 years to assess changes in wetland conditions and plant communities within wetland zones in the Prairie Pothole Region. In 1961-1966, Robert E. Stewart and Harold A. Kantrud conducted a study to investigate the relationship of wetland plant communities to variations of water permanence and chemistry on three study areas: Crystal Springs, Cottonwood, and Mt. Moriah. Within in this region, a severe drought occurred in 1988-1992 followed by the longest deluge starting in 1993 with wetlands still impacted today. In 2013 and 2014, I revisited 80 of the original wetlands measuring water depths and specific conductivity as well as measuring wetland size from aerial imagery. Additionally, I conducted quadrat-based vegetation surveys within 4 wetland zones (i.e., wet meadow, shallow marsh, deep marsh, and open water) to examine changes in species composition, frequency, abundance, and to document progression of invasive plant species (e.g., *Typha*, *Phalaris arundinacea*, *Poa pratensis*, and *Bromus inermis*). Wetlands at the three study areas responded to the excess water from the deluge in unique ways. Wetlands at Crystal Springs were larger, deeper, and fresher in 2013-14 compared to the 1960s. Wetlands at Cottonwood were slightly larger, deeper, and more saline in 2013-14. Wetlands at Mt. Moriah had subtle, almost negligible changes in depth, size,

and salinity from the 1960s study to the 2013-14 study. Although wetlands across the study areas responded to deluge conditions differently, plant communities within wetland zones on average were only 25 % similar in species composition across all study areas from the 1960s to 2013-14, but changes within each wetland zone were unique. Across all study areas, the deluge conditions left most wetlands dominated by open water and with more deep marsh zones. Excess water at Crystal Springs caused merging of wetlands to the extent that a large portion of wetland vegetation and wetland zones have been lost since the 1960s. Some merging occurred at Cottonwood but expansion of invasive plant species caused more wetland zone loss (i.e., reduction or removal of zonal plant communities) at this study area and at Mt. Moriah than did high water conditions. Species richness increased in all zones, but at least 50% of species changed minimally in abundance (i.e., ± 5%) within each zone except open water. Open water zones had 43% of species change by >10% abundance and had less submerged aquatic vegetation overall due to increased wetland depths. Deep marsh zones were mostly monotypic stands of *Typha* in 2013-14, and shallow marsh zones surrounding these monotypic stands were not present or dominated by *Phalaris arundinacea*. Shallow marsh zones in wetlands without *Typha* had *Carex atherodes, Polygonum amphibian var. emersum, Scolochloa festucacea*, and *Phalaris arundinacea* as the most abundant species in 2013-14. Wet meadow zones consisted of several traditional wet meadow species with the addition of traditional low prairie zone and upland species. but all species were in relatively low abundances in 2013-14, with the exception of *Calamagrostis canadensis, Poa pratensis,* and *Spartina pectinata*, which had >15% abundance. All invasive plant species of concern increased in frequency and became some of the most abundant species within

wetland zones. Climatic extremes greatly impacted wetland size, depths, and specific conductivity for Crystal Springs and Cottonwood whereas wetlands at Mt. Moriah were less impacted, appearing more resilient. Climatic extremes in combination with invasive plant species greatly impacted species composition, frequency and abundance of individual plant species in plant communities within wetland zones across all three study areas.

CHAPTER 1. GENERAL INTRODUCTION

Wetlands in the Prairie Pothole Region (PPR) have been studied for over 100 years (van der Valk 2005) and plant communities were some of the first wetland attributes studied in the region (Kantrud et al. 1989). Two themes of wetland plant communities were revealed early: 1) wetland plant communities were arranged in concentric zones; and 2) drought and flood conditions affect zonal arrangements (Kantrud et al. 1989). By the 1960s, there was a need to classify wetlands on more characteristics than water depth, which was not a reliable metric (Kantrud 1992). Robert E. Stewart and Harold A. Kantrud developed a regionalized wetland classification system for the PPR, largely based on their observations of wetland plant communities from work in Stutsman County, North Dakota in 1961-1966 (Stewart and Kantrud 1971). In the 1960s, the focus of wetland research shifted from wetland plant communities to wetland hydrology. This research led to our understanding of how the position of wetlands within the landscape and interactions with groundwater drive changes in wetland plant communities and the overall dynamic nature of wetlands in this region (van der Valk 1989, Euliss et al. 1999).

Hydrologic setting within the landscape (i.e., connection to groundwater) and inter-annual climate variability greatly influence water levels and, therefore, distribution of wetland plant communities (i.e., wetland zones; van der Valk and Davis 1978, van der Valk and Mushet in press). From the 1960s to the mid-1980s, short durations of wet and dry periods oscillated, keeping overall hydrologic conditions relatively stable in central North Dakota (NCDC 2015). The second worst drought of the century occurred from 1988-1992, but was followed in 1993, by a drastic opposite shift to extremely wet conditions that constituted the longest deluge of the century, and possibly of the last 500 years (Winter and Rosenberry 1998; Winter 2003). These climatic extremes led to changes in wetlands that were documented at the U.S. Geological Survey Cottonwood Lake Study Area in central North Dakota (Winter 2003; Winter and Rosenberry 1998). Climatic extremes influences hydrologic conditions for years after they occur (LaBaugh et al. 1996); therefore, wetland conditions and plant communities in wetlands have likely changed considerably.

Invasive plant species also have unique influences on wetland plant communities. *Typha x glauca*, *Phalaris arundinacea*, and *Phragmites australis* are some of the most invasive species for many wetland ecosystems across the continent (Shay et al. 1999, Bernthal and Willis 2004). *Poa pratensis* and *Bromus inermis* account for 62% of exotic cover in uplands in the Northern Great Plains and may form monotypic stands (Cully et al. 2003; DeKeyser et al. 2013). These troublesome invasive species were present in wetland zones in Stewart and Kantrud's 1960s study and likely have increased in abundance and become well established in wetland zones. The overall impact and coverage of invasive plant species within wetland zones in the PPR is unknown.

The wetland conditions and the associated unique wetland plant communities documented during Stewart and Kantrud's 1961-1966 study were never published. However, the original data cards were housed at U.S. Geological Survey's Northern Prairie Wildlife Research Center since the 1960s. The existence of these data, and access to the Waterfowl Production Areas (WPAs) where these data were collected provided an opportunity to quantify responses of wetlands to climatic extremes and document the likely progression of invasive plant species into wetland zones. In 2013-14, I revisited a portion of the original wetlands from Stewart and Kantrud's 1961-1966 study to evaluate changes in wetland conditions and plant communities. My specific objectives were to: 1) quantify changes in water depths and specific conductivity within wetlands; 2) quantify changes in wetland size; 3) quantify changes in species composition within wetland zones; 4) quantify changes in frequency and abundance of individual species within wetland zones; and 5) document the current status of invasive species within wetland zones.

Change in wetlands is inevitable, but the amount and direction of change is most valuable to understand wetland dynamics. My study has the potential to reveal the vulnerability or resilience of wetlands through time with continued climatic change, additional impacts of invasive plant species, and anthropogenic land use change across the PPR.

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CHAPTER 2.

THREE RESPONSES OF WETLAND CONDITIONS TO CLIMATIC EXTREMES IN THE PRAIRIE POTHOLE REGION

Abstract

Wetlands in central North Dakota, were revisited after 50 years to assess changes in wetlands that experienced an extreme drought and deluge in the Prairie Pothole Region. I used data collected during 1961-1966 as a reference study to compare wetland conditions after 50 years. In 2013 and 2014, I revisited 80 wetlands across three study areas and measured water depths, specific conductivity, and wetland size. Wetlands at the three study areas responded to the excess water from the deluge in unique ways. Wetlands at Crystal Springs were on average 7 ha larger, 3.6 m deeper, and overall salinity shifted from brackish to moderately brackish in 2013-14 compared to the 1960s. Wetlands at Cottonwood were on average 2 ha larger, 1.25 m deeper, and remained slightly brackish, but averaged on the high end of this salinity bracket range in 2013-14. Wetlands at Mt. Moriah had subtle, almost negligible, changes in depth, size, and salinity from the 1960s study to the 2013-14 study. The prolonged deluge conditions led to complete merging of 9 out of the 12 wetlands at Crystal Springs. At Cottonwood, only a few basins completely merged but overall connectivity of wetlands increased with vegetated, flooded channels. The low topographic relief at Crystal Springs and Cottonwood contribute to the storing of excess water in these wetlands with associated responses to deluge conditions. In contrast, the higher topographic relief and natural outlets into 2 intermittent streams at Mt. Moriah assisted wetlands to be more resilient to the deluge impacts.

Introduction

Wetlands in the Prairie Pothole Region (PPR) have been studied for >100 years (van der Valk 2005). In the 1960s, wetland research began to diversify, with increased efforts in this region, to better understand the complicated dynamics of small, depressional prairie wetlands (Mitsch and Gosselink 2007). Prior to the 1960s, vegetation of wetlands dominated much of the research conducted in the PPR, acknowledging that species composition and distribution was somehow related to water regime (Mitsch and Gosselink 2007; Kantrud et al. 1989). Robert E. Stewart and Harold A. Kantrud conducted one of the first in-depth ecological studies of prairie wetlands. During 1961-1966, they investigated the relationship of wetland plant communities to variations in water permanence and chemistry on three areas in Stutsman County, North Dakota (Stewart and Kantrud 1964). This research led to the development of a regionalized wetland classification system for the PPR (Stewart and Kantrud 1971), focused on vegetation zones for different wetland permanence classes (e.g., temporary, seasonal, and semipermanent), this system is commonly used today. Many scientists have worked to build upon the foundational work of Stewart and Kantrud to obtain the wealth of knowledge about prairie wetlands we have today.

The highly dynamic inter- and intra-annual climate of the PPR causes alternate periods of drought and deluge within wetlands, producing a cyclic pattern of hydrologic conditions and productivity (Euliss et al. 2004; Euliss et al. 2014). Palmer hydrologic drought indices (PHDI) are good indicators of wetland conditions, because this index assesses long-term moisture supply and indicates severity of a drought or deluge (NCDC 2015). A decade prior to and during Stewart and Kantrud's work, relatively short oscillating periods of wet and dry conditions occurred, suggesting a fairly balanced inter-annual climate as indicated by PHDI (Figure 1). The inter-annual climate remained relatively "stable" until two extreme climatic events occurred back to back. The second worst drought of the century occurred from 1988-1992, comparable in magnitude to the Dust Bowl of the 1930-40s (Winter and Rosenberry 1998). In 1993, a drastic, opposite shift to extremely wet conditions that constituted the longest deluge of the century and possibly of the last 500 years (Swanson et al. 2003; Winter and Rosenberry 1998). Research across the PPR has shown these two climatic events influenced wetland conditions (i.e., size, depth, specific conductivity), but effects of the deluge are still apparent and impacting wetlands (Winter 2003, Mushet et al. 2015, and many others).

Stewart and Kantrud's original data on wetland conditions from the three areas were never published but have been housed at the U.S. Geological Survey's Northern Prairie Wildlife Research Center. Access to both Stewart and Kantrud's data, and the wetlands where data collection occurred, provided a unique opportunity to evaluate how wetland conditions changed over 50 years and in response to two climatic extremes for these study areas. In this study, I compared wetland condition metrics (i.e., wetland size, water depth, specific conductivity, and pH) measured in 2013-2014 to those collected by Stewart and Kantrud in the 1960s with the goal of documenting, quantifying, and assessing changes in wetland conditions.

Methods

Study Area and Wetland Selection

The three study areas, Crystal Springs, Cottonwood, and Mt. Moriah, were located in Stutsman County, North Dakota on the eastern edge of the Missouri Coteau (Figure 2). Individual study areas were approximately 260 ha in size, but wetland class and density varied among study areas (Table 1). Most wetlands were on 5 waterfowl production areas (WPAs), acquired by the U.S. Fish and Wildlife Service prior to Stewart and Kantrud's study. Crystal Springs consisted of two WPAs, Crystal Springs and Zimmerman WPAs, plus 10 wetlands located on private land (Figure 3). Cottonwood consisted of 2 neighboring WPAs, Cottonwood Lake and Smith-Bingham WPAs (Figure 4). Mt. Moriah WPA encompassed the entire Mt. Moriah study area (Figure 5). At all WPAs, wetlands were surrounded by intact, grasslands managed by haying, fire, or grazing. At Crystal Springs, access to 10 wetlands located on private land was granted for both Stewart and Kantrud's (referred to as "1960s study") and my data collection (referred to as "2013-14 study"). During the 1960s, aerial images indicated that these wetlands on private land were surrounded by grasslands. During the 2013-14 study, these same wetlands were completely surrounded by managed grasslands, cropland, or a combination of these land covers.

The topography of the three study areas is the characteristic knob and kettle type prevalent across the PPR (Stewart and Kantrud 1964). Topographic relief was highest at Mt. Moriah (elevation range 520-570 m), with local slopes up to 25 % (Sloan 1972), intermediate at Cottonwood (elevation range 545-570 m), and lowest at Crystal Springs (elevation range 530-545 m). Mt. Moriah and Cottonwood are located on stagnant moraine type glacial deposits. Crystal Springs was specifically chosen for the 1960s survey because it was located on a glacial outwash plain and known to have more saline wetlands (Stewart and Kantrud 1964). At Mt. Moriah, the flood water of two-thirds of wetlands flows through natural overflow outlets into two intermittent, east-flowing streams, which was unique compared to Cottonwood and Crystal Springs (Stewart and Kantrud 1964). A few wetlands at higher elevations at Cottonwood partially drain and supply water through overflow outlets to larger wetlands at lower elevations during high water conditions. All other wetlands at Mt. Moriah and Cottonwood and all wetlands at Crystal springs are in closed basins with little to no drainage (Stewart and Kantrud 1964).

Stewart and Kantrud collected annual, repeated data on 137 wetlands, with the highest density of wetlands at Mt. Moriah (n = 94), followed by Cottonwood (n = 25), and Crystal Springs (n = 18). In 2013 and 2014, I collected repeated data on 80 of the original 137 1960s wetlands across the three original study areas. I chose wetlands randomly but in proportion to the four wetland permanence classes (i.e., temporary, seasonal, semipermanent, and permanent) assigned surveyed at each study area during the 1960s study (Table 2). There was one seasonal wetland at Crystal Springs that I combined with semipermanent wetlands in order to be included in all statistical analyses, but I kept it classified as a seasonal for wetland size analyses to demonstrate the great change of this wetland.

Size

I used ArcMap 10.1 to digitize wetlands and calculated wetland size in hectares from aerial images, with the wet meadow vegetation zone as the outermost boundary. I used 1964 aerial images provided by Chase Lake Wetland Management District to determine wetland size for the 1960s study. I used sketches on original data cards as a reference while I digitized wetlands, especially for small basins that were difficult to distinguish on 1964 images. I used 2012 aerial images downloaded from the U.S. Department of Agricultural (USDA) Geospatial Data Gateway to determine wetland size for the 2013-14 study. I used paired t-tests to compare wetland size by wetland class at each study area between the two time periods. I calculated average percent change for each wetland class at each study area.

Water Depths

Stewart and Kantrud measured wetland depths erratically (1-15 times) in late March through November each year during 1961-1966. For shallow wetlands, they measured depths in inches with yard sticks in the deepest portions, whereas in deeper wetlands depths were read from shore using a spotting scope to read permanently marked poles in wetlands (both depth measurements later converted to cm). In 2013 and 2014, I measured wetland depths at the deepest part of wetlands three times each growing season (first 15 days of May, July, and September) to encompass seasonal variability. I located and recorded the deepest part with GPS waypoints to maintain consistency between sampling events. I used meter sticks to measure depths of shallower wetlands (i.e., <1 m). For deeper wetlands, I measured depths from a kayak using a weighted metric measuring tape.

I condensed the 1960s dataset to include only depth measurements that had comparable timing to the 2013-14 data collection (i.e., early May, July, and September). For each wetland, I used all depth measurements to calculate an individual average depth for every wetland in the 1960s study and likewise for depths collected in the 2013-14 study. I pooled all average wetland depths at each study area and used Analysis of Variance (ANOVA) to compare average wetland depths by study area and wetland class between the 1960s and 2013-14. I calculated annual depth changes from early season (depths in May) to late season (depths in September) for each wetland to understand seasonal and annual variability of water depths within wetlands. I pooled the absolute value of change of water depths per wetland class and used these values to calculate coefficients of variation during the 1960s study and 2013-14 study. I removed some wetlands from coefficient of variation analysis due to missing May 2013 depths or depths not measured at the deepest point of wetland, which resulted in the complete removal of temporary wetlands at Mt. Moriah.

No wetland conditions data were collected during 1988-1992 on the three study areas, but I used aerial images (provided by Chase Lake Wetland Management District) to approximate if surface water was present in study wetlands throughout the drought.

Specific Conductivity and pH

Stewart and Kantrud used a solubridge meter to measure specific conductivity (microsiemens/cm (µS/cm)) inconsistently during the later years (1963-1966) of their study. During August 1964, pH was measured in wet basins only. In 2013-2014, I measured specific conductivity (µS/cm) and pH at the time and location of depth measurements. I used a HANNA Preamplified pH and EC Probe when measurements were below 3999 µS/cm and for the few wetlands that exceeded 3999 µS/cm, I used Oakton Waterproof Multiparameter PCSTestr 35 to measure specific conductivity.

Some wetlands had incomplete specific conductivity data from the 1960s, which resulted in the removal of seasonal and temporary wetlands at Mt. Moriah from analyses. With the reduced data set, I calculated a single average of specific conductivity for each wetland at each study area for each dataset. I used paired t-tests to compare average specific conductivity of permanent and semipermanent wetlands at each study area between the 1960s and 2013-14 studies. I only compared ranges of pH between the two time periods because pH values can vary greatly within a wetland and annually (Swanson et al. 2003; Euliss et al. 2014).

Results

Size

During both studies, wetlands at Crystal Springs were, on average, larger than those at Cottonwood, and both were much larger than wetlands at Mt. Moriah (Table 3). Wetlands at Crystal Springs and Cottonwood on average were larger in 2013-14 compared to the 1960s whereas wetlands at Mt. Moriah changed little in size. The minimum and maximum size increased for all classes at Crystal Springs and Cottonwood between the two time periods. At Mt. Moriah, the minimum values increased for all except seasonal wetlands and maximum values increased for seasonal and semipermanent, but decreased for permanent and temporary wetlands between the two time periods.

Permanent wetlands at Crystal Springs were 102% larger, on average, in 2013-14 compared to the 1960s (Table 3). Semipermanent wetlands increased by 80% on average between the two surveys, but increases were not statistically significant. The one seasonal wetland at Crystal Springs increased by almost 1400% from 0.62 ha in 1960s to 9.22 ha in 2013-14. At Cottonwood, permanent wetlands increased in size on average by 50% and semipermanent wetlands increased in size on average by 104% compared to the

1960s. At Mt. Moriah, all wetland classes increased in size, but semipermanent wetlands increased the most by 51% on average. Permanent, seasonal, and temporary wetlands at Mt. Moriah increased on average by 19%, 9%, and 27% respectively; no increases were statistically significant.

The increased size of wetlands resulted in several completely merged wetlands at Crystal Springs and Cottonwood (Figure 3 and Figure 4). These merged wetlands lost a large portion of their wetland vegetation zones, with individual wetlands harder to identify in 2013-14. At Crystal Springs, 9 out of 10 wetlands on private land completely merged to form a lake-like complex (138 ha; Figure 3b). This lake-like complex was connected to one wetland not surveyed during the 2013-14 study and to Reule Lake (<1 km east) through large channels. The one wetland at Zimmerman WPA merged with a neighboring wetland north off the WPA (Figure 3a). At Cottonwood, two wetlands were completely merged with neighboring wetlands off the WPAs (Figure 4, wetlands 1 and 19a). Two surveyed wetlands completely merged with three wetlands not sampled in the contemporary survey to form a lake-like complex on the Cottonwood Lake WPA (77 ha; Figure 4, wetlands 4a and 3). At Smith-Bingham WPA, only two wetlands completely merged (Figure 4, 20a and 20b) with no wetland vegetation separating the two basins in 2013-14. Additionally, the increased size and excess water caused channels to form between some of the wetlands at Smith Bingham WPA. These channels contained water throughout most of growing season in 2013-14 and increased connectivity of wetlands but intact vegetation zones remained around each respective wetland. No wetlands merged at Mt. Moriah (Figure 5).

Water Depths

Average wetland depths at Crystal Springs and Cottonwood study areas were significantly deeper (Table 4) in the 2013-14 study compared to the 1960s study whereas average wetland depths at Mt. Moriah remained relatively similar between time periods. The average maximum and minimum depths increased at all three study areas except for maximum depths at Mt. Moriah, which decreased. I report statistical results at the wetland class level (Table 5), but present individual depth measurements of wetlands (Figures 6-9) to show seasonal and annual variability within wetland classes for both studies.

At Crystal Springs, permanent wetlands were, on average, 4.5 m deeper and semipermanent wetlands were, on average, 2.3 m deeper compared to the 1960s (Table 4; Figure 6). May 2013 water depth at Crystal Springs wetland 4a was likely not taken at the deepest point so seasonal change in 2013 should be interpreted with caution for this wetland. Coefficients of variation indicated the change of depths across seasons was similar for permanent wetlands between time periods at Crystal Springs, but semipermanent wetlands were less variable in 2013-14 compared to the 1960s (Table 5).

There was some overlap of seasonal wetland depths at Cottonwood between time periods, but both wetland classes were significantly deeper in 2013-14 (Table 4; Figure 7). May 2013 water depths at Cottonwood wetlands 1 and 4a were likely not taken at the deepest point so seasonal change in 2013 should be interpreted with caution for these wetlands. Permanent wetlands were, on average, 1.8 m deeper and semipermanent wetlands were on average 0.7 m deeper compared to the 1960s. At Cottonwood, change of depths for permanent wetlands was less variable in 2013-14, but the change of depths for semipermanent wetlands was more variable during 2013-14 (Table 5).

Average wetland depth changes were more subtle at Mt. Moriah with most depth measurements overlapping between time periods (Table 4; Figure 8 and 9). All wetland classes differed by only <20 cm between the 1960s and 2013-14. Seasonal wetlands at Mt. Moriah were significantly shallower on average in the 2013-14 study but the average depth change was relatively small (5 cm). At Mt. Moriah, seasonal changes in depths of permanent wetlands were more variable in 2013-14, but seasonal changes in depths for semipermanent and seasonal wetlands were more variable during the 1960s (Table 5).

Specific Conductivity and pH

Stewart and Kantrud (1971) used specific conductivity as a surrogate for salinity. They recognized 5 salinity subclasses along a gradient from fresh to saline (Table 6). The Crystal Springs study area in general became less saline in 2013-14 compared to the 1960s ($P = 0.040$). Wetlands at Cottonwood were more saline in 2013-14 compared to the 1960s ($P < 0.001$) but most wetlands remained slightly brackish. Average specific conductivity of wetlands at Mt. Moriah remained slightly brackish ($P = 0.005$) between the two time periods.

Permanent wetlands at Crystal Springs experienced the greatest change of average specific conductivity across all wetland classes and study areas since the 1960s. Crystal Springs had only brackish and subsaline permanent wetlands in the 1960s, but only 1 wetland in 2013-14 came close to the lowest average specific conductivity measurement of wetlands in the 1960s (Figure 10). Average specific conductivity of permanent wetlands went from subsaline (17,345 μS/cm) in the 1960s to moderately brackish (3606 μS/cm) in 2013-14 ($P = 0.012$). Semipermanent wetlands were slightly more saline in 2013-14 compared to the 1960s with all wetlands being moderately brackish ($P = 0.053$).

Permanent wetlands at Cottonwood remained slightly brackish in 2013-14, despite the increased average specific conductivity from 979 µS/cm in 1960s to 1448 µS/cm in 2013-14 (P = 0.008). At Cottonwood, semipermanent wetlands were more saline in 2013-14 compared to the 1960s (P = 0.002) with the average specific conductivity shifting from fresh (438 µS/cm) to slightly brackish (1302 µS/cm). Permanent and semipermanent wetlands at Mt. Moriah remained slightly brackish on average between the two time periods (P = 0.145, P = 0.022 respectively).

Overall pH values remained circumneutral (5.5-7.4) or alkaline (>7.4; Cowardin et al. 1979). During the 1960s study, pH of wetlands at Crystal Springs ranged from 8.6 to 9.2, compared to the 2013-14 range of 7.3 to 9.0. The pH of wetlands at Cottonwood ranged from 6.3 to 8.3 during the 1960s study, compared to the 2013-14 range of 6.4 to 10.1. The pH of wetlands at Mt. Moriah ranged from 6.2 to 9.6 during the 1960s study compared to the 2013-14 range of 5.9 to 8.6.

Discussion

Three study areas had wetlands with unique responses to the climatic extremes in central North Dakota after 50 years. Wetlands at Crystal Springs were deeper, larger, and fresher in 2013-14 compared to the 1960s. Wetlands at Cottonwood were deeper, slightly larger, and more saline in 2013-14. Wetlands at Mt. Moriah had subtle almost negligible changes in depth, size, and salinity since the 1960s. Wetlands have complex interactions with inter-annual climate, landscape position of a wetland, and groundwater that determine wetland depth and hydroperiod and influence specific conductivity and wetland size (Euliss et al. 2004; Euliss et al. 2014), as observed in my study wetlands.

Inter-annual climate differences between the 1960s and 2013-14 were interpreted using PHDI and annual precipitation rates for North Dakota Climate Division 5 (Figure 1; NCDC 2015, Winter and Rosenberry 1998). The annual average precipitation for this area since 1895 was 45.9 cm (Mushet et al. 2015). In the two decades prior to the 1960s study, the Dust Bowl era drought ended and short wet/dry periods followed with an average PHDI = 0.86 for 1941-1966. This was not true for the two decades prior to the 2013-14 study. A severe drought occurred from 1988-1992, with the average PHDI = -3.00 and average annual precipitation of 38.7 cm. To my best approximation, 73-75 of the 80 study wetlands were dry (no surface water) by the end of 1992, with wetlands retaining water only at Crystal Springs and Cottonwood. Hydrologic conditions shifted after 50 cm of rain fell in May, June, and July of 1993, with 24 cm in July alone, the highest monthly precipitation total for ND Climate Division 5 since data collection began in 1895 (NCDC 2015). The above-normal precipitation rates in 1993 started the first flooding event, with average annual precipitation of 53.8 cm for January 1993 – December 2001 and an average PHDI = 4.02 (i.e., a severe wet spell) for this time period. From 2009-2011, a shorter but more intense flooding event occurred with an average PHDI = 5.34 (i.e., an extreme wet spell) and average annual precipitation of 54.7 cm for January 2009 – December 2011. This region has been experiencing the longest deluge in recorded history (i.e., since 1895) with the average PHDI = 2.76 (i.e., a moderate wet spell) and average annual precipitation of 50.5 cm from 1993-2014. The 1960s study examined wetlands during near normal hydrologic conditions (NCDC 2015). However, the 2013-14 results reflect wetland responses to a severe drought immediately followed by moderate deluge that started in 1993, with the deluge having the most lasting influence.

Low topographic relief is characteristic of the PPR (Euliss et al. 2014), as seen at the Crystal Springs and Cottonwood study areas that had <30 m separation between the highest and lowest point within each study area. Most of the wetlands at these two study areas are at the lower boundary of the elevation range. Mt. Moriah had a 50 m elevation range and elevation declines in a west-to-east gradient with wetlands distributed throughout the elevation range. The topographic differences between these study areas and the way wetlands were positioned in the landscape led to three mechanisms for coping with excess water since 1993. These responses are coarsely modified versions of the fill-spill concept as described by Shaw et al. (2012). In one response, wetlands filled until full and then spilled into adjacent wetlands, which created either lake-like complexes at Crystal Springs study area and Cottonwood WPA or small connection channels, like at Smith-Bingham WPA. In the second response, wetlands filled and continued to become deeper, but with little to no evidence of ever spilling, as exemplified by a few wetlands at Cottonwood. For both of these pathways, wetlands stored excess water creating merged, deeper wetlands in 2013-14. The third response was unique to Mt. Moriah; wetlands filled and then spilled into existing intermittent streams that flow into a tributary of the Pipestem River. Thin, stream-like channels are conspicuous in 2012 aerial imagery between most wetlands at Mt. Moriah. In this instance, excess water was removed from wetlands through these natural channels into streams and off the study area when water levels were above spill point, but below the spill point, evapotranspiration would have lowered water levels. These three responses occurred prior to the data collection but the climatic extremes led to the conditions of the 2013-14 study (LaBaugh et al. 1996). Depth measurements from 2013-14 might not be representative of the entire wetland, especially for merged wetlands, and might be conservative in certain instances. For larger, deeper wetlands (i.e., >1 m deep), our GPS units did not have the necessary accuracy to return to the exact point each time by kayak, but these depth measurements still represent great change in wetland depths.

The PHDI and annual precipitation rates were comparable during the years of data collection between the 1960s and 2013-14. For 1961-1966, average PHDI was 0.78 with average annual precipitation of 47 cm (Figure 11). For 2013-2014, average PHDI was 1.67 and average annual precipitation was 48 cm. The seasonal variation of wetland depths captured the immediate response to annual precipitation events during the two studies (Figures 6-9). Wetlands were driest in 1961 and 1963, due to low precipitation rates, and were deepest in 1966 due to uninterrupted wet conditions. In 1962 and 1964, most wetland depths increased after summer precipitation. Wetlands responded similarly to precipitation events in the 2013-14 study, and responses were especially pronounced for semipermanent wetlands at Mt. Moriah and Cottonwood (i.e., wetlands ~1 m deep). Although the duration of 1960s and 2013-14 studies differed, the PHDI indicated that weather patterns (i.e., precipitation events and lack of precipitation events) would induce similar biological responses in wetlands. However, the increased wetland depths at Crystal Springs and Cottonwood indicated that wetlands could not experience the same biological responses in response to seasonal evapotranspiration.

