VEGETATION STRUCTURE AND INFERRED PATTERNS OF FUNCTIONAL GROUP ATTRITION IN A SHRUB ENCROACHED OLD FIELD AND TALLGRASS PRAIRIE MOSAIC

BY

ZACHARY P. KRON

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Plant Biology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2011

Urbana, Illinois

Master's Committee

Affiliate John Taft, Chair
Associate Professor James Dalling
Assistant Professor Michael Dietze

Abstract

Tallgrass prairie is an endangered ecosystem and encroachment by woody species threatens many remnants. Insights are needed into the differences in diversity and species and functional group composition along a gradient of woody encroachment to help gauge restoration potential and gain insights into patterns of disassembly in grassland communities. The study site is a 65 ha (160 acre) tallgrass prairie and old field mosaic in Lake County, Illinois. The three main objectives in this study are to: (1) analyze and classify plant communities, (2) explore seed bank dynamics and its contribution to old field colonization, and (3) determine the patterns of species and functional group richness and cover in a tallgrass prairie:old field mosaic with varying levels of shrub invasion and assess whether there are ordered patterns of loss in richness and cover with increasing shrub canopy cover. Ground layer and shrub layer data were collected from 45 sample plots including 37 located on stratified transects and eight located randomly in high-quality reference prairie habitat. Two community types were identified through field observation and reinforced by cluster analysis, indicator species analysis, and Nonmetric Multidimensional Scaling (NMS). The communities differed significantly in species density, species richness, ground layer cover, floristic quality indices, shrub canopy cover, and percent bare ground. To assess whether germination from the seed bank was limited by the lack of fire at the site, soil samples were heat treated prior to placement in greenhouse flats and germination rates were compared to a control. Heat shock had a variable effect on germination, and the species germinating from the seed bank were dependant upon the treatment. Sørensen Similarity Index indicated that there was very little similarity between the species present in the seed bank and the standing vegetation. To determine if prairie remnants were responsible for the recolonization of the site after agricultural disturbance, species data were examined on a distance gradient to the nearest remnant. Overall species richness, proportion of prairie species, and Floristic Quality Index had no relationship with distance to remnants. Results suggests that many areas of the site are seed limited, further complicating the restoration of plant communities. Possible causes of seed bank failure as a refugium could be attributed to the past history of rigorous cultivation at the site and the recent history of shrub encroachment. Species composition data were converted to plant functional groups based on species traits to assess whether increasing shrub canopy cover leads to loss or decline in richness and cover in species with shared traits. The relationships between functional group richness and ground layer cover to shrub canopy cover were examined with linear regression, discriminant analysis, ANOVA followed by Tukey post-hoc tests, and NMS. Cover of C4 grass, perennial legume, perennial forb, perennial sedge, C3 grass and annual forb functional groups and richness of C4 grass, perennial legume, and perennial forb functional groups follow ordered decline with increasing shrub canopy cover and differences among canopy cover classes were significant. NMS provides a graphical summary indicating functional groups representative of prairie communities are associated with low canopy cover plots compared with closed canopy plots. Comparisons with previous studies at this site suggest shrub species have increased in density three fold in the past fourteen years. Results from this study highlight ordered patterns of losses in the cover and richness of plant functional groups that can be used as a guideline to evaluate sites undergoing shrub encroachment that have important management implications for restoration and management of grassland ecosystems.

Acknowledgements

The completion of this project would not have been feasible without the support from numerous people mentioned below. Thanks to my adviser, John B. Taft, who read the many revisions of this report while always providing useful and insightful feedback. Also thanks to my committee members, James Dalling and Michael Dietze, whose critiques helped refine this project to its present state. A special thanks to the Illinois Toll Highway Authority and the Department of Plant Biology at the University of Illinois at Urbana-Champaign, who provided me funding in the form of a research assistantship and teaching assistantship, respectfully. And finally thanks to my wife, family, and friends who stuck by me during this long process, providing me with the additional support needed to keep me on track.