Wetlands at low landscape positions tend to be discharge wetlands (i.e., receive groundwater discharge) with higher salinities (Stewart and Kantrud 1972; Euliss et al.

2004, 2014). Wetland salinities become diluted with increased water depths and concentrated when water evaporates (Stewart and Kantrud 1972; LaBaugh et al. 1996). These dilutions occur more frequently at wetlands on glacial outwash plains, such as the study wetlands at Crystal Springs (Stewart and Kantrud 1972). Mushet et al. (2015) confirmed the lower wetland salinities since 1993 across Kidder and Stutsman counties, North Dakota, but salinity remained highest for wetlands on glacial outwash plains as indicated at Crystal Springs in 2013-14. At Crystal Springs, salts could have been removed from wetlands via deflation, a process where exposed salts are removed by wind, during drought years and in combination with dilution led to the overall reduced specific conductivity of wetlands at this study area (LaBaugh et al. 1996). In Mushet et al. (2015), increased specific conductivity of wetlands, despite increased water depths, was attributed to merging with more saline neighboring wetlands as seen at semipermanent wetlands at Crystal Springs in 2013-14. The slight but significant increase of specific conductivity for wetlands at Cottonwood was less obvious, but may be due to groundwater effects or an external source of solutes (e.g., upland runoff; Mushet et al. 2015; Leibowitz and Vining 2003). Wetlands at higher elevations tend to be recharge wetlands (i.e., wetlands that recharge groundwater) that are relatively fresh (Stewart and Kantrud 1972, Euliss et al. 2014). The minimal change of specific conductivity at Mt. Moriah can be attributed to several wetlands being either recharge or flow-through wetlands with groundwater interactions allowing for removal of excess water and solutes as indicated by wetland salinities and the topography of this study area.

From the long-term monitoring at the Cottonwood Lake Area and other research following the climatic extremes, we know that many wetlands have gotten deeper and that a substantial number of wetlands have merged across the PPR (Swanson et al. 2003, Winter and Rosenberry 1998, Mushet et al. 2015), as observed in the wetlands at Crystal Springs and Cottonwood. Consolidation drainage intensifies deluge effects in catchments with high rates of wetland drainage and increases the percent of merged wetlands with more stable depths (Anteau 2012, McCauley et al. 2015, Wiltermuth 2014). Further research is needed to determine if wetlands at Crystal Springs and Cottonwood are being impacted by consolidation drainage. The existence of natural wetland drainage connections to streams as seen at Mt. Moriah is rare in the PPR (Euliss et al. 2014). Although it seems intuitive that wetlands connected to streams would be more resilient to high precipitation events, I am unaware of any other study that has documented this.

Wetland productivity is driven by alternating periods of drought and deluge and biotic communities respond to changes of wetland conditions during these periods (Euliss et al. 2004). Plant community and invertebrate community shifts in response to drought and deluge impact the food and habitat availability for wildlife, in particular waterbirds (Anteau 2012, Winter 2003, Mushet et al. 2015, Euliss et al. 2004). Due to the prolonged inundation of wetlands at Crystal Springs and Cottonwood, wetlands are likely less productive with reduced nutrient availability (Euliss et al. 2004). Without drawdowns, invertebrates cannot concentrate near the surface and shoreline mudflats are not exposed, making access to food more difficult for waterbirds (Anteau 2012, McCauley et al. 2015). Additionally, I observed fish in some wetlands at Crystal Springs and Cottonwood, indicating that these wetlands have had more stable water levels, not completely frozen during winter months, and the connectivity has provided pathways for fish to become established (Anteau 2012, McCauley 2015, Mushet et al. 2015). Plant and invertebrate communities were likely affected at Mt. Moriah during the drought and deluge, but recovery times would have been much shorter with the less intense effects of the deluge there. Although some wildlife benefit from more water on the landscape and less saline wetlands (Mushet et al. 2015), the more homogenous landscape found in recent years has likely reduced habitat quality for certain species groups compared to the heterogeneous landscape found prior to the deluge (McCauley et al. 2015, Mushet et al. 2015).

This study provided a unique comparison of three study areas within 50 km of each other, but with different topographic and edaphic conditions. The proximity of the study areas suggested similar, although not identical, climatic conditions. Despite this, wetlands at each study area did not respond uniformly to the deluge conditions since 1993. Small sample size of wetlands and wetland classes within study areas was a limitation for comparing wetland conditions between the 1960s and 2013-14. Consistent, long-term monitoring provides the greatest level of understanding for changes in wetland conditions, but substantial information has been gleaned from the comparison of these two snapshots in time. The permanence of the changes reported here is unknown, but to return the 2013-14 wetland conditions to conditions similar to those documented during the 1960s study at Crystal Springs and Cottonwood would require another severe and likely a longer and more extreme drought than the one from 1988-1992, or a substantial amount of management (e.g., anthropogenic manipulation of water levels, restoration) to remove the increased volume of water in these wetlands (McCauley et al. 2015).

Acknowledgements

This project was funded by U.S. Geological Survey Northern Prairie Wildlife Research Center in Jamestown, North Dakota. Housing and additional logistic support was provided by Chase Lake Wetland Management District in Woodworth, North Dakota. Thank you to Dr. Jane Austin and Dr. Joshua Stafford for comments and edits with this chapter. This project could not have been done without the help of technicians, Beth Harmsen and Alyse Homola.

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Table 1. Study area description for comparison study with waterfowl production areas (WPA), approximate size, legal description, and number of wetlands sampled for 1961-1966 study and 2013-2014 study in Stutsman County, North Dakota.

Study Area	**Approx. Size (ha)**	**Legal Description**	**Wetlands sampled in 1960s**	**Wetlands sampled in 2013-14**
Mt. Moriah			94	51
Mt. Moriah WPA	260	T. 144N., R. 67 W., Sect. 21		
Cottonwood			25	17
Cottonwood Lake WPA	160	T. 142 N., R. 66 W., parts of Sect. 31-33		
Smith-Bingham WPA	100	T. 141 N., R. 66 W., parts of Sect. 3, 4		
Crystal Springs			18	12
Privately owned,	210	T. 139 N., R. 69 W., parts of Sect. 4, 5;		
Crystal Springs WPA		T 140 N. R. 69W., parts of Sect. 32, 33		
Zimmerman WPA	50	T. 140 N., R 69 W., NW qtr of Sect. 22		
Total Wetlands			*137*	*80*

Table 2. Number of wetlands, by permanence class, (Stewart and Kantrud 1971) at each study area used for comparison of wetland conditions from 1960s study and the 2013-14 study in Stutsman County, North Dakota.

	Study Area		
	Mt. Moriah	**Cottonwood**	**Crystal Springs**
Wetland Class	**No. of Wetlands**		
Permanent	7	8	6
Semipermanent	25	9	5
Seasonal	13		1
Temporary	6		
Total	*51*	*17*	*12*

Table 3. Descriptive statistics for wetland size and percent change of wetlands from 1964 to 2012 in Stutsman County, North Dakota. Results of paired t-tests are shown for comparisons between two years; asterisks indicating significance ($P < 0.05$).

		1964 Wetland Size (ha)				**2012 Wetland Size (ha)**						**Percent Change in Size**			
Wetland Class	**(N)**	Mean	SE	MIN	MAX	Mean	SE	MIN	MAX	*P* - value		Mean	SE	MIN	MAX
Crystal Springs															
Permanent	(6)	13.67	6.75	6.90	25.09	25.44	3.85	11.00	37.26	0.001	*	102	20	49	170
Semipermanent	(5)	2.38	2.51	0.62	6.82	4.18	1.84	0.95	11.21	0.088		80	31	26	201
Seasonal	(1)	0.62				9.22				--		1394			
Total	*(12)*	*7.88*	*7.55*	*0.62*	*27.76*	*15.23*	*3.68*	*0.95*	*37.26*	*0.094*					
Cottonwood															
Permanent	(8)	7.53	5.82	0.23	16.74	11.18	3.07	0.31	26.09	0.028	*	50	15	3	140
Semipermanent	(9)	0.61	0.47	0.06	1.25	1.03	0.29	0.18	2.50	0.037	*	104	52	2	500
Total	*(17)*	*3.86*	*5.25*	*0.06*	*16.74*	*5.81*	*1.89*	*0.18*	*26.09*	*0.400*					
Mt. Moriah															
Permanent	(7)	0.82	0.57	0.17	1.81	0.89	0.19	0.23	1.81	0.270		19	5	-16	53
Semipermanent	(25)	0.22	0.22	0.04	0.74	0.35	0.09	0.05	1.97	0.040	*	51	14	-18	279
Seasonal	(13)	0.06	0.06	0.01	0.22	0.06	0.02	0.01	0.25	0.138		9	10	-44	77
Temporary	(6)	0.05	0.07	0.02	0.19	0.06	0.02	0.02	0.16	0.899		27	14	-18	95
Total	*(51)*	*0.24*	*0.35*	*0.01*	*1.81*	*0.31*	*0.06*	*0.01*	*1.97*	*0.343*					

Table 4. Descriptive statistics for comparison of wetland depths in 1961-1966 (1960s) and 2013-2014 in Stutsman County, North Dakota. Results of ANOVAs are shown; asterisks indicating significance ($P < 0.05$).

		1960s Mean Depths (cm)				2013-14 Depths (cm)					
Wetland Class	**(N)**	Mean	SE	MIN	MAX	Mean	SE	MIN	MAX	*P* - value	
Crystal Springs											
Permanent	(6)	23.4	4.0	0	89	474.3	41.0	140	655	< 0.001	*
Semipermanent	(5)	13.0	2.2	0	92	247.6	63.0	96	449	0.002	*
Seasonal	(1)	17.0		0	49	472.0		425	530		
Total	*(12)*	*19.1*	*2.7*	*0*	*92*	*379.8*	*46.0*	*96*	*655*	*< 0.001*	*
Cottonwood											
Permanent	(8)	70.8	9.2	0	194	254.4	44.9	85	457	0.005	*
Semipermanent	(9)	30.0	4.4	0	127	103.4	18.3	0	205	0.007	*
Total	*(17)*	*49.2*	*7.0*	*0*	*194*	*174.5*	*29.3*	*0*	*457*	*0.002*	*
Mt. Moriah											
Permanent	(7)	58.8	7.0	0	112	77.0	10.2	7	157	0.168	
Semipermanent	(25)	31.1	2.4	0	125	34.4	5.8	0	121	0.636	
Seasonal	(13)	9.8	1.6	0	67	4.1	0.9	0	28	0.005	*
Temporary	(6)	1.0	0.4	0	64	7.8	7.4	0	90	0.379	
Total	*(51)*	*25.9*	*2.9*	*0*	*125*	*29.4*	*4.6*	*0*	*157*	*0.544*	

Table 5. Mean annual change of wetland depths and coefficients of variation for wetlands in three study areas within Stutsman County, North Dakota in 1961-1966 (1960s) and 2013-2014.

	Mean Annual Change (cm)		**Coefficient of variation**	
Wetland Class	**1960s**	**2013-14**	**1960s**	**2013-14**
Crystal Springs				
PERM	19	34	74.6	74.1
SEMI	17	44	108.4	69.6
Cottonwood				
PERM	30	41	82.7	60.8
SEMI	24	33	95.4	109.5
Mt. Moriah				
PERM	27	18	51.7	102.3
SEMI	15	11	112.8	99.1
SEAS	26	31	89.2	57.1

Table 6. Salinity subclasses and normal ranges for permanent (PERM) and semipermanent (SEMI) wetlands in the 1961-1966 (1960s) study and 2013-2014 (2013-14) study (adapted from Stewart and Kantrud 1971).

		Crystal Springs				**Cottonwood**				**Mt. Moriah**			
		1960s		2013-14		1960s		2013-14		1960s		2013-14	
Salinity Subclasses	**Normal Range (µS/cm)**	PERM	SEMI	PERM	SEMI	PERM	SEMI	PERM	SEMI	PERM	SEMI	PERM	SEMI
Fresh	<40 - 500					2	1	6				15	12
Slightly brackish	500 - 2000		1	3		5	5	3	7	7	5	7	9
Moderately brackish	2000 - 5000		4	1	4	1	2		2		2	2	3
Brackish	5000 - 15000	3	1										
Subsaline	15000 - 45000	3											

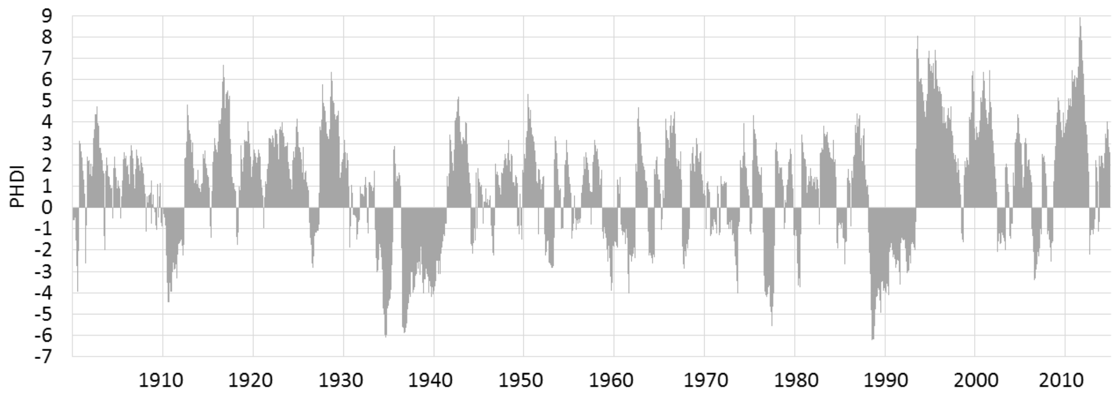

Figure 1. Palmer Hydrologic Drought Index (PHDI) for Climate Division 5of North Dakota from January 1901 – December 2014. Negative integers represent periods of drought and positive integers represent periods of deluge. Date from the National Climate Data Center (http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp#).

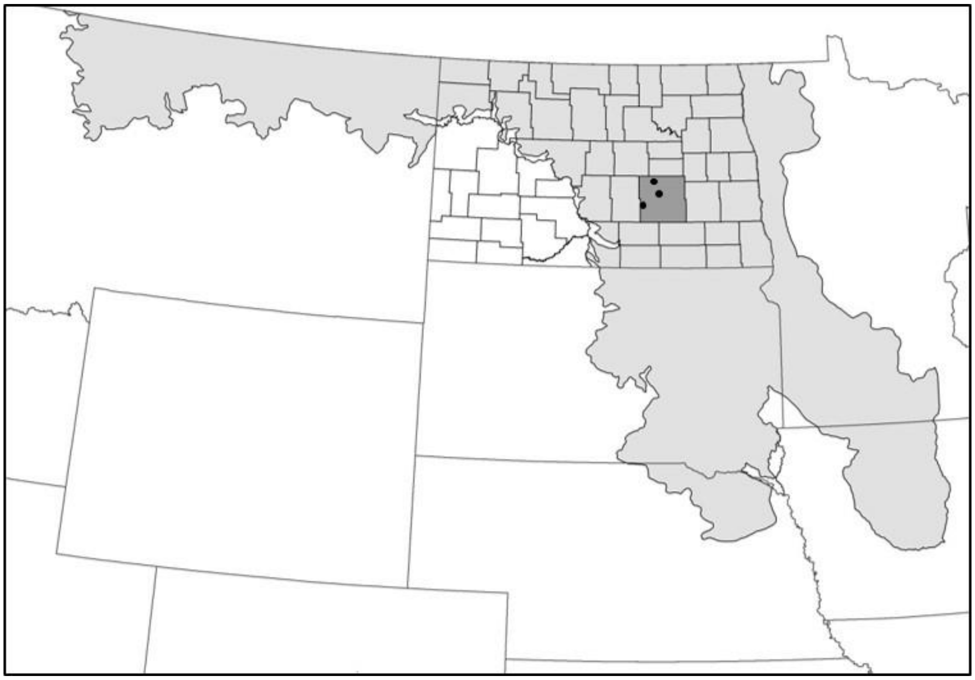

Figure 2. Study area map. Light gray area is the United States portion of the Prairie Pothole Region and dark gray area is Stutsman County, North Dakota. Individual study areas indicated by black dots.

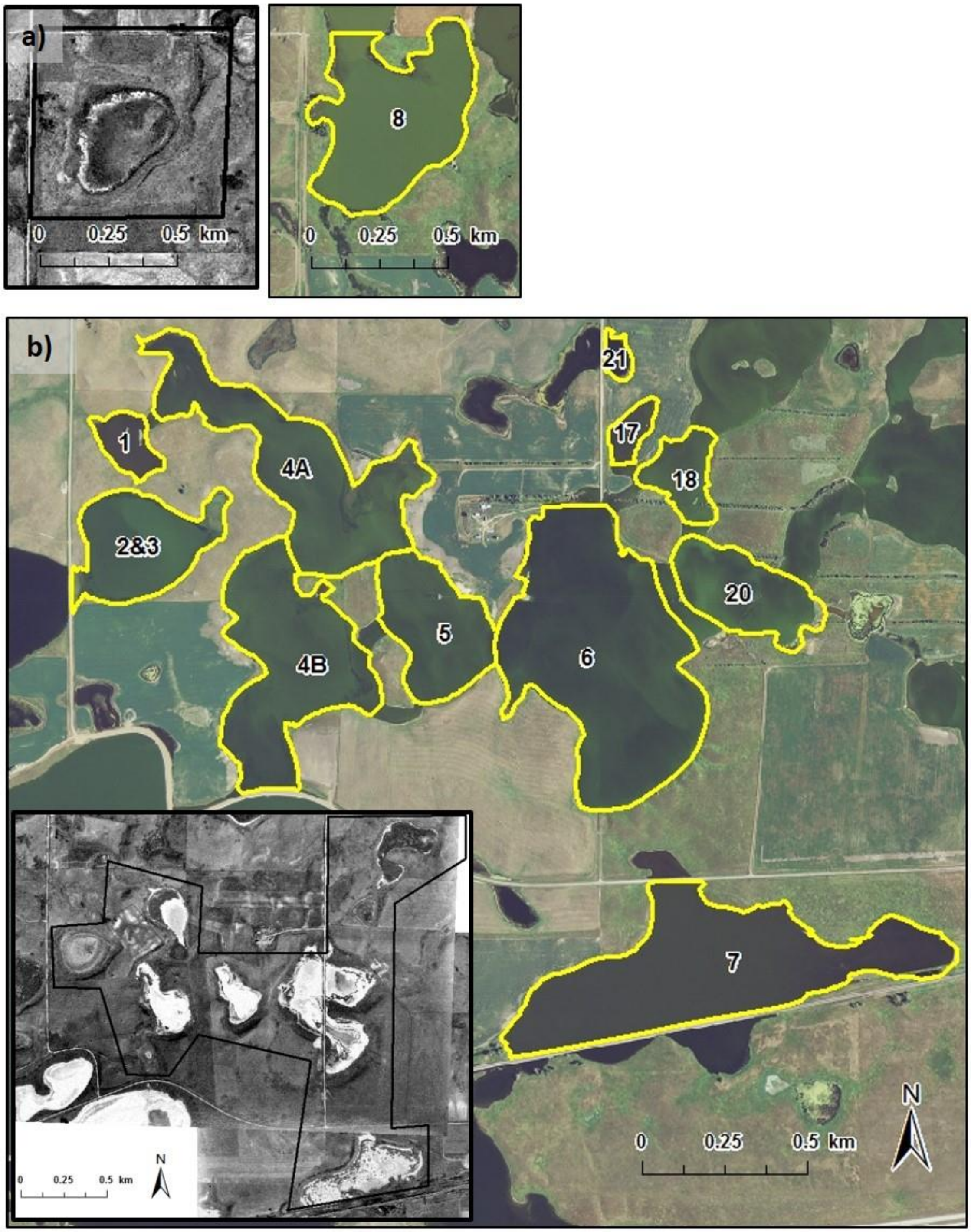

Figure 3. Map of wetlands surveyed (outlined in yellow) in 2013-14 (base image is from 2012, source: USDA Geospatial Data Gateway) at Crystal Springs study area and smaller 1964 image (source: Chase Lake WMD) of same wetlands. Zimmerman WPA (part a) is approximately 5 km northeast of the privately owned wetlands (part b; wetlands 1, 2&3, 4A, 4B, 5, 6, 7, 20, 18, 17, and 21) and Crystal Springs WPA (wetland 7).

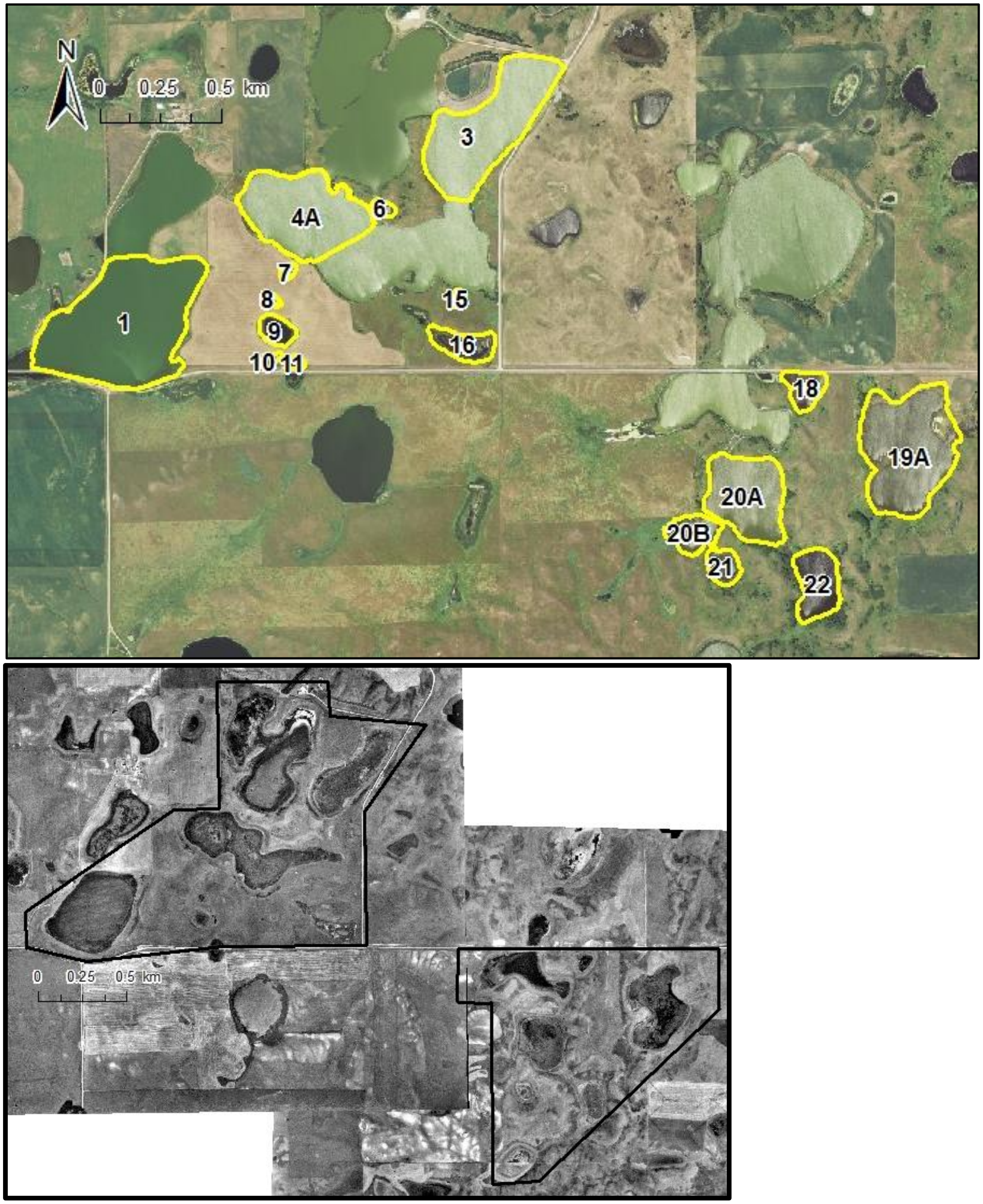

Figure 4. Map of wetlands surveyed (outlined in yellow) in 2013-14 (base image is from 2012, source: USDA Geospatial Data Gateway) at Cottonwood study area with smaller 1964 image (source: Chase Lake WMD). Cottonwood Lake WPA is on the left and Smith-Bingham WPA is on the right in both images.

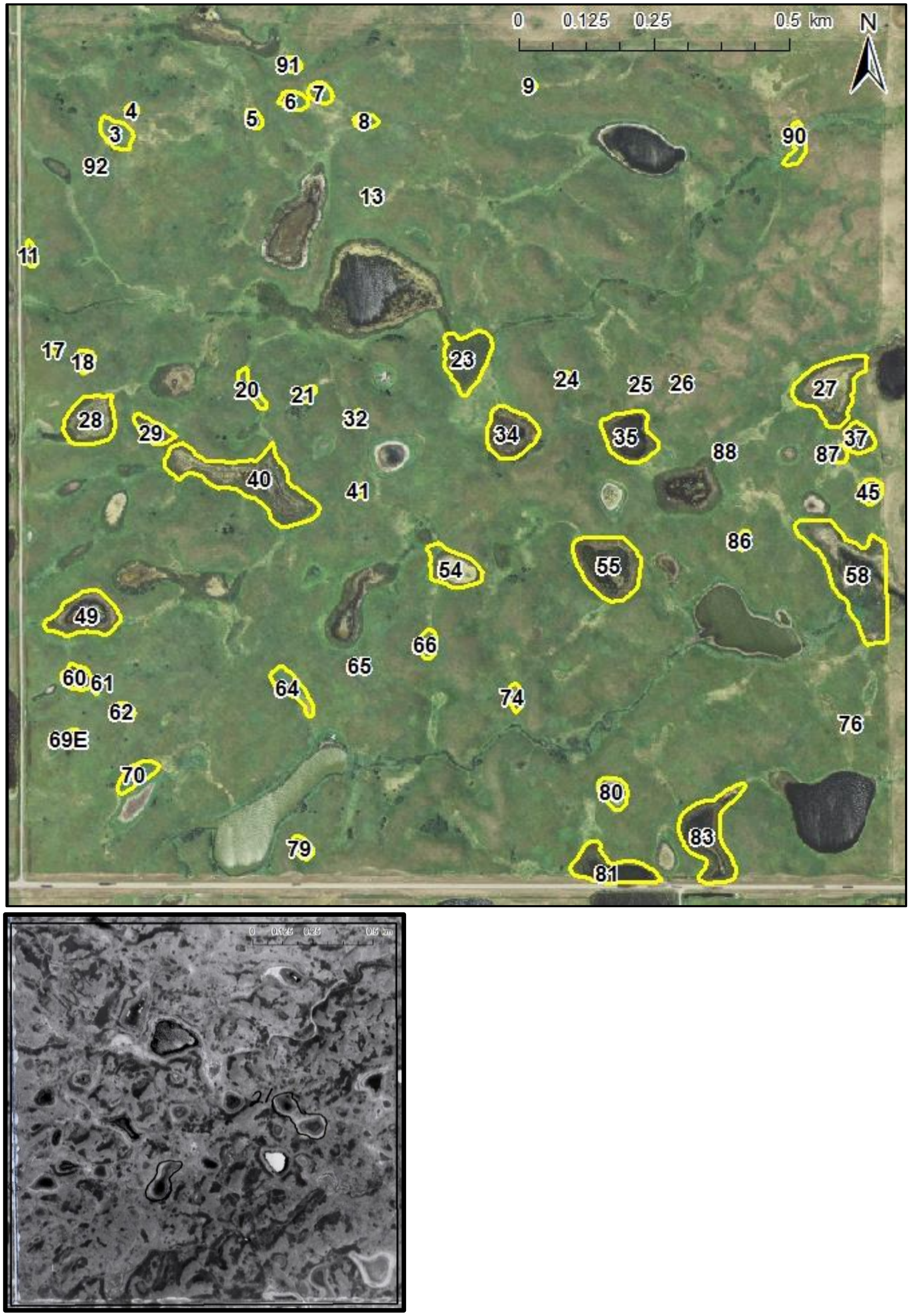

Figure 5. Map of wetlands surveyed (outlined in yellow) in 2013-14 (base image is from 2012, source: USDA Geospatial Data Gateway) at Mt. Moriah study area with smaller 1964 image (source: Chase Lake WMD).

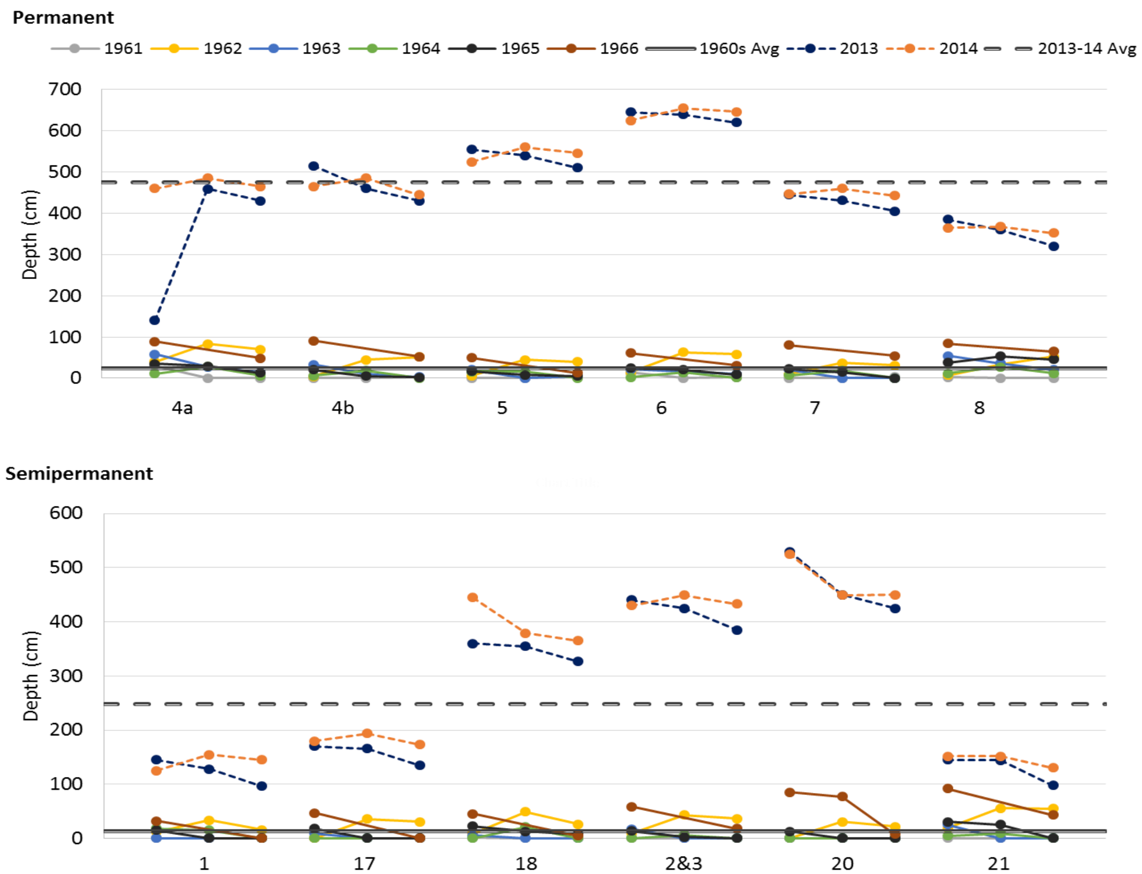

Figure 6. Wetland depths for individual permanent and semipermanent wetlands at Crystal Springs. Solid lines are depths from the 1961-1966 (1960s) study and dashed lines are depths from 2013-2014 study. For each wetland, the first dot is the early May depth, middle dot is the early July depth, and last dot is the early September depths. Horizontal lines represent average wetland depths.

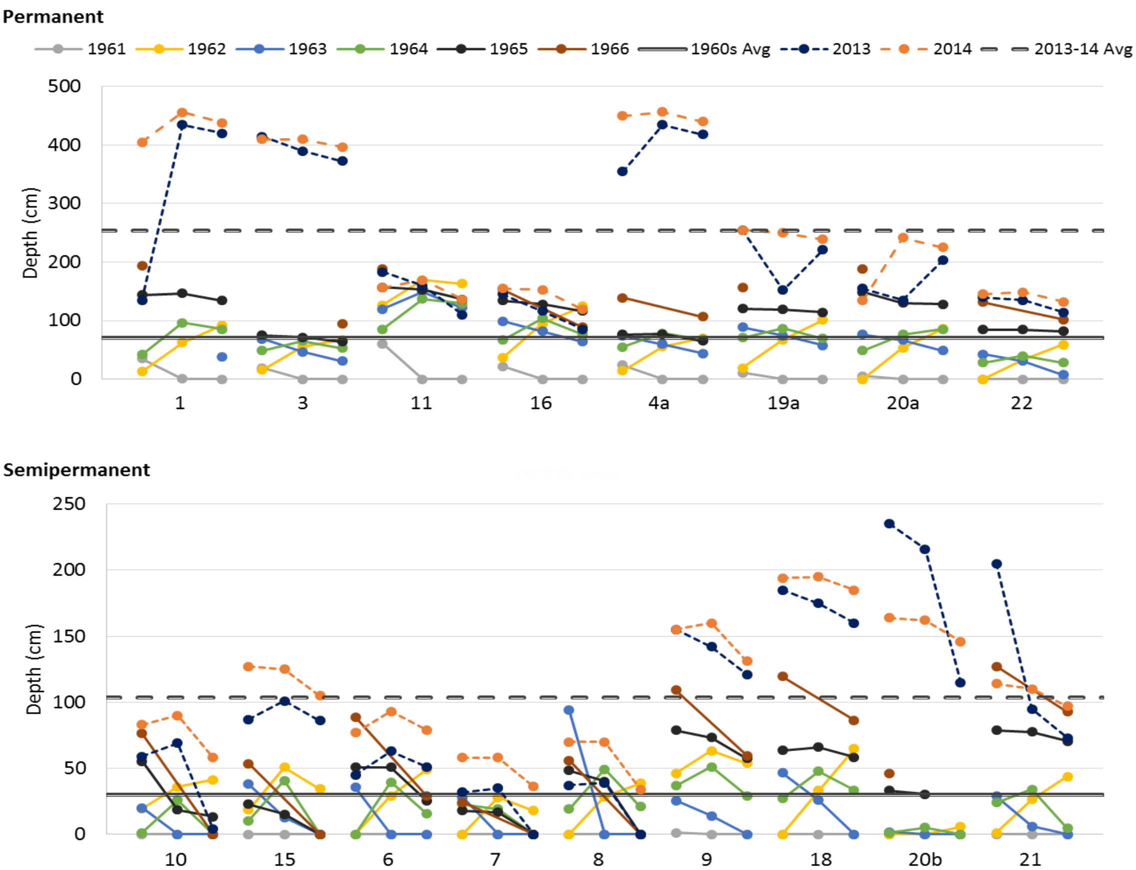

Figure 7. Water depths for permanent and semipermanent wetlands at Cottonwood. Solid lines are depths from 1961-1966 (1960s) study and dashed lines are depths from 2013-2014 study. For each wetland, the first dot is the early May depth, middle dot is the early July depth, and last dot is the early September depths. Horizontal lines represent average wetland depths.

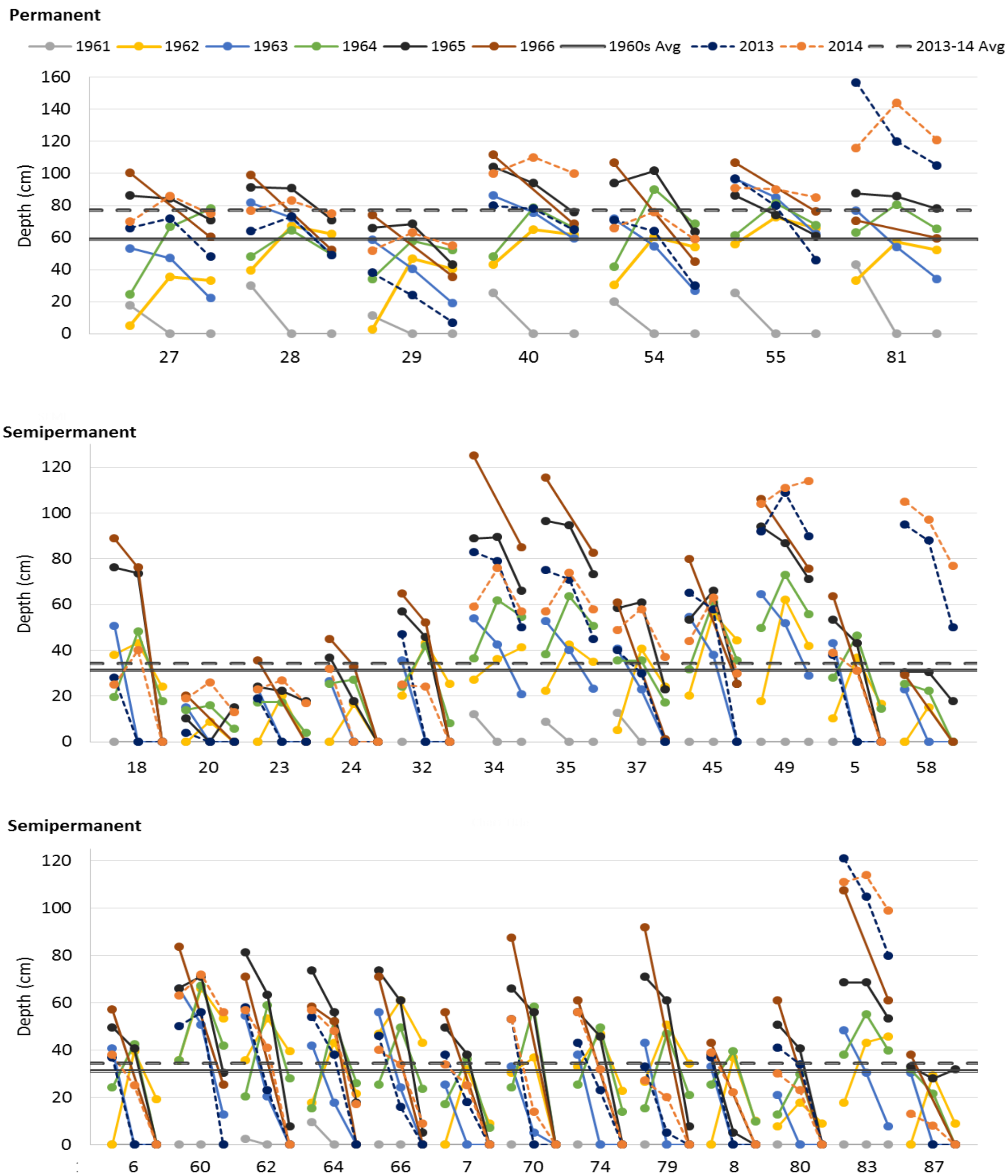

Figure 8. Water depths for each individual permanent and semipermanent wetlands at Mt. Moriah. Solid lines are depths from the 1961-1966 (1960s) study and dashed lines are depths from 2013-2014 study. For each wetland, the first dot is the early May depth, middle dot is the early July depth, and last dot is the early September depths. Horizontal lines represent average wetland depths.

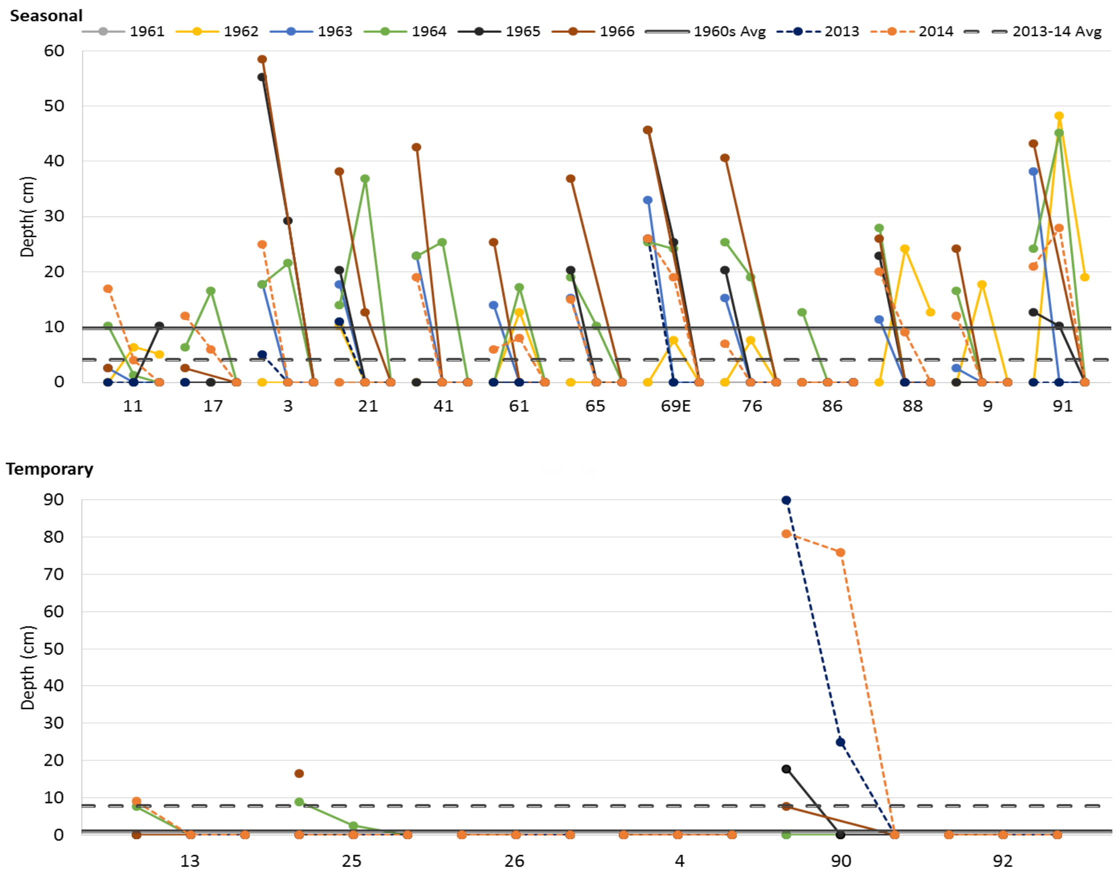

Figure 9. Water depths for seasonal and temporary wetlands at Mt. Moriah. Solid lines are depths from the 1961-1966 (1960s) study and dashed lines are depths from 2013-2014 study. For each wetland, the first dot is the early May depth, middle dot is the early July depth, and last dot is the early September depths. Horizontal lines represent average wetland depths.

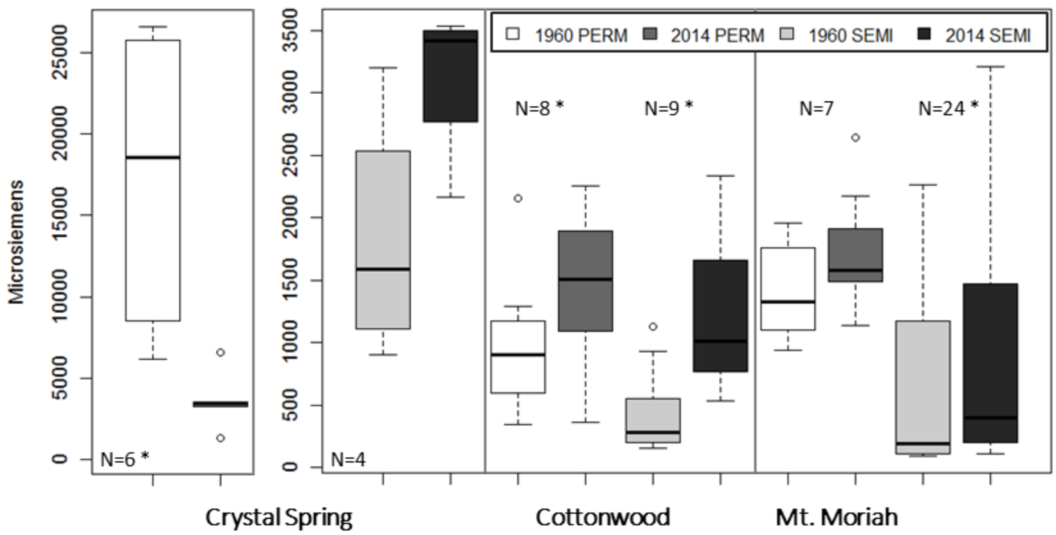

Figure 10. Average specific conductivity for permanent (PERM) and semipermanent (SEMI) wetlands at all study areas from the 1961-1966 study (1960) to the 2013-2014 study (2014). Y axis scale differs for permanent wetlands at Crystal Springs (y = 0 - 25,000) compared to other wetlands (y = 0 - 3,500). Significant results from paired t-tests indicated by asterisks ($P < 0.05$).

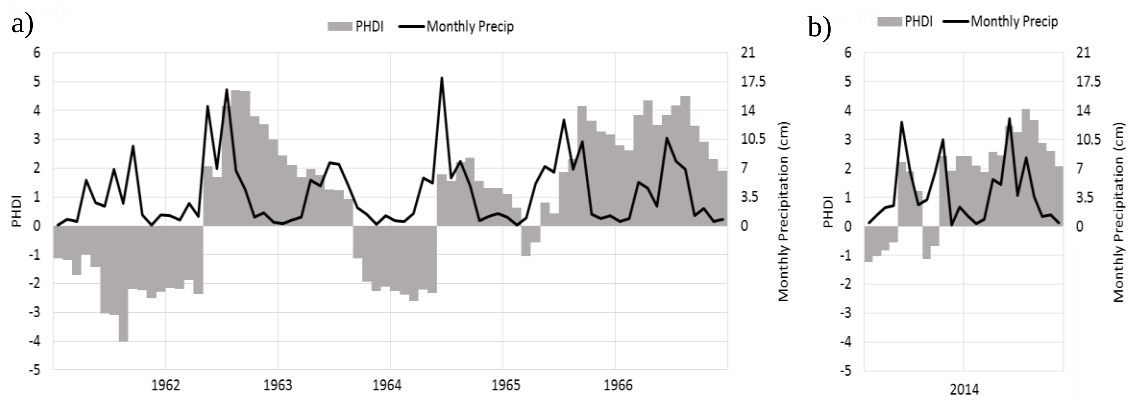

Figure 11. Palmer Hydrologic Drought Index (PHDI) and monthly precipitation data for Division 5 of North Dakota from a) January 1961 – December 1966 and b) January 2013 – December 2014. Data from the National Climate Data Center (http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp#).

CHAPTER 3.

PLANT COMMUNITY CHANGES WITHIN WETLAND ZONES IN THE PRAIRIE POTHOLE REGION AFTER 50 YEARS

Abstract

Wetlands in central North Dakota were revisited after 50 years to assess changes in plant communities within wetland zones in wetlands that experienced an extreme drought immediately followed by an extreme deluge in the Prairie Pothole Region. I used data collected in 1961-1966 as a reference study to compare plant communities within wetland zones. In 2013 and 2014, I revisited 80 wetlands across three study areas (i.e., Crystal Springs, Cottonwood, Mt. Moriah) and conducted quadrat-based vegetation surveys within wetland zones to measure changes in species composition, frequency, and abundance, and to document progression of invasive plant species (e.g., *Typha*, *Phalaris arundinacea*, *Poa pratensis*, and *Bromus inermis*). Plant communities within wetland zones in 2013-14 were on average 25% similar in species composition across all study areas compared to the 1960s, but changes within each wetland zone were unique. The deluge conditions left most wetlands dominated by open water and with more deep marsh zones. Excess water at Crystal Springs caused merging of wetlands to the extent that a large portion of wetland vegetation and wetland zones have been lost since the 1960s. Some merging occurred at Cottonwood but a combination of high water conditions and invasive plant species expansion caused wetland zone loss at this study area, whereas expansion of invasive plant species caused most wetland zone loss at Mt. Moriah. Species richness increased in all zones but at least 50% of species changed minimally in abundance (i.e., ±5%) within each zone except open water. In open water zones, 43% of

species changed by >10% in abundance and became dominated by water compared to vegetation, likely due to the deeper wetland depths. Deep marsh zones were mostly monotypic stands of *Typha* in 2013-14 and shallow marsh zones surrounding these monotypic stands were dominated by *Phalaris arundinacea* or the zone was not present. Shallow marsh zones in wetlands without *Typha* had *Carex atherodes*, *Polygonum amphibian var. emersum*, *Scolochloa festucacea*, and *Phalaris arundinacea* as the most abundant species in 2013-14. Wet meadow zones consisted of several known wet meadow species, with the addition of species normally found in low prairie zones and uplands; however, all species occurred in relatively low abundance in 2013-14, except *Calamagrostis canadensis, Poa pratensis,* and *Spartina pectinata*, which had >15% abundance. All invasive plant species of concern increased in frequency, became some of the most abundant species within wetland zones, and to some degree affected native species abundance. Plant communities within wetland zones greatly differed in overall species composition from the 1960s to 2013-14. Climatic extremes shifted the distribution of wetland zones, especially the rapid shift from drought to flooding and deluge conditions, seemed to facilitate some changes of plant communities within wetland zones.

Introduction

Plant communities were some of the first wetland attributes studied in the Prairie Pothole Region (PPR). Early studies in the North Dakota portion of the PPR revealed two common themes of wetland plant communities: 1) wetland plant communities were arranged in concentric zones; and 2) drought and flood conditions affect zonal arrangements (Kantrud et al. 1989). Shunk (1917) and Metcalf (1931) found that conspicuous zones were usually dominated by a single species or a few species and that water permanence and salinity controlled the composition of zones (Kantrud et al. 1989). Most of the seminal wetland vegetation studies were conducted as part of waterfowl studies to address the knowledge gap of detailed habitat characteristics that influenced wetland use by waterfowl. In the 1960s, Robert E. Stewart and Harold A. Kantrud conducted one such study investigating factors that affect permanency of prairie potholes and relationships between permanency and seasonal use by waterfowl (Stewart and Kantrud 1964).

During that study, Stewart and Kantrud determined that the popular wetland classification system used at that time, referred to as Circular 39 (Shaw and Fredine 1956), was difficult to use due to heavy emphasis on water depth and classifying only the central zones or zones around the wetlands as individual wetland types (Kantrud 1987). Stewart and Kantrud needed to classify entire basin; therefore, they used their 1961-1966 study on three study areas in Stutsman County, North Dakota to develop a regionalized wetland classification system for the PPR (Stewart and Kantrud 1971). This wetland classification system focused on lifeform of plant communities within zones (i.e., wet meadow, shallow marsh, deep marsh, and open water). Wet meadows consist of relatively short stature, fine-textured grass and grasslike plant species. Shallow marsh zones have predominantly intermediate height grass and grasslike plant species. Deep marsh zones consist of coarser and taller plant species compared to shallow marsh zones. Open water zones have submerged aquatic plant species or are devoid of vegetation in deep water. The number of zones increases with wetland permanence class (e.g., temporary, seasonal, and semipermanent). This wetland classification system is commonly used today in the PPR.

Continued research revealed complex responses of wetland vegetation and wetland zone distribution to hydrologic conditions (i.e., drought vs deluge; Euliss et al. 2004). Weller and Spatcher (1965) developed a five stage wetland habitat cycle describing annual changes in vegetation to the annual precipitation cycle. van der Valk and Davis (1978) reduced the Weller and Spatcher cycle to four stages (i.e., dry marsh, regenerating marsh, degenerating marsh, and a lake marsh stage) and discussed seed bank interactions with changing hydrologic conditions. van der Valk and Davis (1978) referred to this idealized cycle as the "wet-dry cycle," in which wetlands that hold at least 1 m of water can take 5 to 30 or more years to complete a single cycle (van der Valk and Davis 1978, Kantrud et al. 1989). The four stages of the wet-dry cycle translate to the four wetland cover types of Stewart and Kantrud's 1971 classification system. Stage and cover types are general terms used to describe the wetland vegetation response to hydrologic conditions, but are ultimately describing to the redistribution of wetland zones throughout the wet-dry cycle.

During 1961-1966, weather conditions were relatively stable with short durations of wet-dry hydrologic conditions until the mid-1980s. However, the PPR experienced a severe drought in 1988-1992, immediately followed by extreme amounts of precipitation in summer of 1993; this lead to a prolonged deluge (NCDC 2015, *see* Chapter 2). These extreme climatic events encouraged new research to document wetland changes and responses to potential shifts in climate. A long-term monitoring research project directed by U.S. Geological Survey (USGS) captured multiple detailed aspects of the drought and deluge effects for a small subset of wetlands in Stutsman County, North Dakota (Winter and Rosenberry 1998, Winter 2003). As the deluge continued into the 2000s, there was a noticeable shift to deeper, larger wetlands across the region in response to multiple years with higher than average annual precipitation rates (Winter 2003). In addition to the climate, anthropogenic change in land use factored into this shift in wetlands (Anteau 2012). Scientists developed models to predict wetland responses to potential climate change conditions and calibrated the models using the long-term data from the USGS study (Poiani and Johnson 1993, Poiani et al. 1995). By 2005, sophisticated models could predict detailed ratios of vegetation to open water in wetlands as well as coarsely predict shifts in wetland zones with differing climatic conditions (Johnson et al. 2005).

In addition to climate, invasive plant species can greatly impact wetland plant communities. Wetlands act as sinks for water, nutrients, and sediments which provide superb habitat for invasive plant species and make wetlands particularly vulnerable to species that can be form monotypic stands (Zedler and Kercher 2004). The establishment of *Typha angustifolia*, *Typha x glauca*, and *Phalaris arundinacea* was evident in the PPR by the 1950s, but was poorly documented (Metcalf 1931, Kantrud et al. 1989, Kantrud 1992). *T. x glauca*, *P. arundinacea*, and *Phragmites australis* are some of the most invasive plant species for wetlands and have become dominant species in many wetland ecosystems across the continent (Shay et al. 1999, Bernthal and Willis 2004). The increased prevalence of invasive plant species, in particular *T. x glauca* (Ralston et al. 2007), has been noticeable within the PPR for some time but remains poorly documented and specific effects on the zonal plant communities also remains unclear.

The subsequent extreme climatic episodes and presence of invasive species have likely caused changes in plant communities in wetland zones since the 1960s and to my knowledge species composition of wetland zones has not been revisited since Stewart and Kantrud's initial work. With access to Stewart and Kantrud's original dataset and study wetlands, a unique opportunity existed to examine plant community changes in wetland zones in the PPR. My main objectives for revisiting the original study wetlands were to quantify changes in species composition within wetland zones, quantify frequency and abundance changes of individual species, and to document the current status of invasives species within these plant communities.

Methods

Study Area and Wetland Selection

The three study areas, Crystal Springs, Cottonwood, and Mt. Moriah, were located in Stutsman County, North Dakota on the eastern edge of the Missouri Coteau (Figure 1). Individual study areas were approximately 260 ha in size but wetland class and density varied between study areas (Table 1). The majority of wetlands were on five waterfowl production areas (WPAs) acquired by the U.S. Fish and Wildlife Service prior to Stewart and Kantrud's study. Crystal Springs study area consisted of two WPAs, Crystal Springs and Zimmerman WPAs, plus ten wetlands located on private land. Cottonwood consisted of two neighboring WPAs, Cottonwood Lake and Smith-Bingham WPAs. Mt. Moriah WPA encompassed the entire Mt. Moriah study area. For both study periods, all wetlands on WPAs were surrounded by intact, managed grasslands (e.g., haying, fire, grazing). At Crystal Springs, access to ten wetlands located on private land was granted for both Stewart and Kantrud's (referred to as "1960s study") and my data collection (referred to as "2013-14 study"). Aerial images indicated that these wetlands on private land were surrounded by grasslands during the 1960s. During the 2013-14 study, those wetlands at Crystal Springs were completely surrounded by managed grasslands, cropland, or a combination of these land covers.

The topography of the three study areas was the characteristic knob and kettle type prevalent across the PPR (Stewart and Kantrud 1964). Topographic relief was highest at Mt. Moriah (elevation range 520-570 m) with local slopes up to 25% (Sloan 1972), intermediate at Cottonwood (elevation range 545-570 m), and lowest at Crystal Springs (elevation range 530-545 m). Mt. Moriah and Cottonwood were located on stagnate moraine type glacial deposits. Crystal Springs was specifically chosen for the 1960s survey because it was located on a glacial outwash plain and known to have more saline waters (Stewart and Kantrud 1964). Mt. Moriah is unique with the presence of two intermittent east-flowing streams with two-thirds of wetlands releasing flood water into these streams through natural overflow outlets (Stewart and Kantrud 1964). A few wetlands at higher elevations at Cottonwood partially drain and supply water through overflow outlets to larger wetlands at lower elevations during high water conditions. All other wetlands at Mt. Moriah and Cottonwood and all wetlands at Crystal Springs are in closed basins with little to no drainage (Stewart and Kantrud 1964).

Stewart and Kantrud collected annual, repeated data on 137 wetlands with the highest density of wetlands at Mt. Moriah (n = 94) followed by Cottonwood (n = 25) and Crystal Springs (n = 18). In 2013 and 2014, I collected repeated data on 80 of the original 137 wetlands across the three original study areas. I chose wetlands randomly but in proportion to the wetland classes assigned at each study area and surveyed during the

1960s study (Table 1 and 2). There was one seasonal wetland at Crystal Springs that I combined with semipermanent wetlands in order to be included in all statistical analyses.

Data Collection

Stewart and Kantrud surveyed entire wetland plant communities 1-2 times each year during 1961-1966 with additional partial surveys of submerged aquatic plants or most central zone during the growing season throughout most years. Stewart and Kantrud conducted walking (i.e., meandering) surveys in each discrete zone and assigned an abundance code for each species recorded in that zone (H. A. Kantrud, Northern Prairie Wildlife Research Center, personal communication). Wet meadow zones were the outermost zone surveyed of each wetland; no surveys were conducted in the low prairie zone in either study. In 2013 and 2014, I surveyed whole wetland plant communities twice during the growing season; early season visits were conducted in June through mid-July and late season visits were from mid-July through August. I surveyed only 63 wetlands during the early season in 2013, but all 80 were surveyed during each remaining visit. I placed 1 m^2 quadrats at 5 approximately-equidistant points along the central, longitudinal axis of each available zone (as defined by Stewart and Kantrud 1971) for each wetland (Figure 2; Kantrud and Newton 1996). I divided the perimeter of each wetland by 5 to determine appropriate distance between quadrats. Most wetlands had intact zones encompassing the target goal of 5 quadrats in 2013-14, but some zones did not circumvent the wetland; thus, I used fewer quadrats in those instances. Within each quadrat, I recorded species composition and assigned relative abundance using similar but more descriptive abundance codes than those used in the 1960s study (Table 3; Naugle et al. 1999). I recorded incidental species observed between quadrats but did not assign abundance codes for these species. In both studies, most plants were identified to species (e.g., *Poa palustris*), but some were only identified to the genus level (e.g., *Poa)* or to functional group (e.g., Unknown Grass). I found many plant species without the required reproductive structures or vital characteristics during my surveys making reliable identification using floristic keys difficult; therefore, I only identified these species to functional group. In many cases, a label of "Unknown Grass" or "*Carex*" referred to a small number of individual distinct species that I observed repeatedly but was unable to identify to genus and species. In 2013-14, I could not reliably distinguish between *Typha angustifolia* and *Typha x glauca* in the field so I combined the two species under the label "*Typha"* to discuss the overall expansion of these invasive cattail species for both the 1960s and the 2013-14 study (Johnston et al. 2009). I used Flora of the Great Plains (Great Plains Flora Association 1986) as the taxonomic reference for plant species collected during both the 1960s study and 2013-14 study.