Table of Contents

Chapter 1

Study Objectives and Site History

1.1 Objectives

<u>Research Objectives</u>

The three main objectives in the current study are to: (1) analyze and classify plant community structure, (2) explore seed bank dynamics, and (3) determine the patterns of species and functional group richness in a tallgrass prairie:old field mosaic with varying levels of shrub invasion and assess whether there are ordered patterns of attrition with increasing shrub canopy cover. The following chapters explore each topic individually. Chapter 2 describes results from a baseline vegetation monitoring program implemented to determine the extent of change and effectiveness of techniques following habitat management. Specifically, the chapter focuses on differences in community types and the vegetative structure and composition of the herbaceous, shrub, and tree layers. Chapter 3 explores existing patterns of species composition and diversity in seed banks and standing vegetation for evidence of species persistence in soil seed banks and colonization from prairie remnants into former agricultural lands to determine if seed limitation is a factor in the current assemblages. Chapter 4 determined whether nonrandom ordered patterns of plant functional group losses in richness and ground layer cover could be detected with increasing woody invasion in native grassland habitats. Chapter 5 closes with a short overview of the findings in the previous chapters and their significance to the scientific community.

<u>Management Objectives</u>

Management encompasses the combined goals of two state organizations, the Illinois State Toll Highway Authority (ISTHA) and the Illinois Department of Transportation (IDOT). Both organizations seek to obtain wetland credits from the site, and have agreed and acted upon a management plan. Objectives include restoring the two major ecosystems at the site, tallgrass prairie and wetlands. Methods for the restoration of the site involve significant shrub removal, returning fire to the site, and seeding the site to improve native species density and cover in the wetlands and prairies.

1.2 Site History

Study area

The study area is the 65 ha (160 acre) North Chicago Wetland Mitigation Site near North Chicago, IL (Figure 1), a parcel owned by the ISTHA and IDOT (42^{o}18'03.16"N and 87^{o}53'00.49"W). The site is situated in an urban environment, surrounded by housing developments to the south, a state highway to the north (Illinois 137), and industrial parks to the east and west (Figure 2). Interest in the vegetation at the site began when the Illinois Department of Transportation (IDOT) requested botanical surveys to determine its botanical resources and potential use as a wetland mitigation site. Extensive botanical surveys have been conducted at this site (e.g., Taft 1996 and 2006), recording 324 species of vascular plants including three state threatened plant species: *Elymus trachycaulus, Oenothera perennis,* and *Veronica scutellata*. The state endangered *Amelanchier sanguinea* was found during baseline vegetation monitoring for the current study in 2009. Remnant prairies and wetlands ranging in quality from degraded to high-quality natural areas have been found throughout the site; however, the highest quality habitats are localized in the far southern extent of the study area (Figure 2). Habitats identified include mesic to wet prairie, sedge meadow, and marsh (Taft 1996, 2006). Wetland mapping has identified a total of 29 wetland acres (Olson et al. 1991; Plocher et al. 1996). This site was chosen as the study area due the unique composition of its upland vegetation, which relates directly to the objectives described above. The site was chosen specifically to determine objectives 1) and 3) above, while objective 2) was added as a preliminary study to answer basic questions regarding the seedbank.

.

Pre European settlement history

According to the General Land Office (GLO) Public Land Survey notes, in the period of 1837-1840 vegetation in this study area was prairie with adjacent areas of wet prairie, marsh, and savanna (Moran 1978). The site lies in the most recently glaciated region of Illinois and is classified as part of the Northeastern Morainal Natural Division (Schwegman et al. 1973).

Soils

Soils in the study area belong to the Beecher-Frankfort-Montgomery association (Paschke and Alexander 1970) and are common in glaciated areas (Figure 4; Soil Survey Staff 2010). Soils are gently sloping and occasionally form depressional areas. Dominant soils mapped include Frankfort silt loam and Montgomery silty clay loam, covering 36% and 47% of the site, respectively (Figure 4; Soil Survey Staff 2010). Frankfort silt loam is characterized by a seasonally high water table roughly 15 cm below the soil surface. Montgomery silty clay formed in clayey lake bed and/or glacial till deposits with marsh vegetation. This is the dominant wetland soil in the study area (Plocher et al. 1996) and is found throughout the study area in the depressions. Ponding on the Montgomery silty clay is common and the water table is always within 30 cm of the soil surface (Soil Survey Staff 2010). Zurich and Nappanee silt loams occur in the northeastern corner of the project area and, according to Paschke and Alexander (1970), formed under forest cover. Soil surveys by Plocher et al. (1996) largely agree with the soil mapping reported by Paschke and Alexander (1970).