Data Analyses

During the early years of their work, Stewart and Kantrud acknowledged unique plant communities as zones (e.g., zone A, B, C, etc.) but had not developed the names for those zonal plant communities. In later years, they assigned wet meadow, shallow marsh, deep marsh, and open water to the unique plant communities (Stewart and Kantrud 1963, Stewart and Kantrud 1971). Prior to analyses, I used the species compositions of assigned zones of the later years and Stewart and Kantrud's (1971) classification system to retroactively assign zones labels for earlier years. Additionally, I used the hand drawn pictures of plant community distributions from Stewart and Kantrud's original data cards to help with zone label assignments. Wetland class (e.g., temporary, permanent) for both studies was assigned using the average of Stewart and Kantrud's wetland class assignments of each wetland from 1961-1966. Prior to analysis, I condensed the 2013-14 abundances codes into the appropriate 1960s abundance codes (Table 3). I then transformed abundance codes into mid-point percentages (e.g., common = 30.5%) for data from both studies. For 2013-14 data, I averaged abundance codes across quadrats available for each species within each zone. For each study, I averaged the abundance codes for each species across all survey visits to get a single 1960s abundance average and a single 2013-14 abundance average for each surveyed zone.

I made one complete species list including incidental species for each study and a species list with only species assigned abundance codes. I used the complete species list to calculate Jaccard's similarity index [(SJ = (c/(a + b + c)) x 100%); where SJ = Jaccard's similarity index, c = number of species common between the 1960s and 2013-14, a = number of species unique to the 1960s, b = number of species unique to 2013-14] to test for overall similarity of the 1960s plant communities and 2013-14 plant communities. To confirm the Jaccard's similarity index, I conducted an additional similarity analysis in Primer version 6 (Clarke and Gorley 2006). I computed resemblance as Kulczynski similarity using presence/absence data (Kulczynski 1928). I grouped site-events (e.g., OW-H) by agglomerative hierarchical clustering (Everett 1980) with group-average linking based on Kulczynski similarities. I used the SIMPER procedure (Clarke and Gorley 2006) to determine taxa contributions to the average similarity within a cluster. I used non-metric multidimensional scaling (MDS) with the Kulczynski similarity data to ordinate sites, using 25 restarts and a minimum stress of 0.01. No environmental data were added to this analysis (e.g., water depth, slope).

To understand individual species changes within zones, I followed a modified version of R code used by Pedrotti et al. (2014). I used surveyed zones (e.g., wet meadow zone at Mt. Moriah wetland 5) as replicate units and I reduced the data set to include only zones that were present during both the 1960s study and the 2013-14 study. For only species assigned abundance codes, I used Fisher's exact test to estimate frequency changes and paired *t*-tests to determine abundance changes within wetland zones.

Results

During the 1960s and the 2013-14 study, the complete species list contained 324 unique species, Stewart and Kantrud identified 196 species in 1961-1966 and I identified 265 species in 2013-2014. Mt. Moriah had the greatest species richness, with 261 species during both studies: 137 species found in the 1960s and 220 species in 2013-14. Cottonwood had 223 species in both studies: 141 in 1960s and 166 species in 2013-14. Crystal Spring had the least amount of species with 194 identified during both studies: 113 species in the 1960s and 148 species in 2013-14. The complete list consisted of 280 unique species classified to species, 37 to genus only, and 7 to functional group (e.g., Unknown Grass). The complete species list was reduced to 281 species with abundance codes, of which 234 were classified to species, 39 to genus only, and 8 to functional group.

In the 80 wetlands surveyed during both studies, the distribution and presence of zones in the 2013-14 study changed noticeably since the 1960s study. There were 14 additional wetlands with deep marsh zones and 12 additional wetlands with open water zones in 2013-14 compared to the 1960s (Table 4). In contrast, there were 24 fewer wetlands with shallow marsh zones and 8 fewer wetlands with wet meadow zones in

2013-14 compared to the 1960s. There was a reduction in the number of wetlands with a specified zone present during both studies for deep marsh, shallow marsh, and wet meadow zones (Table 4). In 2013-14, wet meadow zones existed in 90% and deep marsh zones existed in 76% of the wetlands surveyed that had each respective zone in the 1960s. Only 66% of wetlands that had shallow marsh zones in the 1960s still had this zone in 2013-14. However, open water zones existed in 100% of the wetlands that had open water zones in the 1960s.

Community Changes

Species richness and composition changed considerably between the 1960s and 2013-14. Species richness increased for all zones in 2013-14 compared to the 1960s. There were 291 species in the wet meadow zone (1960: 162, 2014: 238), 221 species in shallow marsh zones (1960: 125, 2014: 167), 127 species in deep marsh zones (1960: 71, 2014: 99), and 92 species in open water zones (1960: 67, 2014: 60). Species richness changes impacted species composition similarity for all zones. Jaccard similarity index results showed that wetlands zones on average were only 25% similar in species composition between the 1960s and 2013-14, ranging from 10% for shallow marsh zones of permanent wetlands at Crystal Springs to 34% similarity of deep marsh zones of permanent wetlands at Mt. Moriah (Table 5). Open water had the lowest average similarity of 22% and deep marsh had the highest average similarity of 27%. Crystal Springs had the lowest average similarities for all zones and Mt. Moriah had the highest average similarities for all zones except shallow marsh, in which Cottonwood had the highest.

Cluster analyses showed a clear distinction of the 1960s zone plant communities and the 2013-14 zone plant communities distinguished at a resemblance value of 50% (i.e., first split in the cluster analysis; Figure 3); all groups were distinct at a resemblance value of 76%. When plotted in 2-dimensional MDS space (stress = 0.02), the first axis (i.e., horizontal axis) distinguished the 1960s study from the 2013-14 study and the second axis (i.e., vertical axis) arrayed zones from driest (i.e., wet meadow, WM) to wettest (i.e., open water, OW).

Individual Species Changes

I compared 236 species in wet meadows, 175 species in shallow marshes, 76 species in deep marshes, and 67 species in open water zones between the 1960s study and the 2013-14 study. More than 50% of individual species in all zones had minimal change (i.e., ±5 wetlands) in frequency. However, 21% individual species in wet meadow and shallow marsh zones increased or decreased in frequency by >10 wetlands whereas <7% of individual species in deep marsh and open water zones changed by that magnitude. Wet meadow and shallow marsh zones had more individual species increase in frequency whereas deep marsh and open water zones had more individual species decrease in frequency.

Wet meadow zones had the greatest number of significant changes in frequency for individual species; 51 species were found more frequently and 25 species were found less frequently (Table 6; Appendix Table A2). The introduced species, *Agropyron repens*, was not found in the 1960s study but had the greatest increase in frequency in wet meadow zones and was found in 66 wetlands in 2013-14 compared to the 1960s whereas the frequency of *Hordium jubatum* had the greatest decrease and was found in 43 fewer wetlands in 2013-14. In 2013-14, I did not find *Agrostis stolonifera* in any of the 39 wetlands in which it was found during the 1960s study. *Carex praegracilis* was found in 23 fewer wetlands but *Carex lanuginosa* and *Carex sartwellii* were both found in 30 more wetlands in 2013-14 compared to the 1960s. *Poa palustris* was found in only 58% of the wetlands it was found in during the 1960s but *Poa pratensis* was found in 79% more basins in 2013-14. Additionally, I found *Bromus inermis* in 50 wetlands, but it was found in only one wetland in the 1960s.

The greatest increase in frequency for the shallow marsh zone was for *Phalaris arundinacea*, which was found 31 wetlands in 2013-14, but was not found in this zone in any wetlands in the 1960s. *Eleocharis macrostachya* decreased the most in frequency, being found in 31 fewer wetlands in 2013-14 compared to the 1960s. *Beckmannia syzigachne* was found in 28 fewer wetlands and *Glyceria grandis* was found in 24 fewer wetlands in 2013-14 compared to the 1960s.

The changes in frequency were not as numerous for deep marsh and open water zones. Deep marsh zones had the fewest significant frequency changes with 3 species found more frequently and 9 species found less frequently. The two extremes for this zone were *Phalaris arundinacea*, found in 11 additional wetlands in 2013-14, whereas *Chenopodium rubrum* was found in 16 fewer wetlands compared to the 1960s. *Typha latifolia* was found in 10 fewer wetlands and *Scirpus acutus* was found in 5 fewer wetlands. *Typha* (i.e., *Typha angustifolia* and *Typha x glauca* combined) was the only species that significantly increased in open water zones and was found in 9 more wetlands, whereas *Zannichellia palustris* was found in 16 fewer wetlands in 2013-14 compared to the 1960s. *Ranunculus longirostris* was found in 13 fewer wetlands.

Abundance changes of plant species further illustrates change within wetland zones. Similar to patterns of frequency changes, wet meadow and shallow marsh zones changed similarly in overall individual species changes with 76% and 60% of species, respectively, increasing or decreasing <5% in abundance. Deep marsh zones had 47% and open water zones had 35% of individual species increasing or decreasing <5% in abundance. More species decreased in abundance than increased in all zones between the 1960s and 2013-14 (Table 6; Appendix Table A3). When species represented by only a single wetland were removed, 39% of species in the open water zones and 35% of deep marsh species decreased by >10% in abundance. However, only 16% of shallow marsh species and 8% of wet meadow species decreased > 0% in abundance. Of the 12 most abundant species for each zone for both the 1960s study and 2013-14 study, most species decreased in abundance (Figures 4-7). Only 3 of the most abundant species across all zones increased in abundance. *Typha* increased by 44% in deep marsh zones, *Phalaris arundinacea* increased by 39% in shallow marsh zones, and *Poa pratensis* increased by 15% in wet meadow zones in 2013-14 (Table 6).

Wet meadow zones had the most significant changes in abundance; 6 species increased and 28 decreased in abundance. *Poa pratensis* increased the most by 15% and *Agrostis stolonifera* decreased the most by 42%. *Carex praegracilis* was less abundant whereas *Carex lanuginosa* and *Carex sartwellii* were more abundant in 2013-14 (Table 6, Table A3). *Poa palustris* decreased to be only 4% abundant in wet meadow zones in 2013-14 whereas *Poa pratensis* increased to be 18% abundant. *Bromus inermis* increased to 6% abundant in 2013-14. *Phalaris arundinacea* increased the most and was 39% in shallow marsh zones whereas *Potamogeton gramineus* decreased the most to be <1%

abundant. *Eleocharis macrostachya* and *Glyceria grandis* were <2% abundant in 2013-14. *Typha* increased the most by 43% in deep marsh zones whereas *Typha latifolia* decreased the most by 36% and *Scirpus acutus* decreased by 30%. No species had significant increases in the open water zone but *Eleocharis macrostachya* decreased the most by 35%. *Ranunculus longirostris* was <1% abundant and *Zannichellia palustris* was not found in this zone in 2013-14.

Typha latifolia, *Typha angustifolia*, and *Typha x glauca* had some of the most conspicuous changes in frequency and abundance between 1960s and 2013-14. *T. latifolia* was a common abundant species in deep marsh zones in the 1960s but occurred infrequently and in low abundance in open water, shallow marsh, and wet meadow zones. In the 1960s, *T. angustifolia* was present in only 6 wetlands and in low abundance (i.e., <3% abundant) in deep marsh and shallow marsh zones. *T. x glauca* was not documented until 1963 and was found more frequently and in greater abundance compared to *T. angustifolia*, but less frequently and less abundant than *T. latifolia*. Therefore, *Typha* describes the changes in both *T. angustifolia* and *T. x glauca*, but better reflects changes in *T. x glauca*. In 2013-14, *Typha* was the most abundant species in deep marsh zones (i.e., 55% abundant) and was found in many open water, shallow marsh, and wet meadow zones in low abundance. I identified *T. latifolia* in most wetlands in 2013-14 but only in low abundance.

Discussion

Wetland plant communities in the three study areas were greatly altered since the 1960s, as indicated by the distribution of wetland zones and noticeable changes in species compositions in 2013-14. A small subset of individual plant species changed considerably in frequency within each zone, in particular in the shallow marsh and wet meadow zones. Species richness increased in all zones since the 1960s, but approximately 50% of species within each zone were occasional or rare (i.e., <1% abundance). All of the invasive plant species of concern increased in frequency and abundance within wetland zones. Although many characteristic plant species remained in 2013-14, each zone had a slight shift in the most abundant plant species.

The most influential factor contributing to the plant community changes within zones was the extreme climatic episodes prior to the 2013-14 study. Plant community changes during the 1988-1992 drought impacted wetland plant communities in 2013-14, despite the drought being nearly 3 decades prior, because extremes such as this drought and the following flood set conditions for the following years (LaBaugh et al. 1996). During the 5 years of drought conditions, full drawdowns occurred for most wetlands within the region with only the deepest wetlands holding water (Winter 2003). At the U.S. Geological Survey's Cottonwood Lake Study Area, several wetlands became completely dominated by *Typha* spp., some wetlands had *Scolochloa festucacea* (usually affiliated with the shallow marsh zone) dominating the central zone surrounded by deep marsh species, and in less permanent wetlands, wet meadow and low-prairie species were able to infiltrate the central zones as a result of the multiyear drought (Stewart and Kantrud 1971, Winter 2003). Heavy rainfall in July 1993 quickly flooded out emergent species that had become established during the drought. Water levels in wetlands rose so high that *Scirpus* spp., *Typha latifolia*, and *Typha angustifolia* were flooded out; even *Typha x glauca*, a species tolerant of high water levels, was eventually flooded out of the center of most wetlands (Winter 2003).

From the distribution of wetland zones in 2013-14, it seems that similar vegetation responses occurred at Crystal Springs, Cottonwood, and Mt. Moriah during the climatic extremes. In 2013-14, there were more open water zones across all study areas and more deep marsh zones at Cottonwood and Mt. Moriah. Water levels rose so much since 1993 that wetlands at Crystal Springs were more recognizable as a complex of connected small lakes, with very little recognizable wetland zonation or vegetation, than as individual wetlands (*see* Chapter 2). Some merging of wetlands and loss of wetland zones occurred at Cottonwood, with most wetlands dominated by open water in 2013-14. Poiani et al. (1995) documented a noticeable loss of combined wet meadow/shallow marsh zones, with large rises or decreases in water levels in their simulation study. Their simulations indicated deep marsh zones expanded into uplands coincident with high water levels and the upland vegetation would expand into the central wetland zones when water levels dropped. However, in both instances, the wet meadow/shallow marsh did not simultaneously move in the same directions as the deep marsh or upland; therefore, wet meadow/shallow marsh zone areas were minimized. The addition of some traditional low prairie zone and upland species into wet meadow zones, and loss of intact shallow marsh zones for permanent wetlands in my 2013-14 data supported the simulation results of Poiani et al. (1995), in particular at Mt. Moriah and Cottonwood.

In addition to responses to climatic extremes, the change in frequency and abundance of invasive species affected the species composition of zones. Invasive species had the most extreme increases of frequency and abundance for species surveyed in 2013-14. I focused on changes for invasive *Typha*, *Phalaris arundinacea*, *Poa pratensis*, and *Bromus inermis* due to the established negative impacts these species have had in other regions and ecosystems. *T. x glauca* (one of the species in *Typha*) and *P. arundinacea* are known to form monotypic stands and outcompete native species in wetlands (Zedler and Kercher 2004). *Typha* had the highest overall abundance of all species documented in 2013-14, was found in every deep marsh zone surveyed, and had formed a monotype in most permanent and several semipermanent deep marsh zones. The complete loss of shallow marsh zones in 14 wetlands and 10 wetlands lacking intact shallow marsh zones suggests that these monotypic stands of *Typha* have contributed to the reduction of shallow marsh zones in those wetlands having monotypic *Typha* stands. *P. arundinacea* was not present in any of the 51 study wetlands at Mt. Moriah in the 1960s, but Stewart and Kantrud found it in one of the wetlands not revisited at this study area. *P. arundinacea* was present in three study wetlands plus one other at Cottonwood and in one study wetland at Crystal Springs. *P. arundinacea* was the most abundant species in shallow marsh zones, but was not present in every shallow marsh surveyed and did not consistently form monotypic stands dominating entire shallow marsh zones. Recent studies indicated that *Poa pratensis* and *B. inermis* account for 62% of the exotic cover in uplands in the Northern Great Plains and may form monotypic stands (Cully et al. 2003; DeKeyser et al. 2013). *Poa pratensis* was a common low prairie zone species in Stewart and Kantrud (1971). It was the second most abundant wet meadow species in 2013-14 and found in 63 wetlands, but had a much lower overall abundance compared to *Typha* and *P. arundinacea* in their respective zones. I did find quadrats dominated by *Poa pratensis*, but rarely a whole wet meadow. Although *B. inermis* was found in 50 wetlands, it was not a major component of wet meadows in 2013-14. Shallow marsh zones remained in permanent wetlands only if *P. arundinacea* was present with only 10 of 20 permanent wetlands having shallow marsh species present but usually only in a few spots and not a complete zone surrounding deep marsh zones. I found the native strain of *Phragmites australis*, based on field identification, at all study areas in 2013-14, but only in small monotypic patches; it was not an abundant species (>1%) in any wetland zone. Similar to *Typha* species, genetic testing is the most reliable method to differ between native and introduced strains of *Phragmites australis*. Currently, it did not appear that the introduced strain of *Phragmites australis* was negatively impacting these study wetlands. However, the introduced strain of *Phragmites australis* is found in almost all counties in North Dakota (Shipunov 2014), so it is likely that the introduced strain of *Phragmites australis* is affecting wetland plant communities in the PPR. Most study wetlands were on WPAs with minimal direct anthropogenic disturbance so the increase in frequency and abundance of *Typha*, *Phalaris arundinacea*, *Poa pratensis*, and *Bromus inermis* was likely due to individual species adaptations, tolerance of variable conditions, and multiple reproductive strategies. This notable increase in the prominence of invasive plant species in wetland zones is troublesome considering they seem to influence native species diversity and can be difficult to eradicate. Their overall influences on native species diversity and wetland function requires further research.

Land use differences between the two studies likely contributed to the observed changes in wetland plant communities. Land use is known influence species dominance within wetland zones (Stewart and Kantrud 1972, Kantrud et al. 1989). During the 1960s study, grazing occurred at Mt. Moriah WPA, Cottonwood WPA, and Zimmerman WPA. Since the 1960s, land around most wetlands in the three study areas has been predominantly idle; some grazing, burning, and haying occurred at almost every WPA for less than 10 of the 50 years. The most abundant species in 2013-14 corresponded to the dominant species associated with idle land (Kantrud et al. 1989). In 2013-14, some wetlands at Crystal Springs were completely or partially surrounded by agricultural land. Wetland plant species were still present in wetlands that had a grassland buffer between crop fields and wetlands whereas in areas without an intact buffer, vegetation near wetland edge consisted of mostly mudflat annual species and agricultural weed species.

Methodological differences between the two studies contributed to the overall reduced abundances of most species. Meandering surveys and quadrat-based surveys, commonly used for vegetation studies, have associated advantages and disadvantages. Meandering surveys are useful to understand the broad patterns for conspicuous species and take less time to conduct in the field but rare species are often overlooked or underestimated. Meandering surveys were appropriate for Stewart and Kantrud because wetland plant species was a component of a larger study and they were familiar with wetland plant species and could accurately identify plant species in the PPR using this survey method. Quadrat-based surveys are more sensitive to rare species and provide more detailed patterns, but are less time efficient. Quadrat-based surveys were appropriate for my sampling because vegetation changes was my main objective and the intensity of this survey method permitted me to find inconspicuous species that might be missed with meandering surveys (e.g., *Carex* spp.). One disadvantage to using the quadrat-based survey was that the increased species richness in 2013-14 reduced the overall species composition similarity between studies, because more species were found in the 2013-14 study. A long-term wetland vegetation monitoring study could be developed using the detailed species account and known locations of quadrats from the 2013-14 study.

Wetland biota (e.g., vegetation and aquatic invertebrate communities) are often used to as indicators of wetland permanence and quality because they are much easier to access and evaluate compared to evaluating wetland hydrology (NRC 1995). Wet meadow and shallow marsh zones are indicators of wetland condition because these zones provide critical food resources for dabbling ducks and other water birds (Guntenspergen et al. 2002). According to a recent Canadian study, width of wet meadow zones decreased with environmental stress and wider wet meadow zones suggested better habitat suitability for species of other tropic levels (Wilson and Bayley 2012). I had the greatest difficulty identifying wet meadow zones in 2013-14 for almost all wetlands and had to actively search for fine-textured sedges to determine if wet meadows were present. This difficulty, and the shift in species composition to include species associated with low prairie zones and uplands, suggests that wet meadows were less conspicuous in 2013-14. Wilson and Bayley (2012) compared anthropogenic stressors of natural wetlands to constructed wetlands; however, it seems natural wet meadows in my study wetlands that were protected and largely devoid of anthropogenic influence have decreased in width, indicating potential environmental stress. Similarly, the reduced shallow marsh areas for wetlands with monotypic *Typha* stands could suggest that this zone is environmentally stressed. Additionally, open water plant communities have been influenced by increased water depths (*see* Chapter 2), causing reduced abundance of submerged aquatic plant species. The changes in wet meadows, shallow marshes, and the submerged aquatic vegetation suggest that these wetlands may not provide the same diversity and quantity of food resources for waterfowl and waterbirds, but targeted research is needed to specifically address this hypothesis.

Wetlands in the PPR were formed over 10,000 years ago (van der Valk 1989) and have survived several climatic extremes (Xia et al. 1997). Wetlands and their vegetation evolved to persist through varying climatic conditions, and therefore wetlands have likely switched between permanence classes many times throughout their existence. However, wetlands and their plant communities did not evolve with nonnative invasive plant species, and the continuing spread of invasive plant species into wetland ecosystems is unprecedented. Invasive plant species were present in wetland zones during the 1960s study, but overall the establishment of these species in wetlands is in its infancy on a geological timeline. Wetland vegetation will continue to respond to the variable inter-annual climate within the region, but permanent impacts of invasive plant species within wetland zones remain unknown.

Wetland zones are still readily discernable in the field, but finding shallow marsh and wet meadow zones may be challenging in wetlands with monotypic stands of *Typha*. Although this study contains only a small fraction of the wetlands in the PPR, it is one of the largest samples of its kind and one of the few studies to incorporate data from the 1960s. Shifts within wetland plant communities in these 80 protected wetlands are concerning because it suggests that plant communities of protected wetlands (i.e., preserved or conserved) are still highly vulnerable to invasive plant species and climatic extremes, which can lead to overall degradation of the remaining wetlands in the PPR. Wetlands do not respond uniformly to drought and deluge conditions (Winter 2003), but invasive plant species have likely become established across the region in a similar matter to these study wetlands. Several factors contributed to changes in species composition and arrangement of wetland zones, such as extreme climate episodes, presence of invasive plant species, and to some extent management of surrounding upland communities. These factors will continue to influence wetland plant community within zones while wetlands persist through time.

Acknowledgements

This project was funded by USGS Northern Prairie Wildlife Research Center in Jamestown, North Dakota. Housing and additional logistical support was provided by Chase Lake Wetland Management District in Woodworth, North Dakota. Thank you to Dr. Jane Austin and Dr. Joshua Stafford for comments and edits with this chapter. Special thanks to Dr. Carol Johnston for her expertise in Primer and comments on research design. Additional thanks to Cami Dixon and Dr. Gary Larson for their help with plant identification. This project could not have been done without the help of technicians, Beth Harmsen and Alyse Homola. Thank you to Brad Smith for statistical analysis advice.

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Table 1. Study area description for waterfowl production areas (WPA), approximate size, legal description, and number of wetlands surveyed for the 1961-1966 (1960s) study and 2013-2014 (2013-14) study in Stutsman County, North Dakota.

Study Area	**Approx. Size (ha)**	**Legal Description**	**Wetlands sampled in 1960s**	**Wetlands sampled in 2013-14**
Mt. Moriah			94	51
Mt. Moriah WPA	260	T. 144N, R. 67 W, Sect. 21		
Cottonwood			25	17
Cottonwood Lake WPA	160	T. 142 N, R. 66 W, parts of Sect. 31-33		
Smith-Bingham WPA	100	T. 141 N, R. 66 W, parts of Sect. 3,4		
Crystal Springs			18	12
Privately owned,	210	T. 139 N, R. 69 W, parts of Sect. 4,5;		
Crystal Springs WPA		T 140 N, R. 69W, parts Sect. 32, 33		
Zimmerman WPA	50	T. 140 N, R 69 W, NW qtr of Sect. 22		
Total Wetlands			*137*	*80*

Table 2. Number of wetlands surveyed in 2013-14, by wetland class and study area for comparison to 1960s study in Stutsman County, North Dakota.

	No. Wetlands		
	Mt. Moriah	**Cottonwood**	**Crystal Springs**
Wetland Class			
Permanent	7	8	6
Semipermanent	25	9	5
Seasonal	13		1
Temporary	6		
Total	*51*	*17*	*12*

Table 3. Comparison of abundance categories used in the 1961-1966 (1960s) study and 2013-2014 (2013-14) study in Stutsman County, North Dakota.

1960s		**2013-14**	
Abundance Code	Percent Abundance	Abundance Code	Percent Abundance
Abundant	> 50	8	> 95
		7	76-95
		6	51-75
Common	10-50	5	26-50
		4	11-25
Fairly Common	1-10	3	6-10
		2	1-5
Occasional	≤ 0.5	1	< 1
Rare	Seldom/Minor Importance		

Table 4. Distribution and presence of wetland zones across permanence classes and study areas in 1961-1966, 2013-2014, and number of zones that were present during both studies for comparison of the 1961-1966 study and 2013-2014 study in Stutsman County, North Dakota.

Zone		1961-1966	2013-2014	Both
Wet Meadow	*Total*	*80*	*72*	*72*
	Permanent	21	19	19
	Semipermanent	40	36	36
	Seasonal	13	12	12
	Temporary	6	5	5
	Crystal Springs	*12*	*11*	*11*
	Permanent	6	6	6
	Semipermanent	6	5	5
	Cottonwood	*17*	*14*	*14*
	Permanent	8	6	6
	Semipermanent	9	8	8
	Mt. Moriah	*51*	*47*	*47*
	Permanent	7	7	7
	Semipermanent	25	23	23
	Seasonal	13	12	12
	Temporary	6	5	5
Shallow Marsh	*Total*	*68*	*49*	*45*
	Permanent	21	10	10
	Semipermanent	40	29	29
	Seasonal	7	8	6
	Temporary		2	
	Crystal Springs	*12*	*4*	*4*
	Permanent	6	2	2
	Semipermanent	6	2	2
	Cottonwood	*17*	*16*	*16*
	Permanent	8	7	7
	Semipermanent	9	9	9
	Mt. Moriah	*39*	*29*	*25*
	Permanent	7	1	1
	Semipermanent	25	18	18
	Seasonal	7	8	6
	Temporary		2	

Table 4 Continued.

Zone		1961-1966	2013-2014	Both
Deep Marsh	*Total*	*29*	*43*	*22*
	Permanent	21	16	16
	Semipermanent	8	24	6
	Seasonal		2	
	Temporary		1	
	Crystal Springs	*8*	*3*	*1*
	Permanent	6	1	1
	Semipermanent	2	2	
	Cottonwood	*11*	*16*	*11*
	Permanent	8	8	8
	Semipermanent	3	8	3
	Mt. Moriah	*10*	*24*	*10*
	Permanent	7	7	7
	Semipermanent	3	14	3
	Seasonal		2	
	Temporary		1	
Open Water	*Total*	*29*	*40*	*29*
	Permanent	21	21	21
	Semipermanent	8	19	8
	Crystal Springs	*8*	*12*	*8*
	Permanent	6	6	6
	Semipermanent	2	6	2
	Cottonwood	*10*	*14*	*10*
	Permanent	8	8	8
	Semipermanent	2	6	2
	Mt. Moriah	*11*	*14*	*11*
	Permanent	7	7	7
	Semipermanent	4	7	4

Table 5. Jaccard's similarity indices for wetland zones across wetland class and study area for the 1961-1966 study and 2013-2014 study in Stutsman County, North Dakota.

	Wet Meadow	Shallow Marsh	Deep Marsh	Open Water
Crystal Springs				
Overall	0.30	0.26	0.27	0.16
Permanent	0.23	0.10	0.21	0.19
Semipermanent	0.28	0.22	0.20	0.14
Cottonwood				
Overall	0.30	0.29	0.38	0.41
Permanent	0.28	0.27	0.34	0.27
Semipermanent	0.26	0.25	0.20	0.22
Mt. Moriah				
Overall	0.31	0.31	0.33	0.39
Permanent	0.24	0.21	0.34	0.23
Semipermanent	0.30	0.31	0.32	0.26
Seasonal	0.32	0.19		
Temporary	0.28			
Average				
Permanent	0.25	0.20	0.30	0.23
Semipermanent	0.28	0.26	0.24	0.21

Table 6. Change in frequency and abundance (%) for plant species between 1960s and 2013-2014 for wetland zones. The change columns indicate direction and magnitude of change i.e., increase or decrease of frequency or abundance. Only the most abundant species and invasive species of each zone are presented. P-values are results from Fisher's exact test (frequency) and paired *t*-tests (abundance). Number of surveyed zones (n) in which a species was present at least one of the years. Nonnative species are capitalized. Complete species list given in Appendix: Tables A2 and A3.

Species	Change in frequency	Absolute change in abundance (%)	Mean abundance 1960s (%)	n
Wet Meadow				
AGROSTIS STOLONIFERA	-39***	-42.3***	42.3	39
Aster simplex var. ramosissimus	1	-8.2***	9.0	60
BROMUS INERMIS	49***	5.9***	0.1	50
Calamagrostis canadensis	4	2.4	28.2	28
Calamagrostis stricta	-9	0.5	13.5	61
Carex praegracilis	-23***	-14.1***	14.7	35
CIRSIUM ARVENSE	41***	1.0	1.8	71
Distichlis spicata	-11*	-33.8***	36.7	16
Hordeum jubatum	-43***	-9.6***	14.6	67
Juncus balticus	6	-6.7**	12.0	45
Phalaris arundinacea	32***	8.6***	0.0	33
Poa	-4	-15.4*	20.7	23
Poa palustris	-27***	-27.9***	31.4	66
POA PRATENSIS	50***	15.0***	3.8	65
Spartina pectinata	-4	-3.2	20.3	70
Shallow Marsh				
BROMUS INERMIS	17***	6.9^{NA}	0.0	17
Carex	13**	-9.9	11.6	24
Carex atherodes	-4	-8.1	33.8	44
CIRSIUM ARVENSE	28***	-1.4	2.9	43
Eleocharis macrostachya	-31***	-20.9***	22.5	41
Glyceria grandis	-24***	-18.7***	20.5	30
Hordeum jubatum	-17***	-12.1**	14.1	30
Lemna trisulca	-11**	-24.3**	24.5	17
Lemna turionifera	-8	-15.4**	15.6	16
Phalaris arundinacea	31***	38.9^{NA}	0.0	31
POA PRATENSIS	19***	5.8^{NA}	0.0	19
Polygonum amphibian var. emersum	-3	-4.4*	12.1	40
Potamogeton gramineus	-12**	-25.4***	25.4	13
Scolochloa festucacea	-8	-16.7**	31.4	22
Sparaganium eurycarpum	-13**	-19.5**	25.9	22
Utricularia vulgaris	-16***	-21.6***	21.8	20

*P < 0.05; **P < 0.01; ***P < 0.001; ^{NA}P: no test was conducted

Table 6 continued.

Species	Change in frequency	Absolute change in abundance (%)	Mean abundance 1960s (%)	n
Deep Marsh				
Carex atherodes	-7	-12.9*	13.2	21
Chenopodium rubrum	-16***	-16.0***	16.0	16
Eleocharis macrostachya	-6	-10.7*	10.8	11
Lemna trisulca	-2	-20.5**	24.3	20
Lemna turionifera	-5	-15.8**	16.4	17
Myriophyllum exalbescens	-3	-11.9*	12.3	11
Potamogeton pectinatus	-6	-12.9*	13.8	11
Scirpus acutus	-5*	-29.9***	39.0	22
Scolochloa festucacea	-4	-24.5**	25.1	12
TYPHA	7**	55.2***	11.4	22
Typha latifolia	-10**	-35.8***	36.4	21
Utricularia vulgaris	1	-16.6***	19.3	21
Open Water				
Ceratophyllum demersum	-1	-20.4*	21.3	7
Chenopodium rubrum	-9**	-28.8**	28.8	9
Eleocharis macrostachya	-10**	-35.3**	35.3	10
Lemna trisulca	-12**	-32.0***	35.5	21
Lemna turionifera	-9*	-15.1**	15.2	17
Myriophyllum exalbescens	-8	-10.0	14.3	20
Potamogeton pectinatus	-8*	-12.4**	18.1	25
Potamogeton pusillus var. pusillus	-11***	-12.9	12.9	11
Ranunculus longirostris	-13	-32.3***	32.3	14
Ruppia maritima	0	-7.8	23.2	5
Utricularia vulgaris	-5	-5.0	22.9	20
Zannichellia palustris	-16***	-12.6**	12.6	16

*P < 0.05; **P < 0.01; ***P < 0.001; ^{NA}P: no test was conducted

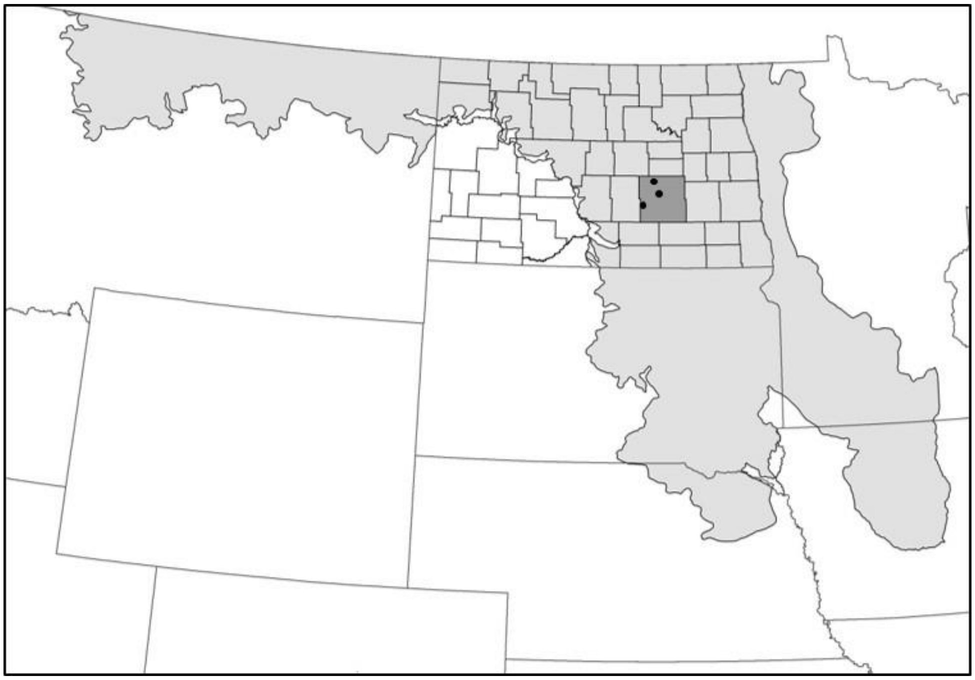

Figure 1. Location of study areas (black dots) in Prairie Pothole Region (light gray area). Dark gray area is Stutsman County, North Dakota.

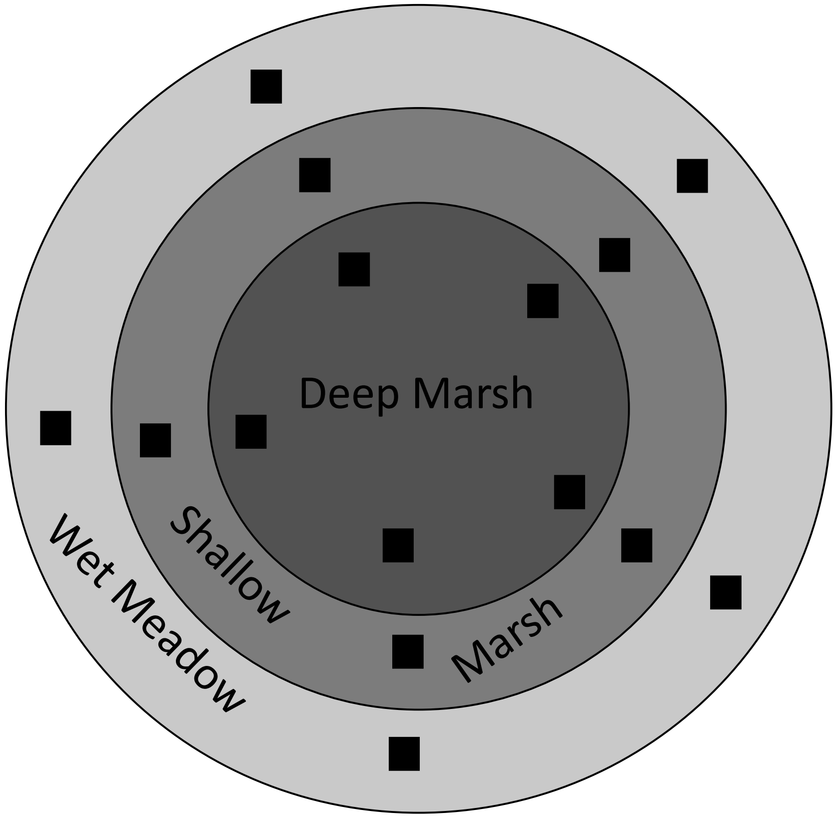

Figure 2. Schematic of quadrat layout for plant communities within wetland zones in 2013-2014 study in Stutsman County, North Dakota.

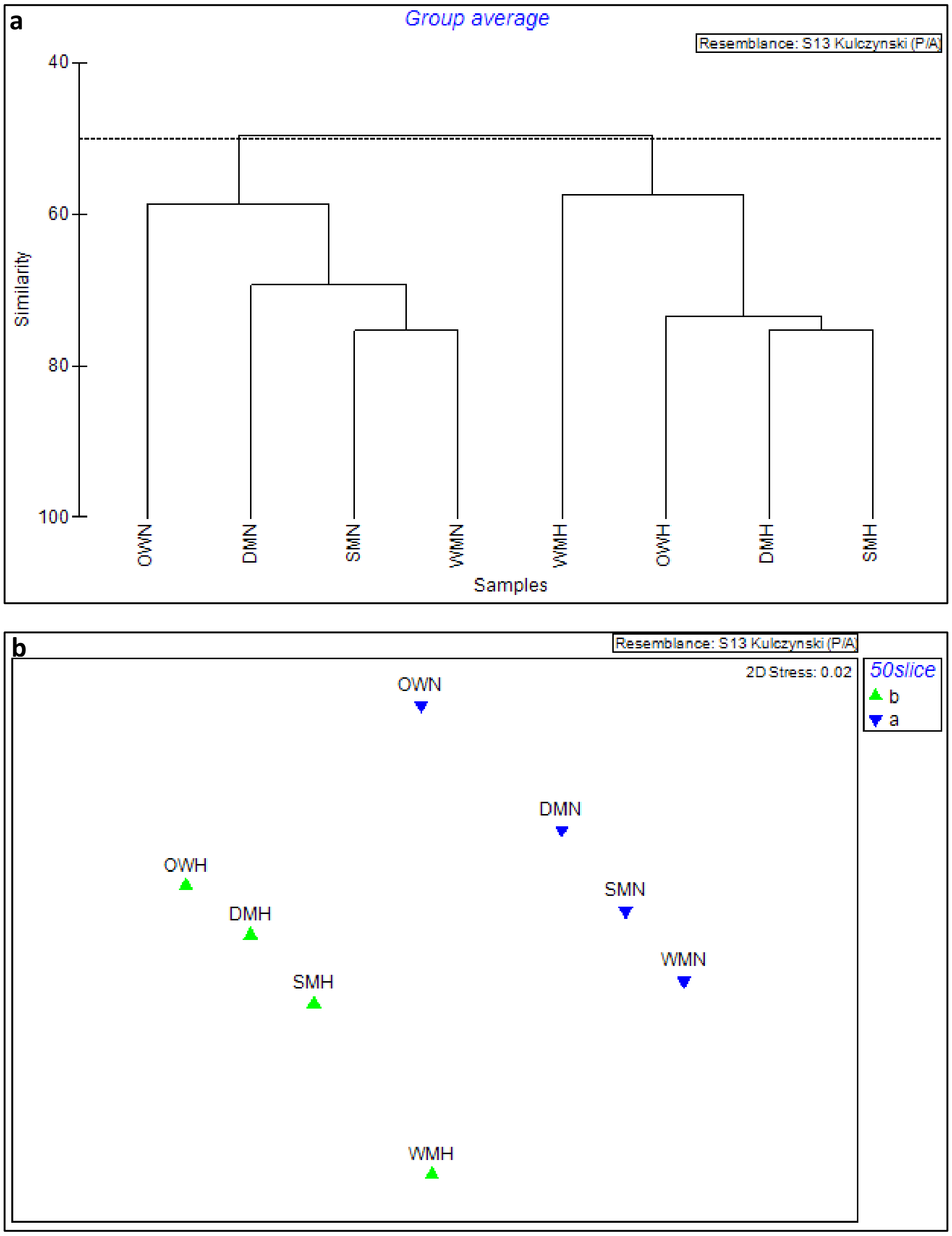

Figure 3. Results from cluster analyses (a) and non-metric multidimensional scaling (b) for zone communities: wet meadow (WM), shallow marsh (SM), deep marsh (DM), and open water (OW) between the 1961-1966 study (H) and the 2013-2014 study (N) with 50% resemblence threshold. On MDS, Group b consists of only zone plant communities from the 1960s and Group a consists of only zone plant communities from 2013-2014.

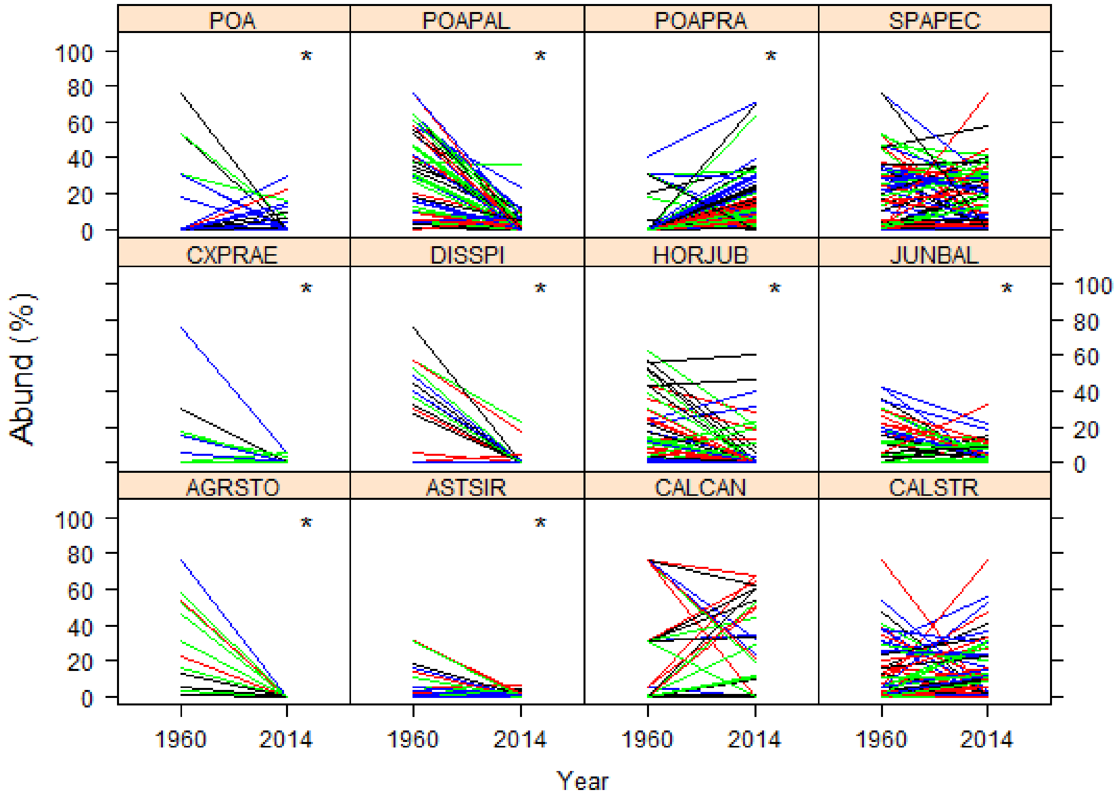

Figure 4. Change in abundance (%) of the 12 most abundant species in wet meadow zones between 1960s (1960) and 2013-2014 (2014) for three study areas in Stutsman County, North Dakota. The first 3 letters of the genus and species epithet is given (see Table A1 for full names). Asterisk indicates statistically significant changes in abundance (*P* < 0.05). Lines represent surveyed zones where the species was found at least once during the studies.

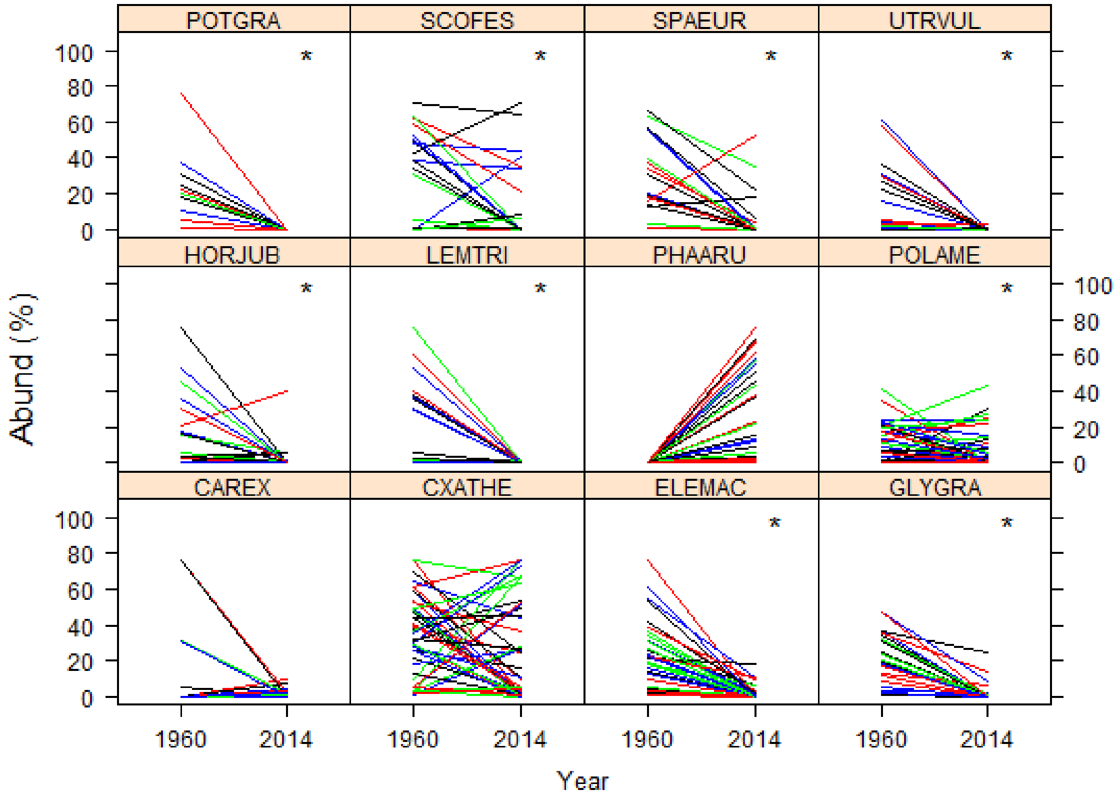

Figure 5. Change in abundance (%) of the 12 most abundant species in shallow marsh zones between 1960s (1960) and 2013-2014 (2014) for three study areas in Stutsman County, North Dakota. The first 3 letters of the genus and species epithet is given (see Table A1 for full names). Asterisk indicates statistically significant changes in abundance ($P < 0.05$). Lines represent surveyed zones where the species was found at least once during the studies.

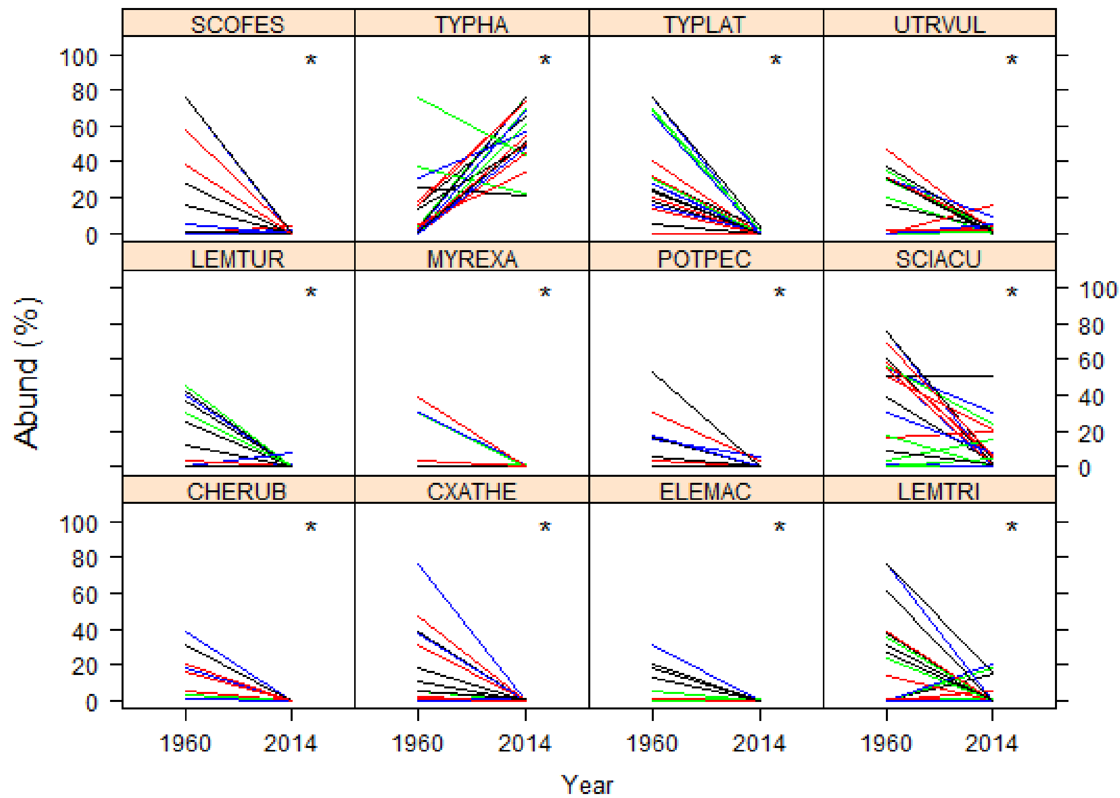

Figure 6. Change in abundance (%) of the 12 most abundant species in deep marsh zones between 1960s (1960) and 2013-2014 (2014) for three study areas in Stutsman County, North Dakota. The first 3 letters of the genus and species epithet is given (see Table A1 for full names). Asterisk indicates statistically significant changes in abundance ($P < 0.05$). Lines represent surveyed zones where the species was found at least once during the studies.

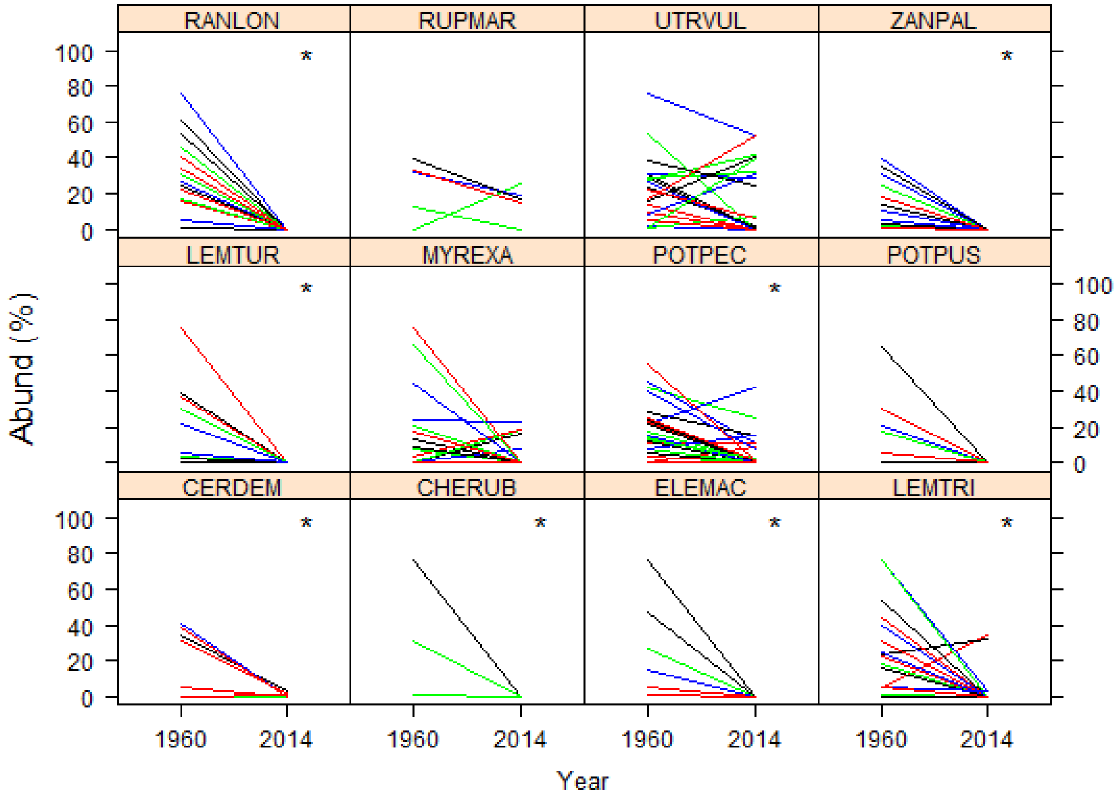

Figure 7. Change in abundance (%) of the 12 most abundant species in open water zones between 1960s (1960) and 2013-2014 (2014) for three study areas in Stutsman County, North Dakota. The first 3 letters of the genus and species epithet is given (see Table A1 for full names). Asterisk indicates statistically significant changes in abundance ($P < 0.05$). Lines represent surveyed zones where the species was found at least once during the studies.

CHAPTER 4.

SUMMARY AND RESEARCH NEEDS

Wetland conditions and plant communities within wetland zones changed considerably between 1961-1966 and 2013-2014. The deluge of the mid-1990s resulted in considerable increases of water on the landscape across the three study areas. Excess water was stored in wetland basins at Crystal Springs and Cottonwood whereas the excess water at Mt. Moriah was able to spill into existing intermittent streams.

Wetlands at Crystal Springs were larger, deeper, and fresher in 2013-14 compared to the 1960s. The increased water depths and merging of wetlands due to deluge conditions at this study area resulted in the overall reduction of wetland zones and wetland plant species. Additionally, plant species tolerant of high salinities were not present in 2013-14 due to the significant reduction and stability of specific conductivity post deluge.

Wetlands at Cottonwood were slightly larger, deeper, and more saline in 2013-14. Deluge conditions led to increased connectivity of wetlands at this study area with some wetlands completely merging, losing wetland zonation and plant species, and some wetlands connected by vegetated channels, mostly *Typha*, holding water throughout the growing season. Nearly all deep marsh zones were monotypic stands of *Typha*, and several shallow marsh zones were monotypic stands of *Phalaris arundinacea*. *Poa pratensis* and *Bromus inermis* were primary species of the upland plant community (personal observation); and consequently, *Poa pratensis* was found consistently in wet meadows as was *B. inermis*, but less often.

Wetlands at Mt. Moriah were more resilient to deluge conditions and therefore had subtle, almost negligent changes in size, depth, and specific conductivity. Despite the minimal change in wetland conditions, plant communities within wetland zones changed considerably and in a similar magnitude as Cottonwood. All deep marsh zones were dominated by monotypic stands of *Typha* in 2013-14 and shallow marsh zones surrounding these monotypic stands were dominated by *Phalaris arundinacea* or were absent. Overall there was a noticeable loss of shallow marsh zones in all permanent and several semipermanent wetlands. Shallow marsh zones in wetlands without *Typha* had high abundances of *Phalaris arundinacea*, but other typical shallow marsh species were also abundant in 2013-14. Wet meadow zones were less conspicuous in 2013-14 within more permanent wetlands, especially for those monotypic stands of *Typha*.

Climatic extremes greatly impacted wetland conditions in 2013-14, which influenced the plant communities within wetland zones across all study areas. Wetland size, depth, and specific conductivity are ephemeral characteristics and will continue to respond to inter- and intra- annual climate. Wetlands on WPAs are protected from drainage but these wetlands remain vulnerable to effects of wetland drainage and other anthropogenic changes on land surrounding WPAs. Shifts in wetland plant communities in these protected wetlands are concerning because it suggests that plant communities of protected wetlands (i.e., preserved or conserved) are still susceptible to invasive plant species establishment, which can led to an overall degradation of the remaining wetlands in the PPR. Wetlands do not respond uniformly to drought and deluge conditions (Winter 2003), but it is likely that wetlands across the region have responded in a similar matter as in these study wetlands and experience great shifts in wetland plant communities. This study documents the shifts in wetland conditions and plant communities but it does not address how these shifts affect ability of wetlands to provide ecosystem functions (e.g., water quality improvement, nutrient cycling) that benefit wildlife and humans simultaneously. Therefore, several research questions still need to be addressed:

1) Future studies should evaluate how the shift to deeper, larger wetlands affects wetland function and wildlife habitat quality;
2) Determine how the establishment of invasive plant species impacts wetland function;
3) If invasive species do affect wetland function, an assessment of the distribution and percent abundance of invasive plant species within wetlands across the PPR may reveal the overall functionality of wetlands in this region.