Disturbance History

Much of the known history of the site relies on historical aerial photography, and vegetation surveys and sampling that began in the 1990's. Previous work (Taft 1996) recreated a land use history of the site. The majority of the northern 3/5ths of the site was cultivated under row crop agriculture until the late 1960's; a small remnant prairie region also was present that appears to have been heavily grazed (Taft 1996). The southern 2/5ths may have been used as pasture for grazing animals, but there is no evidence of overgrazing in the prairie vegetation (Taft 1996). An aerial photo from the 1940's shows a clear fence row pattern around the southern portion of the site, indicating that it was used as pasture at this point in time (Figure 4). Also, shrubs are not evident in the photo, while trees occurred in a savanna like community along the eastern edge of the site. Aerial photography from the late 1960's shows a shift from row crop agriculture to early secondary succession vegetation.

Prairie History in Illinois

Grasslands once stretched from the Rocky Mountains to portions of Indiana and Ohio forming a wedge-shaped configuration towards the east referred to as the prairie peninsula (Kuchler 1964). Following Pleistocene glaciations, a prairie flora became dominant in the region about 6200 yr BP, with seasonal aridity, grazing, and fire playing key roles in grassland development and maintenance (Nelson et al 2006; Anderson 2006). Illinois, occurring near the eastern edge of this grassland, is in an ecotonal prairie:forest transition zone (Anderson 1983). At the time of Euro-American settlements in the mid-19th century, Illinois was about 55 percent prairie with savanna, woodland, and forest comprising much of the remaining land area (Taft et al. 2009). However, due to conversion of much of this grassland habitat to row crop agriculture and the recent encroachment of woody plants in remaining grasslands during extended fire-free intervals, only about .01 percent of the original prairie habitat remains in nearly undisturbed condition. The remaining prairie is spread among 241 remnants (White 1978; IDNR Natural Heritage Database) with 79 percent smaller than 10 acres and 23 percent less than one acre (Taft et al. 2009).

1.3 References

Anderson, R.C. 1983. The eastern prairie-forest transition--an overview. *In* R. Brewer, ed. *Proceedings of the Eighth North American Prairie Conference*. Western Michigan University, Kalamazoo, MI. pp. 86-92

Anderson, R.C. 2006. Evolution and Origin of the Central Grassland of North America: Climate, Fire, and Mammalian Grazers. *Journal of the Torrey Botanical Society* 133(4): 626-647.

Illinois State Geological Survey. 1997. Illinois Historical Aerial Photography. *Illinois Natural Resources Geospatial Data Clearinghouse*. Accessed 20 April, 2011. <http://www.isgs.illinois.edu/nsdihome/webdocs/ilhap/>.

Kuchler, A.W. 1964. Manual to accompany the map, potential natural vegetation of the conterminous United States. *American Geographical Society Special Publication Number 36*, New York, New York, USA.

Moran, R. 1978. Presettlement vegetation of Lake County, Illinois. *Fifth Midwest Prairie Conference Proceedings*. Iowa State University, Ames.

Nelson, D.M, F.S. Hu, E.C. Grimm, B.B. Curry, and J.E. Slate. 2006. The influence of aridity and fire on Holocene prairie communities in the eastern Prairie Peninsula. *Ecology* 87(10): 2523-2536.

Olson, J., A. Nugteren, M. Morris, and T. Brooks. 1991. *Wetland report and description of notable ecological features with Addendum for FAP 120 (US 41), Lake County, near Skokie, Illinois*. 52 pages with appendix.

Paschke, J.E., and J.D. Alexander. 1970. Soil survey, lake County, Illinois. Illinois Agricultural Experiment Station Soil Report No. 88. *United States Department of*

Agriculture, Soil Conservation Service in cooperation with Illinois Agricultural Experiment Station.

Plocher, A., P. Tessene, and J. Olson. 1996. Wetland mitigation site assessment of the US 41/IL 137 Illinois Department of Transportation project area. *Technical report submitted to the Illinois Department of Transportation, Bureau of Design and Environment, Springfield.*

Schwegman, J.E. 1973. Comprehensive plan for the Illinois nature preserves system. *Part 2. The natural divisions of Illinois*. Illinois Nature Preserves Commission. Rockford, Illinois.