The PPR has experienced great change in overall anthropogenic land use and rapid loss of wetlands over the last 50 years. As the threat of wetland loss continues, the protection of wetlands will continue to be crucial to the persistence of these dynamic and highly productive ecosystems. The results from this comparison study indicate that protection of a wetland, in and of itself, may not be sufficient to protect the integrity and quality of wetlands.

Table A1. Complete plant species list for species occurring in wetland zones in 1961-1966 (1960s) and 2013-2014 (2013-14) on three study areas in Stutsman County, North Dakota. Nonnative plant species are in uppercase.

		Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
Species	Abbreviation	1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
Acer negundo	ACENEG		X						
Achillea millefolium subsp. lanulosa	ACHMIL		X						
Agoseris glauca [1]	AGOGLA	X							
Agrimonia striata [1]	AGRSTR		X				X		
Agropyron	AGROPYRON	X	X	X	X		X		
Agropyron caninum subsp. majus var. majus	AGRCAM	X							
Agropyron caninum subsp. majus var. unilater	AGRCAU	X		X					
AGROPYRON CRISTATUM [1]	AGRCRI		X						
AGROPYRON REPENS	AGRREP		X		X		X		X
Agropyron smithii	AGRSMI	X	X	X					
Agrostis	AGROSTIS	X		X					
Agrostis scabra	AGRSCA	X		X					
AGROSTIS STOLONIFERA	AGRSTO	X		X				X	
Agrostis/Poa	AGROSTIS/POA	X							
Alisma	ALISMA		X		X		X		X
Alisma gramineum	ALIGRA			X		X		X	
Alisma subcordatum	ALISUB	X		X		X		X	
Alisma trivale	ALITRI	X		X		X		X	
Allium stellatum	ALLSTE		X						
Alopecurus	ALOPECURUS			X					
Alopecurus aequalis	ALOAEQ	X	X	X	X	X	X	X	X
ALOPECURUS ARUNDINACEUS	ALOARU		X		X		X		

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow 1960s	Wet Meadow 2013-14	Shallow Marsh 1960s	Shallow Marsh 2013-14	Deep Marsh 1960s	Deep Marsh 2013-14	Open Water 1960s	Open Water 2013-14
Alopecurus geniculatus	ALOGEN	X		X					
Amaranthus albus [1]	AMAALB		X						
Amaranthus graecizans [1]	AMAGRA		X						
Amaranthus retroflexus [1]	AMARET		X						
Ambrosia	AMBROSIA	X							
Ambrosia artemisiifolia	AMBART		X		X				
Ambrosia psilostachya	AMBPSI	X	X	X	X		X		
Amorpha canescens	AMOCAN		X		X				
Amorpha fruticosa [1]	AMOFRU		X						
Andropogon gerardii	ANDGER	X	X						
Anemone canadensis	ANECAN	X	X		X				X
Anemone cylindrica	ANECYL		X						
Anemone patens [1]	ANEPAT		X						
Apocynum cannabinum	APOCAN	X	X	X	X		X		
Aquatic moss [1]	MOSS		X	X	X	X	X	X	X
ARCTIUM MINUS	ARCMIN	X	X		X				
Arenaria lateriflora [1]	ARELAT		X						
ARTEMISIA ABSINTHIUM	ARTABS		X		X		X		
ARTEMISIA BIENNIS	ARTBIE	X	X	X	X		X		
Artemisia ludoviciana var. ludoviciana	ARTLUD	X	X		X				
Asclepias	ASCLEPIAS		X		X				
Asclepias incarnata	ASCINC		X		X				
Asclepias speciosa [1]	ASCSPE		X						

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
		1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
Asclepias syriaca	ASCSYR		X		X				
Aster	ASTER	X	X	X	X		X		
Aster brachyactis	ASTBRA	X		X		X			
Aster ericoides	ASTERI	X	X	X	X	X			
Aster simplex var. ramosissimus	ASTSIR	X	X	X	X		X		
Aster/Boltonia	ASTER/BOLTONIA	X		X		X			
Astragalus canadensis [1]	ASTCAN		X						
Atriplex subspicata	ATRSUB	X		X		X		X	
Beckmannia syzigachne	BECSYZ	X	X	X	X	X	X	X	X
Bidens comosa	BIDCOM	X	X	X					
Bidens frondosa	BIDFRO		X		X		X		
Bidens vulgata	BIDVUL			X				X	
Boltonia	BOLTONIA			X		X			
Boltonia asteroides var. latisquama	BOLASL	X		X	X			X	
BRASSICA NIGRA [1]	BRANIG		X						
BROMUS INERMIS	BROINE	X	X		X		X		
BROMUS JAPONICUS	BROJAP	X							
Calamagrostis canadensis	CALCAN	X	X	X	X		X		
Calamagrostis stricta	CALSTR	X	X	X	X		X	X	
Calamovilfa longifolia [1]	CALLON		X		X				
Callitriche	CALLITRICHE			X				X	
Callitriche hermaphroditica	CALHER	X		X				X	
Callitriche verna	CALVER	X		X		X		X	

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
		1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
Calylophus serrulatus	CALSER		X		X				
Campanula rotundifolia	CAMROT	X	X						
Carex	CAREX	X	X	X	X		X		X
Carex aquatilis	CXAQUA							X	
Carex atherodes	CXATHE	X	X	X	X	X	X	X	X
Carex bebbii	CXBEBB	X							
Carex brevior	CXBREV	X	X						
Carex laeviconica	CXLAEV	X	X	X	X				
Carex lanuginosa	CXLANU		X		X		X		X
Carex praegracilis	CXPRAE	X	X	X					
Carex sartwellii	CXSART	X	X		X				
Carex sychnocephala	CXSYCH				X		X		
Carex tetanica	CXTETA		X						
Carex vulpinoidea	CXVULP	X	X	X					
Cerastium arvense	CERARV		X						
Ceratophyllum demersum	CERDEM			X	X	X	X	X	X
Chara[1]	CHARA	X		X		X	X	X	X
Chenopodium	CHENOPODIUM		X						X
CHENOPODIUM ALBUM	CHEALB		X	X	X		X	X	
CHENOPODIUM GLAUCUM	CHEGLA	X	X	X		X		X	
Chenopodium rubrum	CHERUB	X	X	X		X		X	
Cicuta maculata	CICMAC		X	X	X		X		
Cirsium	CIRSIUM		X		X		X		

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
		1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
CIRSIUM ARVENSE	CIRARV	X	X	X	X	X	X		X
Cirsium flodmanii	CIRFLO		X		X		X		
CIRSIUM VULGARE [1]	CIRVUL		X						
Comandra umbellata	COMUMB		X						
CONVOLVULUS ARVENSIS	CONARV		X		X				
Conyza canadensis	CONCAN		X						
Crataegus	CRATAEGUS		X		X				
CYNOGLOSSUM OFFICINALE [1]	CYNOFF		X		X				
Dalea purpurea var. purpurea	DALPUR		X		X				
DESCURAINIA SOPHIA	DESSOP	X		X					
Dichanthelium acuminatum var. acuminatum	DICACA	X		X		X			
Distichlis spicata	DISSPI	X	X	X				X	
ECHINOCHLOA CRUSGALLI	ECHCRU		X	X			X		
Echinochloa muricata var. microstachya	ECHMUR		X						
Elaeagnus commutata	ELACOM		X		X				
Eleocharis	ELEOCHARIS	X		X	X	X		X	
Eleocharis acicularis	ELEACI	X		X				X	
Eleocharis macrostachya	ELEMAC	X	X	X	X	X	X	X	X
Elymus canadensis	ELYCAN	X	X		X				
Epilobium ciliatum	EPICIL	X	X		X		X		
Epilobium leptophyllum	EPILEP		X		X		X		
Equisetum	EQUISETUM	X	X						
Equisetum arvense	EQUARV		X						

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
		1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
Equisetum fluviatile	EQUFLU		X						
Equisetum hyemale	EQUHYE	X	X		X				
Equisetum laevigatum	EQULAE	X	X		X				
Eragrostis	ERAGROSTIS	X							
ERYSIMUM CHEIRANTHOIDES	ERYCHE		X		X				
EUPHORBIA ESULA	EUPESU		X		X		X		
Euphorbia serpyllifolia	EUPSEF	X		X					
Euthamia graminifolia var. graminifolia	EUTGRG	X	X						
Filamentous algae [1]	ALGAE		X	X	X		X	X	X
Fragaria virginiana	FRAVIR		X		X				
Gaillardia aristata [1]	GAIARI		X						
Galium boreale	GALBOR	X	X		X				
Gentiana andrewsii [1]	GENAND		X						
Gentianopsis procera [1]	GENPRO	X							
Geum aleppicum	GEUALE		X						
Geum macrophyllum [1]	GEUMAC		X						
Glyceria	GLYCERIA								X
Glyceria borealis	GLYBOR			X					
Glyceria grandis	GLYGRA	X		X	X	X	X	X	X
Glyceria striata [1]	GLYSTR		X						
Glycyrrhiza lepidota	GLYLEP	X	X		X		X		
Grindelia squarrosa	GRISQS	X	X	X					
Heliathus	HELIANTHUS	X	X						

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
		1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
Helianthus maximilianii	HELMAX	X	X		X		X		
Helianthus rigidus subsp. subrhomboideus	HELRIG		X		X				
HESPERIS MATRONALIS [1]	HESMAT				X				
Hierochloe odorata [1]	HIEODO		X						
Hippuris vulgaris	HIPVUL			X		X		X	
Hordeum jubatum	HORJUB	X	X	X	X	X	X	X	X
Impatiens capensis	IMPCAP		X						
Iva xanthifolia [1]	IVAXAN		X						
Juncus	JUNCUS	X	X		X		X		
Juncus balticus	JUNBAL	X	X	X	X	X	X		
Juncus dudleyi [1]	JUNDUD	X							
Juncus interior	JUNINT	X	X						
Juncus longistylis	JUNLON			X					
Juncus tenuis	JUNTEN	X	X						
Juncus torreyi	JUNTOR	X	X						
Juniperus scopulorum [1]	JUNSCO				X				
KOCHIA SCOPARIA	KOCSCO	X	X	X	X	X			
Koeleria pyramidata	KOEPYR	X	X	X					
Lactuca oblongifolia	LACOBL	X	X		X				
LACTUCA SERRIOLA	LACSER	X	X	X		X			
Lemna trisulca	LEMTRI		X	X	X	X	X	X	X
Lemna turionifera	LEMTUR	X	X	X	X	X	X	X	X
Liatris	LIATRIS		X						

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
		1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
Liatris ligulistylis	LIALIG	X							
Lilium philadelphicum	LILPHI		X						
Linum perenne var. lewisii [1]	LINPER		X						
Lithospermum canescens	LITCAN		X						
Lobelia spicata	LOBSPI	X	X						
Lotus	LOTUS	X							
Lotus purshianus	LOTPUR		X		X				
Lycopus	LYCOPUS			X					
Lycopus americanus	LYCAME	X	X	X	X		X		X
Lycopus asper	LYCASP	X	X	X	X	X	X	X	X
Lysimachia ciliata	LYSCIL		X		X				
Lysimachia hybrida	LYSHYB	X		X	X			X	
Lysimachia thyrsiflora	LYSTHY		X		X		X		
MALVA NEGLECTA [1]	MALNEG		X						
MEDICAGO LUPULINA	MEDLUP		X		X				
MEDICAGO SATIVA	MEDSAT		X						
MELILOTUS	MELILOTUS	X	X		X				
MELILOTUS ALBA	MELALB	X	X		X				
MELILOTUS OFFICINALIS	MELOFF	X	X		X		X		X
Mentha arvensis	MENARV	X	X	X	X	X	X	X	X
Monarda fistulosa var. fistulosa [1]	MONFIF		X		X				
Muhlenbergia asperifolia	MUHASP	X	X						
Muhlenbergia cuspidata	MUHCUS		X						

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
		1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
Muhlenbergia racemosa	MUHRAC	X							
Muhlenbergia richardsonis	MUHRIC	X							
Myriophyllum exalbescens	MYREXA	X	X	X	X	X	X	X	X
Myriophyllum heterophyllum	MYRHET	X		X					
Oenothera biennis [1]	OENBIE		X						
Onosmodium molle var. occidentale	ONOMOL		X						
Orthocarpus luteus	ORTLUT	X							
Oxalis stricta	OXASTR		X		X		X		
Panicum capillare	PANCAP	X		X		X			
Panicum virgatum	PANVIR	X	X		X				
Parthenocissus quinquefolia [1]	PARQUI		X		X				
PASTINACA SATIVA [1]	PASSAT		X						
Phalaris arundinacea	PHAARU	X	X	X	X		X		X
PHLEUM PRATENSE	PHLPRA	X	X						
Phragmites australis	PHRAUS	X	X	X	X	X	X	X	
Physalis virginiana [1]	PHYVIR				X				
Picea glauca [1]	PICGLA				X				
Pinus sylvestris [1]	PINSYL				X				
PLANTAGO MAJOR	PLAMAJ		X		X				
Poa	POA	X	X						
Poa palustris	POAPAL	X	X	X	X		X	X	
POA PRATENSIS	POAPRA	X	X		X				
POA/AGROSTIS	POA/AGROSTIS	X							

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow 1960s	Wet Meadow 2013-14	Shallow Marsh 1960s	Shallow Marsh 2013-14	Deep Marsh 1960s	Deep Marsh 2013-14	Open Water 1960s	Open Water 2013-14
Polygonum	POLYGONUM	X	X		X		X		X
Polygonum amphibian var. emersum	POLAME	X	X	X	X	X	X	X	X
Polygonum amphibian var.stipulaceum	POLAMS	X	X	X	X	X	X	X	X
Polygonum aviculare	POLAVI	X		X		X			
POLYGONUM CONVOLVULUS	POLCON		X		X		X		
Polygonum lapathifolium	POLLAP	X		X				X	
Polygonum ramosissimum	POLRAM	X	X		X				
Populus deltoides subsp. monilifera[1]	POPDEL		X		X				
Potamogeton	POTAMOGETON		X		X		X		X
Potamogeton foliosus[1]	POTFOL								X
Potamogeton gramineus	POTGRA	X		X	X	X		X	X
Potamogeton pectinatus	POTPEC		X	X	X	X	X	X	X
Potamogeton pusillus var. pusillus	POTPUP			X		X		X	
Potamogeton richardsonii	POTRIC					X		X	
Potamogeton zosteriformis	POTZOS								X
Potentilla	POTENTILLA		X	X					
Potentilla anserina	POTANS	X	X	X	X	X	X		
Potentilla arguta	POTARG	X							
Potentilla norvegica	POTNOR	X	X	X	X	X			
Potentilla rivalis	POTRIV		X		X				
Prenanthes racemosa subsp. multiflora	PRERAC	X							
Prunus	PRUNUS		X						
Prunus americana	PRUAME		X						

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
		1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
Prunus virginiana	PRUVIR		X		X		X		
Psoralea argophylla	PSOARG		X						
Puccinellia nuttalliana	PUCNUT	X	X	X		X		X	
Ranunculus cymbalaria	RANCYM	X	X	X	X	X	X		
Ranunculus flabellaris	RANFLB			X					
Ranunculus longirostris	RANLON	X		X		X		X	X
Ranunculus macounii	RANMAC	X	X		X				
Ranunculus pensylvanicus	RANPEN		X		X		X		
Ranunculus rhomboideus	RANRHO	X		X					
Ranunculus sceleratus	RANSCE	X	X	X	X	X	X	X	X
Ranunculus	RANUNCULUS		X				X		X
Ratibida pinnata [1]	RATPIN		X						
Rhamnus	RHAMNUS		X						
RHAMNUS CATHARTICA	RHACAT		X						
Ribes [1]	RIBES		X		X				
Ribes americanum	RIBAME		X		X				
Riccia fluitans [1]	RICFLU		X	X	X	X	X	X	X
Ricciocarpos natans [1]	RICNAT			X		X		X	
Rorippa palustris subsp. glabra var. fernaldia	RORPAF	X	X	X	X	X	X	X	X
Rosa arkansana	ROSARK	X	X		X				
Rosa woodsii	ROSWOO	X	X		X				
Rubus idaeus subsp. sachalinensis[1]	RUBIDA		X		X				
Rudbeckia hirta	RUDHIR	X	X		X		X		

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
		1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
Rumex	RUMEX		X	X	X		X		X
RUMEX CRISPUS	RUMCRI	X	X	X	X				
RUMEX DOMESTICUS [1]	RUMDOM		X						
Rumex maritimus	RUMMAR	X	X	X	X	X	X	X	X
Rumex mexicanus	RUMMEX	X	X	X	X		X		
Rumex occidentalis	RUMOCC	X		X		X			
Ruppia maritima	RUPMAR				X			X	X
Sagittaria	SAGITTARIA								X
Sagittaria cuneata	SAGCUN	X		X	X	X	X	X	X
Salicornia rubra	SALRUB	X		X		X		X	
Salix	SALIX	X	X	X	X				
Salix amygdaloides	SALAMY		X		X				X
Salix exigua subsp. interior	SALEXI	X	X		X		X		
SALSOLA IBERICA	SALIBE	X							
Schizachyrium scoparium	SCHSCO		X		X				
Scirpus	SCIRPUS				X		X		X
Scirpus acutus	SCIACU	X	X	X	X	X	X	X	X
Scirpus atrovirens	SCIATV	X	X		X				
Scirpus fluviatilis	SCIFLU		X	X	X	X	X	X	X
Scirpus heterochaetus	SCIHET			X		X	X	X	
Scirpus maritimus var. paludosus	SCIMAR	X		X		X		X	
Scirpus pungens	SCIPUN	X	X	X	X	X	X		X
Scirpus validus	SCIVAL	X	X	X	X	X	X	X	X

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
		1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
Scolochloa festucacea	SCOFES	X	X	X	X	X	X	X	X
Scutellaria galericulata	SCUGAL		X		X		X		
Senecio congestus	SENCON		X		X	X	X		X
Setaria	SETARIA	X							
SETARIA GLAUCA	SETGLA		X		X				
Sium suave	SIUSUA	X	X	X	X	X	X	X	X
Solanum ptycanthum[1]	SOLPTY		X		X				
Solanum triflorum[1]	SOLTRI				X				
Solidago	SOLIDAGO		X	X			X		
Solidago canadensis	SOLCAN	X	X		X				
Solidago gigantea[1]	SOLGIG		X		X				
Solidago mollis	SOLMOL		X						
Solidago ptarmicoides[1]	SOLPTA		X						
Solidago rigida	SOLRIG	X	X				X		
SONCHUS ARVENSIS	SONARV	X	X	X	X	X	X		X
Sparaganium eurycarpum	SPAEUR		X	X	X	X	X	X	X
Spartina	SPARTINA	X		X					
Spartina gracilis	SPAGRA	X							
Spartina pectinata	SPAPEC	X	X	X	X		X		X
Spiraea alba	SPIALB	X	X						
Stachys palustris	STAPAL	X	X	X	X		X		
Stellaria longifolia	STELOF		X						
Stellaria longipes[1]	STELOP	X							

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
		1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
Suaeda depressa	SUADEP	X	X	X				X	
Symphoricarpos occidentalis	SYMOCC	X	X		X				
TARAXACUM OFFICINALE	TAROFF		X		X		X		
Teucrium canadense var. boreale	TEUCAN	X	X	X	X	X	X	X	
Thalictrum venulosum	THAVEN		X		X				
THLASPI ARVENSE [1]	THLARV				X				
Toxicodendron rydbergii	TOXRYD		X		X				
TRAGOPOGON DUBIUS [1]	TRADUB		X		X				
Triglochin maritima var. elata	TRIMAR	X	X						
TYPHA	TYPHA	X	X	X	X	X	X	X	X
Typha latifolia	TYPLAT	X	X	X	X	X	X	X	X
Unknow Forb	UNK FORB		X		X		X		
Unknown Grass	UNK GRASS		X		X		X		
Unknown Grasslike	UNK GRASSLIKE		X		X				
Unknown Seedling	UNK SEEDLING		X		X		X		
Unknown Shrub	UNK SHRUB		X						
Unknown Submerged Aquatic	UNK SAV				X		X		X
Unknown Tree	UNK TREE		X		X				
Unknown Vine	UNK VINE		X		X				
Urtica dioica	URTDIO	X	X	X	X	X	X		
Utricularia vulgaris	UTRVUL		X	X	X	X	X	X	X
Utricularia vulgaris	UTRVUL		X	X	X	X	X	X	X
Verbena	VERBENA	X							

[1]Species not assigned abundance codes

Table A1. Continued.

Species	Abbreviation	Wet Meadow		Shallow Marsh		Deep Marsh		Open Water	
		1960s	2013-14	1960s	2013-14	1960s	2013-14	1960s	2013-14
Verbena hastata	VERHAS	X	X	X	X				
Verbena stricta	VERSTR				X				
Vernonia fasciculata var. corymbosa	VERFAS	X	X						
Viola	VIOLA		X						
Viola pedatifida	VIOPED		X						
Viola sororia	VIOSOR				X				
X Agrohordeum macounii	AGRMAC	X							
Xanthium strumarium	XANSTR	X	X	X	X		X		X
Zannichellia palustris	ZANPAL	X		X		X		X	X
Zigadenus elegans	ZIGELE		X						
Zigadenus venenosus	ZIGVEN		X						
Zizia aptera	ZIZAPT	X	X						

[1]Species not assigned abundance codes

Table A2. Changes in frequency for species in 1960s and 2013-14 at all zones for all observed species for three study areas in Stutsman County, North Dakota. The absolute change in percent abundance is reported together with means of the two studies. Nonnative species are in uppercase. *P*-values are derived from Fisher's exact test.

Species	*P*	Change	1960s	2013-14
Wet Meadow				
Acer negundo	1.00	1	0	1
Achillea millefolium subsp. lanulosa	0.12	4	0	4
Agropyron	<0.001	-13	13	0
Agropyron caninum subsp. majus var. majus	<0.001	-31	31	0
Agropyron caninum subsp. majus var. unilaterale	<0.001	-18	18	0
AGROPYRON REPENS	<0.001	66	0	66
Agropyron smithii	<0.001	-12	12	0
Agrostis	<0.001	-7	7	0
Agrostis scabra	0.12	-4	4	0
AGROSTIS STOLONIFERA	<0.001	-39	39	0
Agrostis/Poa	0.50	-2	2	0
Alisma subcordatum	1.00	-1	1	0
Allium stellatum	0.50	2	0	2
Alopecurus aequalis	0.37	-3	4	1
ALOPECURUS ARUNDINACEUS	0.50	2	0	2
Ambrosia	1.00	-1	1	0
Ambrosia artemisiifolia	0.01	7	0	7
Ambrosia psilostachya	0.04	-13	32	19
Amorpha canescens	<0.01	11	0	11
Andropogon gerardii	0.03	8	2	10
Anemone canadensis	<0.01	17	31	48
Anemone cylindrica	1.00	1	0	1
Apocynum cannabinum	<0.001	26	9	35
ARCTIUM MINUS	1.00	-1	1	0
ARTEMISIA ABSINTHIUM	<0.001	21	0	21
ARTEMISIA BIENNIS	<0.001	-12	12	0
Artemisia ludoviciana var. ludoviciana	0.07	-10	21	11
Asclepias	<0.001	16	0	16
Asclepias incarnata	1.00	1	0	1
Asclepias syriaca	<0.01	11	0	11
Aster	1.00	1	12	13
Aster brachyactis	<0.01	-8	8	0
Aster ericoides	0.59	-4	24	20
Aster simplex var. ramosissimus	1.00	1	46	47
Aster/Boltonia	0.50	-2	2	0
Atriplex subspicata	<0.01	-10	10	0
Beckmannia syzigachne	<0.001	-12	12	0
Bidens comosa	1.00	0	1	1

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
Bidens frondosa	0.50	2	0	2
Boltonia asteroides var. latisquama	<0.001	-36	36	0
BROMUS INERMIS	<0.001	49	1	50
BROMUS JAPONICUS	1.00	-1	1	0
Calamagrostis canadensis	0.59	4	20	24
Calamagrostis stricta	0.15	-9	55	46
Callitriche verna	1.00	-1	1	0
Calylophus serrulatus	1.00	1	0	1
Campanula rotundifolia	1.00	-1	1	0
Carex	<0.001	40	9	49
Carex atherodes	<0.001	43	13	56
Carex bebbii	1.00	-1	1	0
Carex brevior	1.00	-1	2	1
Carex laeviconica	0.82	-2	12	10
Carex lanuginosa	<0.001	33	0	33
Carex praegracilis	<0.001	-23	31	8
Carex sartwellii	<0.001	30	1	31
Carex tetanica	0.01	7	0	7
Carex vulpinoidea	0.12	-4	4	0
Cerastium arvense	0.50	2	0	2
Chenopodium	0.06	5	0	5
CHENOPODIUM ALBUM	0.03	6	0	6
CHENOPODIUM GLAUCUM	1.00	-1	2	1
Chenopodium rubrum	0.17	-5	7	2
Cicuta maculata	0.50	2	0	2
Cirsium	0.03	6	0	6
CIRSIUM ARVENSE	<0.001	41	30	71
Cirsium flodmanii	0.03	6	0	6
Comandra umbellata	<0.01	10	0	10
CONVOLVULUS ARVENSIS	0.25	3	0	3
Crataegus	0.12	4	0	4
Dalea purpurea var. purpurea	1.00	1	0	1
Dichanthelium acuminatum var. acuminatum	0.12	-4	4	0
Distichlis spicata	0.01	-11	15	4
ECHINOCHLOA CRUSGALLI	0.50	2	0	2
Echinochloa muricata var. microstachya	1.00	1	0	1
Elaeagnus commutata	<0.01	9	0	9
Eleocharis macrostachya	1.00	0	27	27
Elymus canadensis	1.00	1	2	3
Epilobium ciliatum	1.00	1	2	3
Epilobium leptophyllum	1.00	1	0	1
Equisetum	1.00	0	1	1
Equisetum arvense	1.00	1	0	1

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
Equisetum fluviatile	1.00	1	0	1
Equisetum hyemale	1.00	1	1	2
Equisetum laevigatum	0.44	3	2	5
Eragrostis	1.00	-1	1	0
EUPHORBIA ESULA	<0.01	10	0	10
Euphorbia serpyllifolia	1.00	-1	1	0
Euthamia graminifolia var. graminifolia	1.00	-1	2	1
Fragaria virginiana	0.01	7	0	7
Galium boreale	<0.001	18	1	19
Geum aleppicum	0.50	2	0	2
Glyceria grandis	0.12	-4	4	0
Glycyrrhiza lepidota	<0.01	18	30	48
Grindelia squarrosa	<0.001	-14	15	1
Helianthus maximilianii	0.12	10	21	31
Helianthus rigidus subsp. subrhomboideus	<0.001	27	0	27
Heliathus	0.50	2	0	2
Hordeum jubatum	<0.001	-43	66	23
Impatiens capensis	0.25	3	0	3
Juncus	1.00	-1	1	0
Juncus balticus	0.40	6	31	37
Juncus interior	1.00	0	1	1
Juncus tenuis	1.00	-1	1	0
Juncus torreyi	<0.01	-9	9	0
KOCHIA SCOPARIA	0.10	-6	8	2
Koeleria pyramidata	0.06	-6	7	1
Lactuca oblongifolia	<0.001	37	0	37
LACTUCA SERRIOLA	0.68	-2	4	2
Lemna trisulca	0.25	3	0	3
Lemna turionifera	0.25	3	0	3
Liatris	<0.01	11	0	11
Liatris ligulistylis	0.25	-3	3	0
Lilium philadelphicum	0.03	6	0	6
Lithospermum canescens	0.25	3	0	3
Lobelia spicata	0.50	-2	2	0
Lotus	1.00	-1	1	0
Lotus purshianus	0.01	7	0	7
Lycopus americanus	1.00	-1	5	4
Lycopus asper	0.01	16	29	45
Lysimachia ciliata	1.00	1	0	1
Lysimachia hybrida	<0.001	-20	20	0
Lysimachia thyrsiflora	0.06	5	0	5
MEDICAGO LUPULINA	1.00	1	0	1
MEDICAGO SATIVA	0.12	4	0	4

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
MELILOTUS	0.21	-4	5	1
MELILOTUS ALBA	1.00	-1	5	4
MELILOTUS OFFICINALIS	0.04	10	7	17
Mentha arvensis	0.23	-7	20	13
Muhlenbergia asperifolia	0.09	-8	14	6
Muhlenbergia cuspidata	1.00	1	0	1
Muhlenbergia racemosa	1.00	-1	1	0
Muhlenbergia richardsonis	1.00	-1	1	0
Myriophyllum exalbescens	1.00	1	2	3
Onosmodium molle var. occidentale	1.00	1	0	1
Orthocarpus luteus	0.25	-3	3	0
Oxalis stricta	0.12	4	0	4
Panicum capillare	0.25	-3	3	0
Panicum virgatum	0.65	-3	13	10
Phalaris arundinacea	<0.001	32	1	33
PHLEUM PRATENSE	0.03	-6	6	0
Phragmites australis	1.00	0	2	2
Poa	0.52	-4	15	11
Poa palustris	<0.001	-27	65	38
POA PRATENSIS	<0.001	50	13	63
POA/AGROSTIS	0.50	-2	2	0
Polygonum	<0.01	10	1	11
Polygonum amphibian var. emersum	1.00	0	34	34
Polygonum amphibian var.stipulaceum	<0.001	16	3	19
Polygonum aviculare	0.50	-2	2	0
POLYGONUM CONVOLVULUS	0.03	6	0	6
Polygonum lapathifolium	1.00	-1	1	0
Polygonum ramosissimum	0.50	-2	2	0
Potamogeton	0.50	2	0	2
Potamogeton gramineus	1.00	-1	1	0
Potentilla	0.01	7	0	7
Potentilla anserina	0.35	-6	22	16
Potentilla norvegica	0.03	-9	12	3
Potentilla rivalis	1.00	1	0	1
Prenanthes racemosa subsp. multiflora	1.00	-1	1	0
Prunus americana	1.00	1	0	1
Prunus virginiana	0.50	2	0	2
Psoralea argophylla	0.50	2	0	2
Puccinellia nuttalliana	<0.01	-11	12	1
Ranunculus	1.00	1	0	1
Ranunculus cymbalaria	0.03	-6	6	0
Ranunculus macounii	0.12	-5	6	1
Ranunculus rhomboideus	1.00	-1	1	0

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
Ranunculus sceleratus	0.37	3	1	4
RHAMNUS CATHARTICA	1.00	1	0	1
Ribes americanum	1.00	1	0	1
Rorippa palustris subsp. glabra var. fernaldiana	0.12	-4	4	0
Rosa arkansana	<0.001	29	1	30
Rosa woodsii	1.00	-1	4	3
Rudbeckia hirta	0.40	4	5	9
Rumex	<0.01	14	2	16
RUMEX CRISPUS	1.00	-1	1	0
Rumex maritimus	1.00	-1	4	3
Rumex mexicanus	<0.001	-12	12	0
Rumex occidentalis	0.25	-3	3	0
Salicornia rubra	0.50	-2	2	0
Salix	1.00	-1	1	0
Salix exigua subsp. interior	0.25	-3	3	0
SALSOLA IBERICA	1.00	-1	1	0
Schizachyrium scoparium	0.50	2	0	2
Scirpus acutus	0.08	7	3	10
Scirpus atrovirens	1.00	-1	1	0
Scirpus fluviatilis	<0.01	9	0	9
Scirpus maritimus var. paludosus	1.00	-1	1	0
Scirpus pungens	0.62	-3	11	8
Scirpus validus	0.62	2	1	3
Scolochloa festucacea	0.43	4	6	10
Scutellaria galericulata	0.50	2	0	2
Setaria	1.00	-1	1	0
SETARIA GLAUCA	0.50	2	0	2
Sium suave	0.12	4	0	4
Solidago	0.12	4	0	4
Solidago canadensis	0.06	12	39	51
Solidago mollis	1.00	1	0	1
Solidago rigida	<0.01	12	2	14
SONCHUS ARVENSIS	<0.001	32	31	63
Sparaganium eurycarpum	1.00	1	0	1
Spartina	0.50	-2	2	0
Spartina gracilis	0.50	-2	2	0
Spartina pectinata	0.47	-4	64	60
Spiraea alba	1.00	1	1	2
Stachys palustris	0.49	5	23	28
Stellaria longifolia	0.50	-2	2	0
Suaeda depressa	0.50	-2	2	0
Symphoricarpos occidentalis	<0.001	41	2	43
TARAXACUM OFFICINALE	<0.001	35	0	35

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
Teucrium canadense var. boreale	0.74	-3	37	34
Thalictrum venulosum	1.00	1	0	1
Toxicodendron rydbergii	0.50	2	0	2
Triglochin maritima var. elata	0.50	-2	2	0
TYPHA	<0.001	41	0	41
Typha latifolia	0.37	3	1	4
Unknow Forb	<0.001	57	0	57
Unknown Grass	<0.001	47	0	47
Unknown Grasslike	0.25	3	0	3
Unknown Seedling	<0.001	12	0	12
Unknown Shrub	0.25	3	0	3
Unknown Tree	1.00	1	0	1
Unknown Vine	0.50	2	0	2
Urtica dioica	<0.01	10	2	12
Utricularia vulgaris	1.00	1	0	1
Verbena hastata	0.12	-4	4	0
Vernonia fasciculata var. corymbosa	0.12	-5	6	1
Viola	0.25	3	0	3
Viola pedatifida	0.12	4	0	4
X Agrohordeum macounii	1.00	-1	1	0
Xanthium strumarium	0.03	-6	6	0
Zigadenus elegans	1.00	1	0	1
Zigadenus venenosus	1.00	1	0	1
Zizia aptera	0.61	3	7	10
Shallow Marsh				
Agropyron	1.00	-1	1	0
AGROPYRON REPENS	<0.001	16	0	16
Agropyron smithii	0.49	-2	2	0
Agrostis	0.24	-3	3	0
Agrostis scabra	1.00	-1	1	0
AGROSTIS STOLONIFERA	<0.001	-16	16	0
Alisma	0.06	5	0	5
Alisma gramineum	1.00	-1	1	0
Alisma subcordatum	0.24	-3	3	0
Alisma trivale	<0.001	-24	24	0
Alopecurus	1.00	-1	1	0
Alopecurus aequalis	0.06	-8	13	5
ALOPECURUS ARUNDINACEUS	1.00	1	0	1
Alopecurus geniculatus	0.49	-2	2	0
Ambrosia artemisiifolia	1.00	1	0	1
Ambrosia psilostachya	1.00	0	1	1
Amorpha canescens	1.00	1	0	1
Anemone canadensis	<0.01	9	0	9

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
Apocynum cannabinum	0.03	7	1	8
ARTEMISIA ABSINTHIUM	<0.001	14	0	14
ARTEMISIA BIENNIS	0.62	2	1	3
Artemisia ludoviciana var. ludoviciana	0.49	2	0	2
Asclepias	0.24	3	0	3
Asclepias syriaca	1.00	1	0	1
Aster	0.16	-5	7	2
Aster brachyactis	0.24	-3	3	0
Aster ericoides	0.62	-2	3	1
Aster simplex var. ramosissimus	<0.01	13	7	20
Atriplex subspicata	0.06	-5	5	0
Beckmannia syzigachne	<0.001	-28	31	3
Bidens comosa	1.00	-1	1	0
Bidens vulgata	0.49	-2	2	0
Boltonia	1.00	-1	1	0
Boltonia asteroides var. latisquama	<0.001	-25	27	2
BROMUS INERMIS	<0.001	17	0	17
Calamagrostis canadensis	<0.001	16	2	18
Calamagrostis stricta	0.30	5	7	12
Callitriche	1.00	-1	1	0
Callitriche hermaphroditica	0.49	-2	2	0
Callitriche verna	<0.001	-20	20	0
Carex	<0.01	13	7	20
Carex atherodes	0.20	-4	44	40
Carex laeviconica	1.00	1	1	2
Carex lanuginosa	<0.01	8	0	8
Carex praegracilis	1.00	-1	1	0
Carex sartwellii	0.03	6	0	6
Carex sychnocephala	1.00	1	0	1
Carex vulpinoidea	1.00	-1	1	0
Ceratophyllum demersum	1.00	0	1	1
CHENOPODIUM ALBUM	0.32	-4	7	3
CHENOPODIUM GLAUCUM	0.49	2	0	2
Chenopodium rubrum	<0.01	-12	13	1
Cicuta maculata	1.00	1	1	2
Cirsium	0.03	6	0	6
CIRSIUM ARVENSE	<0.001	28	15	43
Cirsium flodmanii	0.49	2	0	2
CONVOLVULUS ARVENSIS	1.00	1	0	1
Crataegus	1.00	1	0	1
Dichanthelium acuminatum var. acuminatum	1.00	-1	1	0
ECHINOCHLOA CRUSGALLI	1.00	-1	1	0
Eleocharis	0.24	-3	3	0

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
Eleocharis acicularis	<0.01	-8	8	0
Eleocharis macrostachya	<0.001	-31	41	10
Elymus canadensis	1.00	1	0	1
Epilobium ciliatum	0.24	3	0	3
Epilobium leptophyllum	1.00	1	0	1
Equisetum laevigatum	0.49	2	0	2
ERYSIMUM CHEIRANTHOIDES	1.00	1	0	1
EUPHORBIA ESULA	0.03	6	0	6
Galium boreale	1.00	1	0	1
Glyceria borealis	1.00	-1	1	0
Glyceria grandis	<0.001	-24	30	6
Glycyrrhiza lepidota	<0.001	14	0	14
Helianthus maximilianii	0.24	3	0	3
Helianthus rigidus subsp. subrhomboideus	1.00	1	0	1
Hippuris vulgaris	0.12	-4	4	0
Hordeum jubatum	<0.001	-17	26	9
Juncus balticus	0.27	4	2	6
Juncus longistylis	1.00	-1	1	0
KOCHIA SCOPARIA	0.24	-3	3	0
Lactuca oblongifolia	<0.01	9	0	9
LACTUCA SERRIOLA	1.00	-1	1	0
Lemna trisulca	<0.01	-11	15	4
Lemna turionifera	0.06	-8	13	5
Lotus purshianus	0.12	4	0	4
Lycopus	1.00	-1	1	0
Lycopus americanus	0.20	4	1	5
Lycopus asper	<0.01	16	12	28
Lysimachia ciliata	0.24	3	0	3
Lysimachia hybrida	<0.01	-11	12	1
Lysimachia thyrsiflora	0.24	3	0	3
MELILOTUS	1.00	1	0	1
MELILOTUS ALBA	0.49	2	0	2
MELILOTUS OFFICINALIS	0.12	4	0	4
Mentha arvensis	1.00	0	22	22
Myriophyllum exalbescens	0.52	-3	7	4
Panicum capillare	0.49	-2	2	0
Phalaris arundinacea	<0.001	31	0	31
Phragmites australis	1.00	1	2	3
PLANTAGO MAJOR	0.49	2	0	2
Poa palustris	<0.01	15	4	19
POA PRATENSIS	<0.001	19	0	19
Polygonum	0.01	10	3	13
Polygonum amphibian var. emersum	0.62	-3	36	33

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
Polygonum amphibian var.stipulaceum	1.00	0	10	10
POLYGONUM CONVOLVULUS	0.24	3	0	3
Polygonum lapathifolium	<0.01	-8	8	0
Potamogeton	0.49	2	0	2
Potamogeton gramineus	<0.01	-12	13	1
Potamogeton pectinatus	0.36	-3	4	1
Potamogeton pusillus var. pusillus	0.49	-2	2	0
Potentilla	0.06	6	1	7
Potentilla anserina	1.00	1	2	3
Potentilla norvegica	0.01	-10	13	3
Prunus virginiana	1.00	1	0	1
Puccinellia nuttalliana	0.06	-5	5	0
Ranunculus cymbalaria	0.20	-4	5	1
Ranunculus flabellaris	1.00	-1	1	0
Ranunculus longirostris	0.06	-5	5	0
Ranunculus macounii	0.49	2	0	2
Ranunculus pensylvanicus	1.00	1	0	1
Ranunculus rhomboideus	1.00	-1	1	0
Ranunculus sceleratus	1.00	-1	3	2
Ribes americanum	1.00	1	0	1
Rorippa palustris subsp. glabra var. fernaldiana	0.01	-11	16	5
Rosa arkansana	0.49	2	0	2
Rosa woodsii	1.00	1	0	1
Rumex	0.02	9	3	12
RUMEX CRISPUS	0.06	-6	7	1
Rumex maritimus	0.52	-3	7	4
Rumex mexicanus	0.12	-6	9	3
Rumex occidentalis	0.06	-5	5	0
Ruppia maritima	1.00	1	0	1
Sagittaria cuneata	0.03	-7	8	1
Salicornia rubra	1.00	-1	1	0
Salix	1.00	-1	1	0
Salix exigua subsp. interior	1.00	1	0	1
Scirpus	0.12	4	0	4
Scirpus acutus	<0.01	-12	17	5
Scirpus fluviatilis	0.38	-4	9	5
Scirpus heterochaetus	0.49	-2	2	0
Scirpus maritimus var. paludosus	0.03	-6	6	0
Scirpus pungens	0.27	-4	6	2
Scirpus validus	0.32	-4	7	3
Scolochloa festucacea	0.12	-8	19	11
Scutellaria galericulata	1.00	1	0	1
Senecio congestus	1.00	1	0	1

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
SETARIA GLAUCA	1.00	1	0	1
Sium suave	<0.01	-16	29	13
Solidago	1.00	-1	1	0
Solidago canadensis	<0.001	11	0	11
SONCHUS ARVENSIS	<0.001	20	9	29
Sparaganium eurycarpum	<0.01	-13	22	9
Spartina pectinata	<0.001	17	4	21
Stachys palustris	<0.001	20	3	23
Suaeda depressa	1.00	-1	1	0
Symphoricarpos occidentalis	0.01	7	0	7
TARAXACUM OFFICINALE	<0.001	11	0	11
Teucrium canadense var. boreale	<0.01	14	15	29
Thalictrum venulosum	1.00	1	0	1
Toxicodendron rydbergii	1.00	1	0	1
TYPHA	<0.001	22	4	26
Typha latifolia	0.19	-6	12	6
Unknow Forb	<0.001	29	0	29
Unknown Grass	<0.001	26	0	26
Unknown Grasslike	0.12	4	0	4
Unknown Seedling	<0.01	9	0	9
Unknown Submerged Aquatic	0.12	4	0	4
Unknown Tree	1.00	1	0	1
Urtica dioica	0.14	6	4	10
Utricularia vulgaris	<0.001	-16	19	3
Verbena hastata	0.49	-2	2	0
Viola sororia	1.00	1	0	1
Xanthium strumarium	0.24	-3	3	0
Zannichellia palustris	1.00	-1	1	0
Deep Marsh				
Alisma	1.00	0	1	1
Alisma gramineum	1.00	-1	1	0
Alisma subcordatum	0.11	-4	4	0
Alisma trivale	0.49	-2	2	0
Alopecurus aequalis	0.23	-3	3	0
ALOPECURUS ARUNDINACEUS	1.00	1	0	1
Aster brachyactis	0.49	-2	2	0
Aster/Boltonia	1.00	-1	1	0
Atriplex subspicata	0.49	-2	2	0
Beckmannia syzigachne	0.11	-4	4	0
Boltonia	1.00	-1	1	0
Callitriche verna	1.00	-1	1	0
Carex	1.00	1	0	1
Carex atherodes	0.07	-7	15	8

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
Carex lanuginosa	1.00	1	0	1
Ceratophyllum demersum	1.00	-1	4	3
CHENOPODIUM GLAUCUM	0.23	-3	3	0
Chenopodium rubrum	<0.001	-16	16	0
CIRSIUM ARVENSE	1.00	-1	8	7
Eleocharis macrostachya	0.09	-6	9	3
Glyceria grandis	0.05	-5	5	0
Hippuris vulgaris	0.49	-2	2	0
Hordeum jubatum	0.13	-5	7	2
Juncus balticus	1.00	0	1	1
KOCHIA SCOPARIA	1.00	-1	1	0
Lemna trisulca	0.76	-2	14	12
Lemna turionifera	0.22	-5	12	7
Lycopus asper	0.74	2	5	7
Mentha arvensis	0.02	-6	6	0
Myriophyllum exalbescens	0.53	-3	9	6
Panicum capillare	1.00	-1	1	0
Phalaris arundinacea	<0.001	11	0	11
Phragmites australis	1.00	1	2	3
Polygonum	0.49	2	0	2
Polygonum amphibian var. emersum	1.00	-1	2	1
Polygonum amphibian var.stipulaceum	1.00	0	3	3
POLYGONUM CONVOLVULUS	1.00	1	0	1
Potamogeton	0.23	3	0	3
Potamogeton pectinatus	0.10	-6	10	4
Potamogeton pusillus var. pusillus	0.49	-2	2	0
Potentilla anserina	1.00	-1	1	0
Potentilla norvegica	0.23	-3	3	0
Puccinellia nuttalliana	0.49	-2	2	0
Ranunculus cymbalaria	0.49	-2	2	0
Ranunculus longirostris	0.02	-6	6	0
Ranunculus sceleratus	1.00	-1	6	5
Rorippa palustris subsp. glabra var. fernaldiana	0.23	-3	3	0
Rumex	1.00	0	1	1
Rumex maritimus	0.74	-2	7	5
Rumex occidentalis	0.23	-3	3	0
Sagittaria cuneata	0.02	-6	6	0
Salix exigua subsp. interior	1.00	1	0	1
Scirpus	0.02	6	0	6
Scirpus acutus	0.05	-5	22	17
Scirpus fluviatilis	0.66	-2	4	2
Scirpus heterochaetus	0.23	-3	3	0
Scirpus maritimus var. paludosus	0.05	-5	5	0

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
Scirpus pungens	1.00	0	2	2
Scirpus validus	0.74	-2	7	5
Scolochloa festucacea	0.33	-4	9	5
Senecio congestus	1.00	-1	1	0
Sium suave	1.00	-1	7	6
SONCHUS ARVENSIS	1.00	-1	4	3
Sparaganium eurycarpum	0.19	-4	5	1
Spartina pectinata	0.11	4	0	4
Stachys palustris	1.00	1	0	1
Teucrium canadense var. boreale	0.49	-3	7	4
TYPHA	<0.01	7	15	22
Typha latifolia	<0.01	-10	20	10
Unknow Forb	0.23	3	0	3
Unknown Grass	0.23	3	0	3
Unknown Seedling	0.23	3	0	3
Unknown Submerged Aquatic	0.11	4	0	4
Urtica dioica	1.00	-1	2	1
Utricularia vulgaris	1.00	1	14	15
Zannichellia palustris	0.05	-5	5	0
Open Water				
Alisma gramineum	0.01	-7	7	0
Alisma subcordatum	0.49	-2	2	0
Alisma trivale	0.49	-2	2	0
Alopecurus aequalis	0.11	-4	4	0
Atriplex subspicata	1.00	-1	1	0
Beckmannia syzigachne	0.05	-5	5	0
Callitriche	1.00	-1	1	0
Callitriche hermaphroditica	1.00	-1	1	0
Callitriche verna	0.49	-2	2	0
Carex	1.00	-1	1	0
Carex atherodes	<0.001	-11	11	0
Ceratophyllum demersum	1.00	-1	5	4
CHENOPODIUM GLAUCUM	0.11	-4	4	0
Chenopodium rubrum	<0.01	-9	9	0
Distichlis spicata	1.00	-1	1	0
Eleocharis	1.00	-1	1	0
Eleocharis acicularis	1.00	-1	1	0
Eleocharis macrostachya	<0.01	-10	10	0
Glyceria grandis	0.01	-7	7	0
Hippuris vulgaris	0.49	-2	2	0
Hordeum jubatum	0.49	-2	2	0
Lemna trisulca	<0.01	-12	20	8
Lemna turionifera	0.02	-9	14	5

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
Lycopus asper	1.00	-1	1	0
Lysimachia hybrida	1.00	-1	1	0
Mentha arvensis	1.00	-1	1	0
Myriophyllum exalbescens	0.06	-8	16	8
Phalaris arundinacea	1.00	1	0	1
Phragmites australis	0.49	-2	2	0
Polygonum	1.00	1	0	1
Polygonum amphibian var. emersum	1.00	-1	1	0
Polygonum amphibian var.stipulaceum	0.05	-6	7	1
Polygonum lapathifolium	0.49	-2	2	0
Potamogeton	0.05	5	0	5
Potamogeton gramineus	0.49	-2	2	0
Potamogeton pectinatus	0.05	-8	24	16
Potamogeton perfoliatus	1.00	-1	1	0
Potamogeton pusillus var. pusillus	<0.001	-11	11	0
Potamogeton richardsonii	0.05	-5	5	0
Potamogeton zosteriformis	1.00	1	0	1
Puccinellia nuttalliana	1.00	-1	1	0
Ranunculus	1.00	1	0	1
Ranunculus longirostris	<0.001	-13	14	1
Ranunculus sceleratus	0.35	-3	4	1
Rorippa palustris subsp. glabra var. fernaldiana	1.00	-1	1	0
Rumex	0.49	-2	2	0
Rumex maritimus	<0.01	-8	8	0
Ruppia maritima	1.00	0	4	4
Sagittaria	1.00	1	0	1
Sagittaria cuneata	<0.01	-10	10	0
Salix amygdaloides	1.00	1	0	1
Scirpus	1.00	1	0	1
Scirpus acutus	<0.01	-10	12	2
Scirpus fluviatilis	0.49	-2	2	0
Scirpus heterochaetus	1.00	-1	1	0
Scirpus maritimus var. paludosus	0.49	-2	2	0
Scirpus validus	0.11	-4	4	0
Scolochloa festucacea	0.24	-3	3	0
Sium suave	0.05	-6	7	1
Sparaganium eurycarpum	0.01	-7	7	0
Suaeda depressa	0.49	-2	2	0
TYPHA	0.04	7	2	9
Typha latifolia	0.02	-6	6	0
Unknow Forb	0.24	3	0	3
Unknown Submerged Aquatic	0.05	5	0	5
Utricularia vulgaris	0.28	-5	20	15

Table A2. Continued.

Species	*P*	Change	1960s	2013-14
Zannichellia palustris	<0.001	-16	16	0

Table A3. Changes in percent abundance in 1960s (1961-1966) and 2013-14 at all wetland zones for all observed species for three study areas in Stutsman County, North Dakota. The absolute change in percent abundance is reported together with means of the two studies. Nonnative species are in uppercase. *P*-values are derived from paired *t* tests and n is the number of wetland zones.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Wet Meadow					
Acer negundo	1	…	0.1	0.0	0.1
Achillea millefolium subsp. lanulosa	4	…	1.9	0.0	1.9
Agropyron	13	0.09	-4.2	4.2	0.0
Agropyron caninum subsp. majus var. majus	31	<0.01	-4.6	4.6	0.0
Agropyron caninum subsp. majus var. unilaterale	18	<0.01	-2.0	2.0	0.0
AGROPYRON REPENS	66	…	6.9	0.0	6.9
Agropyron smithii	12	<0.01	-14.7	14.7	0.0
Agrostis	7	<0.01	-39.1	39.1	0.0
Agrostis scabra	4	0.26	-1.8	1.8	0.0
AGROSTIS STOLONIFERA	39	<0.001	-42.3	42.3	0.0
Agrostis/Poa	2	0.49	-15.5	15.5	0.0
Alisma subcordatum	1	…	-0.5	0.5	0.0
Allium stellatum	2	…	0.1	0.0	0.1
Alopecurus aequalis	5	0.07	-18.2	18.4	0.2
ALOPECURUS ARUNDINACEUS	2	…	0.1	0.0	0.1
Ambrosia	1	…	-0.5	0.5	0.0
Ambrosia artemisiifolia	7	…	3.9	0.0	3.9
Ambrosia psilostachya	37	<0.001	-8.6	9.9	1.3
Amorpha canescens	11	…	0.4	0.0	0.4
Andropogon gerardii	12	0.75	0.2	0.5	0.7
Anemone canadensis	55	<0.01	-4.0	4.9	0.9
Anemone cylindrica	1	…	0.1	0.0	0.1
Apocynum cannabinum	35	0.25	-1.4	2.3	0.9

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
ARCTIUM MINUS	1	…	-0.5	0.5	0.0
ARTEMISIA ABSINTHIUM	21	…	2.3	0.0	2.3
ARTEMISIA BIENNIS	12	0.13	-5.5	5.5	0.0
Artemisia ludoviciana var. ludoviciana	27	<0.01	-7.7	7.8	0.1
Asclepias	16	…	0.3	0.0	0.3
Asclepias incarnata	1	…	0.2	0.0	0.2
Asclepias syriaca	11	…	0.6	0.0	0.6
Aster	23	0.26	-1.5	2.0	0.5
Aster brachyactis	8	0.10	-6.8	6.8	0.0
Aster ericoides	36	<0.01	-7.2	7.5	0.3
Aster simplex var. ramosissimus	60	<0.001	-8.2	9.0	0.8
Aster/Boltonia	2	…	-0.5	0.5	0.0
Atriplex subspicata	10	0.08	-5.8	5.8	0.0
Beckmannia syzigachne	12	0.16	-3.1	3.1	0.0
Bidens comosa	2	0.63	-0.2	0.3	0.1
Bidens frondosa	2	…	2.8	0.0	2.8
Boltonia asteroides var. latisquama	36	<0.001	-5.6	5.6	0.0
BROMUS INERMIS	50	<0.001	5.9	0.1	6.0
BROMUS JAPONICUS	1	…	-0.5	0.5	0.0
Calamagrostis canadensis	28	0.74	2.4	28.2	30.6
Calamagrostis stricta	61	0.85	0.5	13.5	14.1
Callitriche verna	1	…	-0.5	0.5	0.0
Calylophus serrulatus	1	…	1.1	0.0	1.1
Campanula rotundifolia	1	…	-0.5	0.5	0.0
Carex	56	0.27	2.6	3.0	5.6
Carex atherodes	57	0.18	2.7	3.2	5.8

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Carex bebbii	1	…	-0.5	0.5	0.0
Carex brevior	3	0.96	0.0	0.3	0.3
Carex laeviconica	20	0.28	-4.5	7.4	2.9
Carex lanuginosa	33	…	9.1	0.0	9.1
Carex praegracilis	35	<0.001	-14.1	14.7	0.6
Carex sartwellii	31	<0.001	10.0	0.0	10.0
Carex tetanica	7	…	0.5	0.0	0.5
Carex vulpinoidea	4	…	-0.5	0.5	0.0
Cerastium arvense	2	…	0.5	0.0	0.5
Chenopodium	5	…	8.4	0.0	8.4
CHENOPODIUM ALBUM	6	…	0.2	0.0	0.2
CHENOPODIUM GLAUCUM	3	0.20	-3.6	3.7	0.1
Chenopodium rubrum	8	0.29	-5.1	6.7	1.6
Cicuta maculata	2	…	0.1	0.0	0.1
Cirsium	6	…	0.9	0.0	0.9
CIRSIUM ARVENSE	71	0.23	1.0	1.8	2.7
Cirsium flodmanii	6	…	0.1	0.0	0.1
Comandra umbellata	10	…	0.3	0.0	0.3
CONVOLVULUS ARVENSIS	3	…	0.1	0.0	0.1
Crataegus	4	…	0.1	0.0	0.1
Dalea purpurea var. purpurea	1	…	0.1	0.0	0.1
Dichanthelium acuminatum var. acuminatum	4	…	-0.5	0.5	0.0
Distichlis spicata	16	<0.001	-33.8	36.7	2.9
ECHINOCHLOA CRUSGALLI	2	…	2.4	0.0	2.4
Echinochloa muricata var. microstachya	1	…	0.1	0.0	0.1
Elaeagnus commutata	9	…	0.3	0.0	0.3

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Eleocharis macrostachya	45	0.08	-3.4	6.1	2.7
Elymus canadensis	5	0.56	-0.1	0.2	0.1
Epilobium ciliatum	5	0.53	-0.1	0.2	0.1
Epilobium leptophyllum	1	…	0.1	0.0	0.1
Equisetum	2	0.77	0.3	0.3	0.6
Equisetum arvense	1	…	1.1	0.0	1.1
Equisetum fluviatile	1	…	1.2	0.0	1.2
Equisetum hyemale	3	0.60	0.3	0.2	0.5
Equisetum laevigatum	6	0.85	0.0	0.2	0.1
Eragrostis	1	…	-5.5	5.5	0.0
EUPHORBIA ESULA	10	…	0.4	0.0	0.4
Euphorbia serpyllifolia	1	…	-5.5	5.5	0.0
Euthamia graminifolia var. graminifolia	3	0.27	-0.3	0.3	0.0
Fragaria virginiana	7	…	1.2	0.0	1.2
Galium boreale	20	0.02	1.0	0.0	1.0
Geum aleppicum	2	…	0.1	0.0	0.1
Glyceria grandis	4	…	-0.5	0.5	0.0
Glycyrrhiza lepidota	49	0.02	-2.9	3.7	0.9
Grindelia squarrosa	15	0.05	-3.8	3.8	0.0
Helianthus maximilianii	38	0.03	-3.8	4.7	0.9
Helianthus rigidus subsp. subrhomboideus	27	…	0.5	0.0	0.5
Heliathus	2	…	0.1	0.0	0.1
Hordeum jubatum	67	<0.001	-9.6	14.6	5.0
Impatiens capensis	3	…	2.2	0.0	2.2
Juncus	1	…	-0.5	0.5	0.0
Juncus balticus	45	<0.01	-6.7	12.0	5.3

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Juncus interior	2	0.75	0.4	0.3	0.6
Juncus tenuis	1	…	-0.5	0.5	0.0
Juncus torreyi	9	0.02	-1.3	1.3	0.0
KOCHIA SCOPARIA	9	0.35	-2.9	5.9	3.0
Koeleria pyramidata	8	0.65	-0.2	0.4	0.3
Lactuca oblongifolia	37	…	1.2	0.0	1.2
LACTUCA SERRIOLA	5	0.41	-3.0	3.9	0.9
Lemna trisulca	3	…	0.2	0.0	0.2
Lemna turionifera	3	…	0.3	0.0	0.3
Liatris	11	…	0.3	0.0	0.3
Liatris ligulistylis	3	…	-0.5	0.5	0.0
Lilium philadelphicum	6	…	0.2	0.0	0.2
Lithospermum canescens	3	…	0.2	0.0	0.2
Lobelia spicata	2	…	-0.5	0.5	0.0
Lotus	1	…	-0.5	0.5	0.0
Lotus purshianus	7	…	0.1	0.0	0.1
Lycopus americanus	8	0.33	-4.0	4.1	0.1
Lycopus asper	51	0.67	0.5	2.8	3.2
Lysimachia ciliata	1	…	3.1	0.0	3.1
Lysimachia hybrida	20	0.03	-4.9	4.9	0.0
Lysimachia thyrsiflora	5	…	0.2	0.0	0.2
MEDICAGO LUPULINA	1	…	15.3	0.0	15.3
MEDICAGO SATIVA	4	…	0.9	0.0	0.9
MELILOTUS	6	0.16	-10.4	10.4	0.0
MELILOTUS ALBA	9	0.21	-11.5	11.7	0.2
MELILOTUS OFFICINALIS	20	0.40	-1.3	2.8	1.5