Soil Survey Staff. 2010. Natural Resources Conservation Service, United States Department of Agriculture. *Web Soil Survey*. Available online at http://websoilsurvey.nrcs.usda.gov accessed [03/20/2010].

Taft, J.B. 1996. Floristic survey and assessment of the Illinois Department of Transportation North Chicago (US Route 41/IL Route 137) Wetland Mitigation Site in Lake County. Technical Report submitted to the Illinois Department of Transportation, Springfield.

Taft, J.B. 2006. Floristic Survey and Assessment of the North Chicago Wetland Mitigation Site, Lake County, Illinois. Center for Wildlife and Plant Ecology. Illinois Natural History Survey Technical Report. Submitted to the Illinois Department of Transportation, Bureau of Location and Environment, 28 September 2006.

Taft, J.B., R.C. Anderson, and L. Iverson. 2009. Vegetation ecology and change in terrestrial ecosystems. Chapter 4 In: Taylor, C., Taft, J., Warwick, C. (eds.) *Canaries in the Catbird Seat*. Illinois Natural History Survey Special Publication 30.

Taft, J.B., Z. Kron, and A. Plocher. 2010. Baseline quantitative vegetation monitoring in terrestrial and wetland communities in the North Chicago wetland mitigation site, Lake County, Illinois. *Technical report 2010(07) submitted to the Illinois Tollway Authority, Downers Grove*.

Taft, JB and ZP Kron. 2011. Results from vegetation monitoring during 2010 in terrestrial communities at the North Chicago Wetland Mitigation Site, Lake County, Illinois. Illinois Natural History Survey. *Technical report 2011(12) submitted to Illinois Tollway Authority, Downers Grove, Illinois*.

White, J. 1978. Illinois natural areas inventory technical report. *Vol. 1: Survey methods and results.* Illinois Natural Areas Inventory, Urbana., IL.

Figures

Figure 1. Adapted from Taft et al. (2010). Lake County is the northeastern most county in the state of Illinois. The North Chicago Wetland Mitigation site is outlined in black.