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Mentha arvensis	29	0.08	-2.7	3.1	0.4
Muhlenbergia asperifolia	17	0.13	-3.0	3.8	0.7
Muhlenbergia cuspidata	1	…	1.1	0.0	1.1
Muhlenbergia racemosa	1	…	-0.5	0.5	0.0
Muhlenbergia richardsonis	1	…	-30.5	30.5	0.0
Myriophyllum exalbescens	5	0.38	-1.6	2.2	0.6
Onosmodium molle var. occidentale	1	…	0.1	0.0	0.1
Orthocarpus luteus	3	…	-0.5	0.5	0.0
Oxalis stricta	4	…	0.2	0.0	0.2
Panicum capillare	3	…	-0.5	0.5	0.0
Panicum virgatum	20	0.15	-6.3	7.1	0.8
Phalaris arundinacea	33	<0.001	8.6	0.0	8.6
PHLEUM PRATENSE	6	0.21	-2.4	2.4	0.0
Phragmites australis	4	0.40	-0.2	0.3	0.1
Poa	23	0.01	-15.4	20.7	5.3
Poa palustris	66	<0.001	-27.9	31.4	3.6
POA PRATENSIS	65	<0.001	15.0	3.8	18.7
POA/AGROSTIS	2	…	-30.5	30.5	0.0
Polygonum	12	0.15	1.9	0.0	2.0
Polygonum amphibian var. emersum	46	0.04	-1.7	2.8	1.1
Polygonum amphibian var.stipulaceum	20	0.11	1.2	0.3	1.6
Polygonum aviculare	2	…	-0.5	0.5	0.0
POLYGONUM CONVOLVULUS	6	…	0.6	0.0	0.6
Polygonum lapathifolium	1	…	-0.5	0.5	0.0
Polygonum ramosissimum	2	…	-0.5	0.5	0.0
Potamogeton	2	…	0.6	0.0	0.6

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Potamogeton gramineus	1	…	-5.5	5.5	0.0
Potentilla	7	…	0.3	0.0	0.3
Potentilla anserina	23	<0.01	-5.4	6.5	1.1
Potentilla norvegica	15	0.19	-2.7	2.8	0.0
Potentilla rivalis	1	…	0.1	0.0	0.1
Prenanthes racemosa subsp. multiflora	1	…	-5.5	5.5	0.0
Prunus americana	1	…	2.8	0.0	2.8
Prunus virginiana	2	…	0.9	0.0	0.9
Psoralea argophylla	2	…	0.1	0.0	0.1
Puccinellia nuttalliana	13	0.02	-11.4	11.6	0.1
Ranunculus	1	…	0.2	0.0	0.2
Ranunculus cymbalaria	6	0.16	-3.3	3.3	0.0
Ranunculus macounii	6	0.25	-1.2	1.3	0.2
Ranunculus rhomboideus	1	…	-0.5	0.5	0.0
Ranunculus sceleratus	5	0.41	-5.7	6.1	0.4
RHAMNUS CATHARTICA	1	…	1.4	0.0	1.4
Ribes americanum	1	…	0.1	0.0	0.1
Rorippa palustris subsp. glabra var. fernaldiana	4	0.26	-1.8	1.8	0.0
Rosa arkansana	30	<0.001	0.3	0.0	0.3
Rosa woodsii	6	0.27	-6.1	6.2	0.1
Rudbeckia hirta	13	0.60	-0.1	0.2	0.1
Rumex	16	0.17	1.3	0.1	1.4
RUMEX CRISPUS	1	…	-0.5	0.5	0.0
Rumex maritimus	6	0.46	4.3	1.2	5.4
Rumex mexicanus	12	0.04	-1.3	1.3	0.0
Rumex occidentalis	3	…	-0.5	0.5	0.0

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Salicornia rubra	2	0.44	-3.0	3.0	0.0
Salix	1	…	-0.5	0.5	0.0
Salix exigua subsp. interior	3	0.32	-2.2	2.2	0.0
SALSOLA IBERICA	1	…	-30.5	30.5	0.0
Schizachyrium scoparium	2	…	1.5	0.0	1.5
Scirpus acutus	13	0.13	0.4	0.1	0.5
Scirpus atrovirens	1	…	-0.5	0.5	0.0
Scirpus fluviatilis	9	…	5.1	0.0	5.1
Scirpus maritimus var. paludosus	1	…	-5.5	5.5	0.0
Scirpus pungens	13	<0.01	-7.2	9.3	2.1
Scirpus validus	4	0.51	0.3	0.1	0.4
Scolochloa festucacea	13	0.14	-6.0	11.8	5.8
Scutellaria galericulata	2	…	1.4	0.0	1.4
Setaria	1	…	-0.5	0.5	0.0
SETARIA GLAUCA	2	…	11.5	0.0	11.5
Sium suave	4	…	0.1	0.0	0.1
Solidago	4	…	1.0	0.0	1.0
Solidago canadensis	61	<0.001	-6.6	7.5	0.9
Solidago mollis	1	…	0.1	0.0	0.1
Solidago rigida	16	0.57	-0.2	0.4	0.2
SONCHUS ARVENSIS	64	0.04	-2.3	3.9	1.6
Sparaganium eurycarpum	1	…	0.1	0.0	0.1
Spartina	2	0.49	-15.5	15.5	0.0
Spartina gracilis	2	0.44	-3.0	3.0	0.0
Spartina pectinata	70	0.24	-3.2	20.3	17.2
Spiraea alba	3	0.37	1.6	0.2	1.7

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Stachys palustris	42	0.53	0.3	0.6	0.8
Stellaria longifolia	2	…	-0.5	0.5	0.0
Suaeda depressa	2	…	-0.5	0.5	0.0
Symphoricarpos occidentalis	44	0.94	0.0	0.5	0.5
TARAXACUM OFFICINALE	35	…	3.3	0.0	3.3
Teucrium canadense var. boreale	49	0.38	-0.7	1.7	0.9
Thalictrum venulosum	1	…	5.1	0.0	5.1
Toxicodendron rydbergii	2	…	0.2	0.0	0.2
Triglochin maritima var. elata	2	…	-0.5	0.5	0.0
TYPHA	41	…	1.9	0	1.9
Typha latifolia	4	0.89	0.0	0.1	0.1
Unknown Forb	57	…	1.1	0.0	1.1
Unknown Grass	47	…	5.6	0.0	5.6
Unknown Grasslike	3	…	1.1	0.0	1.1
Unknown Seedling	12	…	0.2	0.0	0.2
Unknown Shrub	3	…	0.1	0.0	0.1
Unknown Tree	1	…	0.1	0.0	0.1
Unknown Vine	2	…	1.4	0.0	1.4
Urtica dioica	12	0.75	-0.8	2.6	1.8
Utricularia vulgaris	1	…	0.1	0.0	0.1
Verbena hastata	4	…	-0.5	0.5	0.0
Vernonia fasciculata var. corymbosa	6	0.19	-7.2	7.2	0.0
Viola	3	…	0.3	0.0	0.3
Viola pedatifida	4	…	0.1	0.0	0.1
X Agrohordeum macounii	1	…	-0.5	0.5	0.0
Xanthium strumarium	6	0.32	-13.7	13.7	0.0

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Zigadenus elegans	1	…	0.1	0.0	0.1
Zigadenus venenosus	1	…	0.5	0.0	0.5
Zizia aptera	15	0.60	-0.1	0.2	0.2
Shallow Marsh					
Agropyron	1	…	-30.5	30.5	0.0
AGROPYRON REPENS	16	…	4.9	0.0	4.9
Agropyron smithii	2	0.47	-6.3	6.3	0.0
Agrostis	3	…	-0.5	0.5	0.0
Agrostis scabra	1	…	-30.5	30.5	0.0
AGROSTIS STOLONIFERA	16	<0.01	-13.3	13.3	0.0
Alisma	5	…	0.3	0.0	0.3
Alisma gramineum	1	…	-0.5	0.5	0.0
Alisma subcordatum	3	0.25	-7.2	7.2	0.0
Alisma trivale	24	<0.01	-6.3	6.3	0.0
Alopecurus	1	…	-5.5	5.5	0.0
Alopecurus aequalis	17	0.13	-4.2	5.4	1.1
ALOPECURUS ARUNDINACEUS	1	…	75.5	0.0	75.5
Alopecurus geniculatus	2	0.45	-40.5	40.5	0.0
Ambrosia artemisiifolia	1	…	1.1	0.0	1.1
Ambrosia psilostachya	2	0.63	-0.2	0.3	0.1
Amorpha canescens	1	…	0.3	0.0	0.3
Anemone canadensis	9	…	0.2	0.0	0.2
Apocynum cannabinum	9	0.18	1.6	0.1	1.6
ARTEMISIA ABSINTHIUM	14	…	0.9	0.0	0.9
ARTEMISIA BIENNIS	4	0.24	2.0	0.1	2.1
Artemisia ludoviciana var. ludoviciana	2	…	0.1	0.0	0.1

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Asclepias	3	…	0.1	0.0	0.1
Asclepias syriaca	1	…	1.8	0.0	1.8
Aster	9	0.06	-10.9	10.9	0.0
Aster brachyactis	3	0.40	-10.5	10.5	0.0
Aster ericoides	4	0.99	-0.3	7.9	7.6
Aster simplex var. ramosissimus	24	0.13	-6.0	6.8	0.8
Atriplex subspicata	5	0.05	-3.5	3.5	0.0
Beckmannia syzigachne	31	<0.01	-5.4	5.5	0.1
Bidens comosa	1	…	-5.5	5.5	0.0
Bidens vulgata	2	…	-0.5	0.5	0.0
Boltonia	1	…	-30.5	30.5	0.0
Boltonia asteroides var. latisquama	27	<0.001	-9.8	9.9	0.1
BROMUS INERMIS	17	…	6.9	0.0	6.9
Calamagrostis canadensis	18	0.10	4.2	1.7	5.9
Calamagrostis stricta	17	0.55	1.9	2.7	4.6
Callitriche	1	…	-0.5	0.5	0.0
Callitriche hermaphroditica	2	0.44	-3.0	3.0	0.0
Callitriche verna	20	<0.01	-8.3	8.3	0.0
Carex	24	0.05	-9.9	11.6	1.7
Carex atherodes	44	0.13	-8.1	33.8	25.7
Carex laeviconica	3	0.48	-9.2	10.2	1.0
Carex lanuginosa	8	…	5.5	0.0	5.5
Carex praegracilis	1	…	-0.5	0.5	0.0
Carex sartwellii	6	…	1.9	0.0	1.9
Carex sychnocephala	1	…	4.2	0.0	4.2
Carex vulpinoidea	1	…	-0.5	0.5	0.0

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Ceratophyllum demersum	2	0.56	-2.5	2.8	0.3
CHENOPODIUM ALBUM	10	0.04	-0.3	0.4	0.1
CHENOPODIUM GLAUCUM	2	…	0.7	0.0	0.7
Chenopodium rubrum	14	0.02	-9.1	9.4	0.3
Cicuta maculata	3	0.50	0.8	0.2	1.0
Cirsium	6	…	0.5	0.0	0.5
CIRSIUM ARVENSE	43	0.25	-1.4	2.9	1.6
Cirsium flodmanii	2	…	3.1	0.0	3.1
CONVOLVULUS ARVENSIS	1	…	0.2	0.0	0.2
Crataegus	1	…	0.1	0.0	0.1
Dichanthelium acuminatum var. acuminatum	1	…	-0.5	0.5	0.0
ECHINOCHLOA CRUSGALLI	1	…	-0.5	0.5	0.0
Eleocharis	3	0.12	-22.2	22.2	0.0
Eleocharis acicularis	8	0.05	-2.8	2.8	0.0
Eleocharis macrostachya	41	<0.001	-20.9	22.5	1.7
Elymus canadensis	1	…	0.1	0.0	0.1
Epilobium ciliatum	3	…	0.2	0.0	0.2
Epilobium leptophyllum	1	…	0.1	0.0	0.1
Equisetum laevigatum	2	…	0.2	0.0	0.2
ERYSIMUM CHEIRANTHOIDES	1	…	0.2	0.0	0.2
EUPHORBIA ESULA	6	…	0.2	0.0	0.2
Galium boreale	1	…	1.4	0.0	1.4
Glyceria borealis	1	…	-5.5	5.5	0.0
Glyceria grandis	30	<0.001	-18.7	20.5	1.8
Glycyrrhiza lepidota	14	…	0.6	0.0	0.6
Helianthus maximilianii	3	…	0.1	0.0	0.1

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Helianthus rigidus subsp. subrhomboideus	1	…	0.1	0.0	0.1
Hippuris vulgaris	4	0.36	-8.0	8.0	0.0
Hordeum jubatum	30	<0.01	-12.1	14.1	2.0
Juncus balticus	8	0.63	-2.1	4.1	2.0
Juncus longistylis	1	…	-5.5	5.5	0.0
KOCHIA SCOPARIA	3	0.32	-2.2	2.2	0.0
Lactuca oblongifolia	9	…	0.9	0.0	0.9
LACTUCA SERRIOLA	1	…	-0.5	0.5	0.0
Lemna trisulca	17	<0.01	-24.3	24.5	0.2
Lemna turionifera	16	<0.01	-15.4	15.6	0.2
Lotus purshianus	4	…	0.1	0.0	0.1
Lycopus	1	…	-0.5	0.5	0.0
Lycopus americanus	6	0.51	-0.7	0.9	0.2
Lycopus asper	30	0.04	1.5	0.9	2.4
Lysimachia ciliata	3	…	0.4	0.0	0.4
Lysimachia hybrida	12	<0.01	-11.4	11.4	0.0
Lysimachia thyrsiflora	3	…	0.2	0.0	0.2
MELILOTUS	1	…	0.1	0.0	0.1
MELILOTUS ALBA	2	…	0.8	0.0	0.8
MELILOTUS OFFICINALIS	4	…	5.3	0.0	5.3
Mentha arvensis	32	0.36	-1.3	2.8	1.5
Myriophyllum exalbescens	10	0.11	-6.3	7.1	0.8
Panicum capillare	2	0.44	-3.0	3.0	0.0
Phalaris arundinacea	31	…	38.9	0.0	38.9
Phragmites australis	4	0.90	0.0	0.5	0.5
PLANTAGO MAJOR	2	…	1.1	0.0	1.1

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Poa palustris	19	0.34	2.0	2.2	4.2
POA PRATENSIS	19	…	5.8	0.0	5.8
Polygonum	15	0.42	-5.1	9.1	4.0
Polygonum amphibian var. emersum	40	0.05	-4.4	12.1	7.8
Polygonum amphibian var.stipulaceum	15	0.08	-5.8	6.1	0.3
POLYGONUM CONVOLVULUS	3	…	0.5	0.0	0.5
Polygonum lapathifolium	8	0.23	-4.9	4.9	0.0
Potamogeton	2	…	6.3	0.0	6.3
Potamogeton gramineus	13	<0.001	-25.4	25.4	0.0
Potamogeton pectinatus	4	0.12	-12.9	13.4	0.5
Potamogeton pusillus var. pusillus	2	0.39	-18.0	18.0	0.0
Potentilla	8	0.92	-0.1	0.7	0.6
Potentilla anserina	5	0.40	-5.9	6.2	0.3
Potentilla norvegica	15	0.20	-2.7	2.8	0.0
Prunus virginiana	1	…	0.2	0.0	0.2
Puccinellia nuttalliana	5	0.08	-15.5	15.5	0.0
Ranunculus cymbalaria	6	0.31	-5.7	5.8	0.2
Ranunculus flabellaris	1	…	-0.5	0.5	0.0
Ranunculus longirostris	5	0.28	-8.5	8.5	0.0
Ranunculus macounii	2	…	0.2	0.0	0.2
Ranunculus pensylvanicus	1	…	0.3	0.0	0.3
Ranunculus rhomboideus	1	…	-5.5	5.5	0.0
Ranunculus sceleratus	5	0.21	-0.2	0.3	0.1
Ribes americanum	1	…	1.1	0.0	1.1
Rorippa palustris subsp. glabra var. fernaldiana	19	0.18	-2.2	2.3	0.0
Rosa arkansana	2	…	1.7	0.0	1.7

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Rosa woodsii	1	…	0.1	0.0	0.1
Rumex	15	0.08	0.3	0.1	0.4
RUMEX CRISPUS	7	…	-0.5	0.5	0.0
Rumex maritimus	9	0.81	-0.1	0.4	0.3
Rumex mexicanus	11	<0.001	-0.4	0.4	0.0
Rumex occidentalis	5	0.27	-7.5	7.5	0.0
Ruppia maritima	1	…	2.0	0.0	2.0
Sagittaria cuneata	8	0.09	-7.5	7.7	0.2
Salicornia rubra	1	…	-0.5	0.5	0.0
Salix	1	…	-5.5	5.5	0.0
Salix exigua subsp. interior	1	…	0.7	0.0	0.7
Scirpus	4	…	3.5	0.0	3.5
Scirpus acutus	19	0.70	-1.2	5.1	3.9
Scirpus fluviatilis	11	0.26	-10.9	15.2	4.3
Scirpus heterochaetus	2	…	-0.5	0.5	0.0
Scirpus maritimus var. paludosus	6	0.11	-10.0	10.0	0.0
Scirpus pungens	7	0.04	-21.2	23.4	2.2
Scirpus validus	9	0.50	-1.0	2.2	1.2
Scolochloa festucacea	22	<0.01	-16.7	31.4	14.7
Scutellaria galericulata	1	…	1.8	0.0	1.8
Senecio congestus	1	…	0.2	0.0	0.2
SETARIA GLAUCA	1	…	0.1	0.0	0.1
Sium suave	29	0.04	-1.9	2.5	0.5
Solidago	1	…	-0.5	0.5	0.0
Solidago canadensis	11	…	0.4	0.0	0.4
SONCHUS ARVENSIS	32	0.02	-4.5	5.2	0.7

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Sparaganium eurycarpum	22	<0.01	-19.5	25.9	6.4
Spartina pectinata	24	0.02	4.9	0.7	5.6
Stachys palustris	23	0.02	0.7	0.1	0.7
Suaeda depressa	1	…	-0.5	0.5	0.0
Symphoricarpos occidentalis	7	…	1.7	0.0	1.7
TARAXACUM OFFICINALE	11	…	4.3	0.0	4.3
Teucrium canadense var. boreale	34	0.01	0.8	0.3	1.1
Thalictrum venulosum	1	…	0.6	0.0	0.6
Toxicodendron rydbergii	1	…	1.8	0.0	1.8
TYPHA	26	0.03	4.8	0.5	5.2
Typha latifolia	15	0.06	-6.6	6.8	0.2
Unknow Forb	29	…	1.3	0.0	1.3
Unknown Grass	26	…	5.1	0.0	5.1
Unknown Grasslike	4	…	0.8	0.0	0.8
Unknown Seedling	9	…	0.9	0.0	0.9
Unknown Submerged Aquatic	4	…	8.0	0.0	8.0
Unknown Tree	1	…	0.1	0.0	0.1
Urtica dioica	11	0.70	1.3	3.1	4.3
Utricularia vulgaris	20	<0.001	-21.6	21.8	0.2
Verbena hastata	2	…	-0.5	0.5	0.0
Viola sororia	1	…	0.3	0.0	0.3
Xanthium strumarium	3	0.17	-3.0	3.0	0.0
Zannichellia palustris	1	…	-0.5	0.5	0.0
Deep Marsh					
Alisma	2	0.63	-0.2	0.25	0.05
Alisma gramineum	1	…	-30.5	30.5	0

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Alisma subcordatum	4	0.29	-9.25	9.25	0
Alisma trivale	2	0.18	-4.25	4.25	0
Alopecurus aequalis	3	…	-0.5	0.5	0
ALOPECURUS ARUNDINACEUS	1	…	0.13	0	0.13
Aster brachyactis	2	…	-0.5	0.5	0
Aster/Boltonia	1	…	-5.5	5.5	0
Atriplex subspicata	2	0.39	-18	18	0
Beckmannia syzigachne	4	0.36	-8	8	0
Boltonia	1	…	-0.5	0.5	0
Callitriche verna	1	…	-0.5	0.5	0
Carex	1	…	1.83	0	1.83
Carex atherodes	21	0.01	-12.9	13.2	0.3
Carex lanuginosa	1	…	0.8	0.0	0.8
Ceratophyllum demersum	6	0.23	-6.7	7.0	0.3
CHENOPODIUM GLAUCUM	3	…	-0.5	0.5	0.0
Chenopodium rubrum	16	<0.001	-16.0	16.0	0.0
CIRSIUM ARVENSE	12	0.15	-5.3	5.5	0.2
Eleocharis macrostachya	11	0.02	-10.7	10.8	0.1
Glyceria grandis	5	0.30	-7.0	7.0	0.0
Hippuris vulgaris	2	…	-0.5	0.5	0.0
Hordeum jubatum	8	0.18	-14.2	14.2	0.0
Juncus balticus	2	0.63	-0.2	0.3	0.1
KOCHIA SCOPARIA	1	…	-5.5	5.5	0.0
Lemna trisulca	20	<0.01	-20.5	24.3	3.8
Lemna turionifera	17	<0.01	-15.8	16.4	0.6
Lycopus asper	10	0.41	0.3	0.3	0.6

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Mentha arvensis	6	…	-0.5	0.5	0.0
Myriophyllum exalbescens	11	0.04	-11.9	12.3	0.4
Panicum capillare	1	…	-0.5	0.5	0.0
Phalaris arundinacea	11	…	1.6	0.0	1.6
Phragmites australis	5	0.85	0.0	0.2	0.2
Polygonum	2	…	0.1	0.0	0.1
Polygonum amphibian var. emersum	3	0.65	-0.2	0.3	0.2
Polygonum amphibian var.stipulaceum	4	0.11	-0.3	0.4	0.1
POLYGONUM CONVOLVULUS	1	…	0.3	0.0	0.3
Potamogeton	3	…	3.4	0.0	3.4
Potamogeton pectinatus	11	0.02	-12.9	13.8	0.9
Potamogeton pusillus var. pusillus	2	…	-0.5	0.5	0.0
Potentilla anserina	1	…	-0.5	0.5	0.0
Potentilla norvegica	3	…	-0.5	0.5	0.0
Puccinellia nuttalliana	2	0.18	-4.3	4.3	0.0
Ranunculus cymbalaria	2	…	-0.5	0.5	0.0
Ranunculus longirostris	6	0.22	-6.8	6.8	0.0
Ranunculus sceleratus	10	0.37	-2.9	3.6	0.6
Rorippa palustris subsp. glabra var. fernaldiana	3	…	-0.5	0.5	0.0
Rumex	2	0.51	-2.7	2.8	0.1
Rumex maritimus	10	0.15	-6.3	6.4	0.1
Rumex occidentalis	3	0.18	-20.5	20.5	0.0
Sagittaria cuneata	6	0.04	-14.9	14.9	0.0
Salix exigua subsp. interior	1	…	1.2	0.0	1.2
Scirpus	6	…	10.6	0.0	10.6
Scirpus acutus	22	<0.001	-29.9	39.0	9.1

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Scirpus fluviatilis	6	0.18	-11.6	11.8	0.1
Scirpus heterochaetus	3	0.40	-10.5	10.5	0.0
Scirpus maritimus var. paludosus	5	0.14	-20.1	20.1	0.0
Scirpus pungens	3	0.55	-14.1	17.8	3.7
Scirpus validus	11	0.93	-0.5	4.8	4.3
Scolochloa festucacea	12	0.02	-24.5	25.1	0.7
Senecio congestus	1	…	-0.5	0.5	0.0
Sium suave	12	0.14	-5.0	5.2	0.2
SONCHUS ARVENSIS	7	0.17	-8.8	8.9	0.1
Sparaganium eurycarpum	6	0.19	-18.6	18.6	0.0
Spartina pectinata	4	…	0.8	0.0	0.8
Stachys palustris	1	…	0.1	0.0	0.1
Teucrium canadense var. boreale	10	0.19	-0.2	0.4	0.2
TYPHA	22	<0.001	43.8	11.4	55.2
Typha latifolia	21	<0.001	-35.8	36.4	0.5
Unknow Forb	3	…	0.5	0.0	0.5
Unknown Grass	3	…	6.4	0.0	6.4
Unknown Seedling	3	…	0.5	0.0	0.5
Unknown Submerged Aquatic	4	…	2.7	0.0	2.7
Urtica dioica	2	0.55	-14.1	15.5	1.4
Utricularia vulgaris	21	<0.001	-16.6	19.3	2.7
Zannichellia palustris	5	0.11	-14.0	14.0	0.0
Open Water					
Alisma gramineum	7	0.10	-11.9	11.9	0.0
Alisma subcordatum	2	…	-0.5	0.5	0.0
Alisma trivale	2	…	-0.5	0.5	0.0

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Alopecurus aequalis	4	0.17	-1.1	1.1	0.0
Atriplex subspicata	1	…	-0.5	0.5	0.0
Beckmannia syzigachne	5	0.08	-13.4	13.4	0.0
Callitriche	1	…	-30.5	30.5	0.0
Callitriche hermaphroditica	1	…	-0.5	0.5	0.0
Callitriche verna	2	0.44	-3.0	3.0	0.0
Carex	1	…	-30.5	30.5	0.0
Carex atherodes	11	0.06	-5.7	5.7	0.0
Ceratophyllum demersum	7	0.03	-20.4	21.3	0.9
CHENOPODIUM GLAUCUM	4	…	-0.5	0.5	0.0
Chenopodium rubrum	9	<0.01	-28.8	28.8	0.0
Distichlis spicata	1	…	-30.5	30.5	0.0
Eleocharis	1	…	-0.5	0.5	0.0
Eleocharis acicularis	1	…	-22.2	22.2	0.0
Eleocharis macrostachya	10	<0.01	-35.3	35.3	0.0
Glyceria grandis	7	0.09	-10.5	10.5	0.0
Hippuris vulgaris	2	0.47	-4.9	4.9	0.0
Hordeum jubatum	2	0.48	-39.3	39.3	0.0
Lemna trisulca	21	<0.001	-32.0	35.5	3.5
Lemna turionifera	17	0.01	-15.1	15.2	0.1
Lycopus asper	1	…	-0.5	0.5	0.0
Lysimachia hybrida	1	…	-30.5	30.5	0.0
Mentha arvensis	1	…	-0.5	0.5	0.0
Myriophyllum exalbescens	20	0.09	-10.0	14.3	4.3
Phalaris arundinacea	1	…	0.1	0.0	0.1
Phragmites australis	2	…	-0.5	0.5	0.0

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Polygonum	1	…	6.1	0.0	6.1
Polygonum amphibian var. emersum	1	…	-8.5	8.5	0.0
Polygonum amphibian var.stipulaceum	7	0.31	-11.7	11.9	0.2
Polygonum lapathifolium	2	…	-0.5	0.5	0.0
Potamogeton	5	…	11.5	0.0	11.5
Potamogeton gramineus	2	0.37	-8.9	8.9	0.0
Potamogeton pectinatus	25	<0.01	-12.4	18.1	5.8
Potamogeton perfoliatus	1	…	-8.0	8.0	0.0
Potamogeton pusillus var. pusillus	11	0.06	-12.9	12.9	0.0
Potamogeton richardsonii	5	0.05	-13.9	13.9	0.0
Potamogeton zosteriformis	1	…	5.8	0.0	5.8
Puccinellia nuttalliana	1	…	-5.5	5.5	0.0
Ranunculus	1	…	0.1	0.0	0.1
Ranunculus longirostris	14	<0.001	-32.3	32.3	0.0
Ranunculus sceleratus	5	0.32	-6.7	6.9	0.2
Rorippa palustris subsp. glabra var. fernaldiana	1	…	-0.5	0.5	0.0
Rumex	2	0.44	-3.0	3.0	0.0
Rumex maritimus	8	0.02	-13.4	13.4	0.0
Ruppia maritima	5	0.42	-7.8	23.2	15.4
Sagittaria	1	…	1.1	0.0	1.1
Sagittaria cuneata	10	<0.01	-7.6	7.6	0.0
Salix amygdaloides	1	…	0.1	0.0	0.1
Scirpus	1	…	0.1	0.0	0.1
Scirpus acutus	12	0.05	-7.8	7.8	0.0
Scirpus fluviatilis	2	…	-0.5	0.5	0.0
Scirpus heterochaetus	1	…	-0.5	0.5	0.0

Table A3. Continued.

Species	n	*P*	Absolute Change	Mean 1960s	Mean 2013-14
Scirpus maritimus var. paludosus	2	…	-0.5	0.5	0.0
Scirpus validus	4	…	-0.5	0.5	0.0
Scolochloa festucacea	3	0.19	-13.4	13.4	0.0
Sium suave	8	0.04	-9.4	9.4	0.0
Sparaganium eurycarpum	7	0.23	-1.9	1.9	0.0
Suaeda depressa	2	0.49	-15.5	15.5	0.0
TYPHA	10	0.29	0.8	0.1	0.9
Typha latifolia	6	0.17	-1.3	1.3	0.0
Unknow Forb	3	…	13.9	0.0	13.9
Unknown Submerged Aquatic	5	…	5.2	0.0	5.2
Utricularia vulgaris	20	0.35	-5.0	22.9	17.8
Zannichellia palustris	16	<0.01	-12.6	12.6	0.0