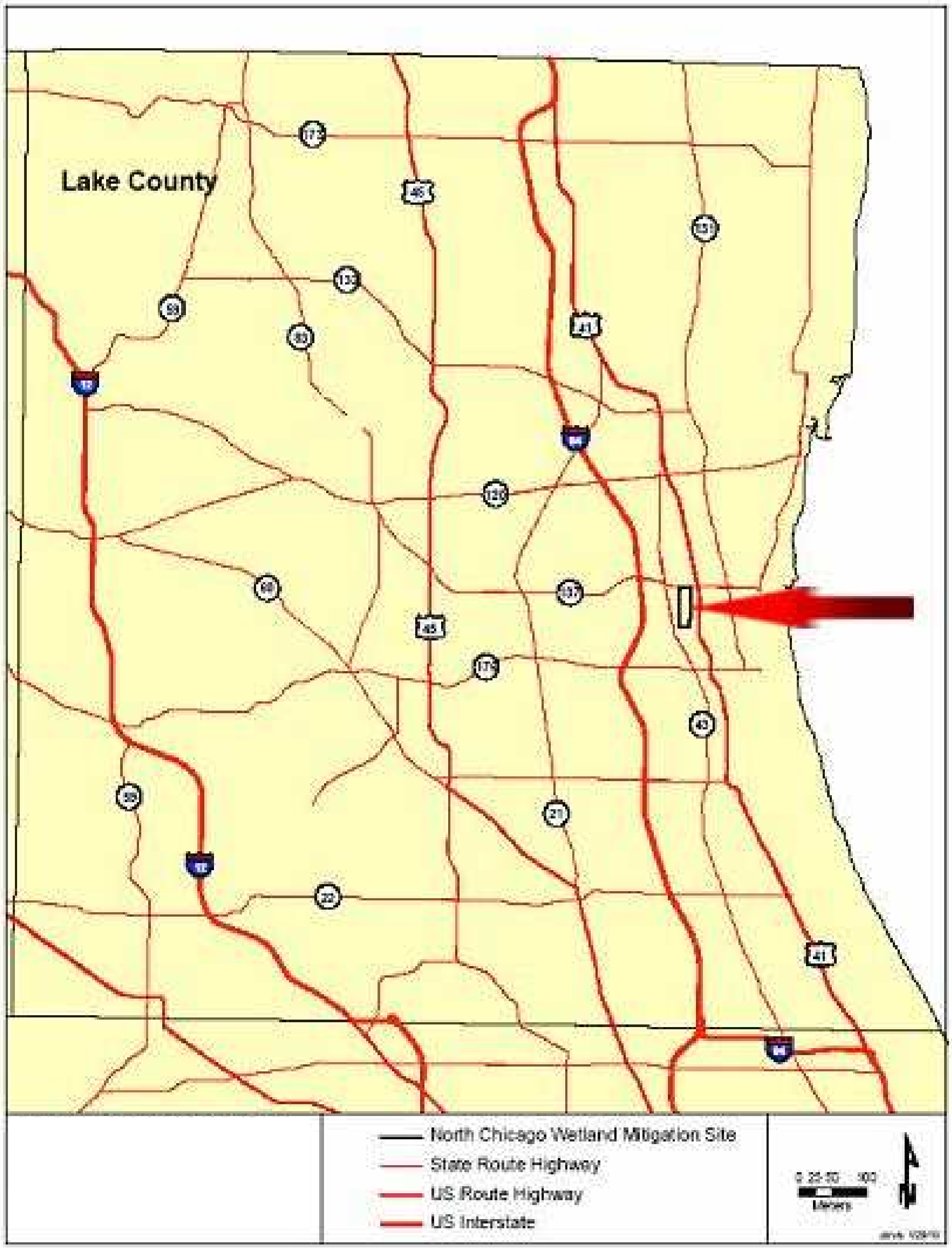


Figure 2. Adapted from Taft et al. (2010). Point data depict the locations of the three state threatened species *Elymus trachycalus*, *Oenothera perennis*, and *Veronica scutellata* and the state endangered *Amelanchier sanguinea*. Species distributions may also be represented by polygons of the same color if the population was dense or widespread. High quality natural areas are represented by colored polygons and include marsh, wet prairie, wet mesic prairie, prairie, and sedge meadow.

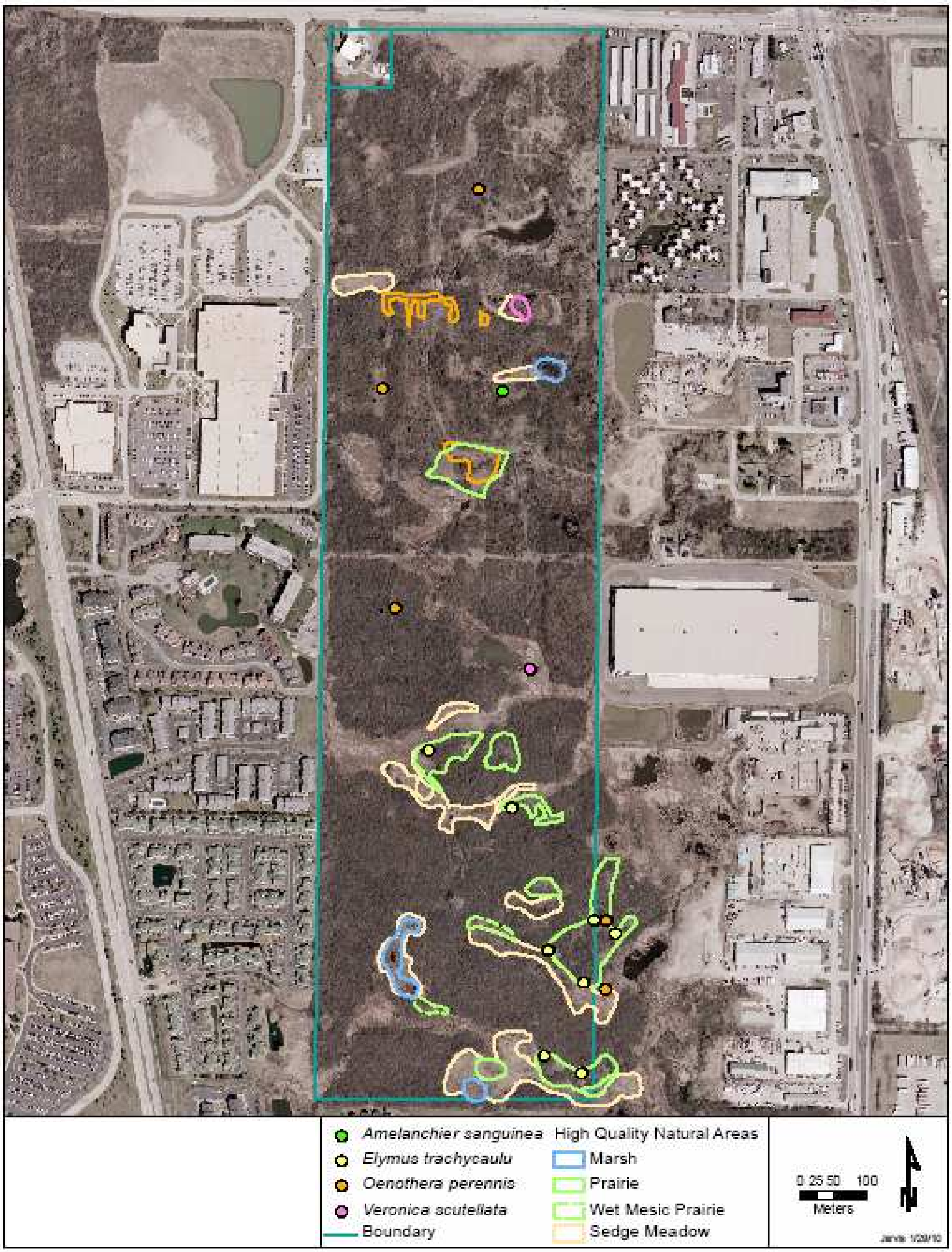


Figure 3. Soils map of the North Chicago Wetland Mitigation Site. The site is outlined by a thin blue line and each soil type is delineated by an orange polygon. The code found in the middle of each polygon corresponds to the soil type found in the legend. All information is adapted from Soil Survey Staff (2010).

Lake County, Illinois (IL097)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
298A	Beecher silt loam, 0 to 2 percent slopes	6.9	4.2%
298B	Beecher silt loam, 2 to 4 percent slopes	4.2	2.6%
320A	Frankfort silt loam, 0 to 2 percent slopes	7.4	4.5%
320B	Frankfort silt loam, 2 to 4 percent slopes	50.3	30.5%
320B2	Frankfort silty clay loam, 2 to 4 percent slopes, eroded	2.1	1.3%
465A	Montgomery silty clay loam, 0 to 2 percent slopes	77.6	47.1%
983B	Zurich and Nappanee silt loams, 2 to 4 percent slopes	15.8	9.6%
4103A	Houghton muck, ponded, 0 to 2 percent slopes	0.5	0.3%
Totals for Area of Interest		**164.8**	**100.0%**

Figure 4. 1941 aerial photograph of the North Chicago Wetland Mitigation site (outlined in red) (ISGS 1997). The site is a mosaic of cultivated land and open pasture, with cultivated land concentrated in the north and pasture concentrated in the south. Shrubs and trees are uncommon at the site at this time, and occur only along the eastern edge of the site and fencerows of the southern pasture.

Chapter 2

Quantitative Vegetation Patterns

Abstract

Introduction – The initial purpose of this project was to establish a baseline vegetation monitoring program to determine the extent of change and effectiveness of techniques following habitat management. Specifically the project focuses on differences in community types and the vegetative structure and composition of the herbaceous, shrub, and tree layers.

Questions – Can the separation of plots into the two basic community types, prairie and old field, be supported by cluster analysis? What are the differences in the herbaceous layer between the identified communities? What are the differences in the shrub layer between old field and prairie communities? What is the structure and composition of forested plots?

Location - Tallgrass prairie and old field mosaic at the North Chicago Wetland Mitigation Site in Lake County, Illinois.

Methods - Ground layer and shrub canopy data were collected from 45 sample plots including 37 located on stratified transects and eight located randomly in high-quality reference prairie habitat. Indicator species analysis determined whether there were non-random patterns of species affiliation. Differences in the attributes of the herbaceous layer, shrub layer, and trees were determined with means comparisons tests between community types. The arrangement of species, plots, and community types were examined with Nonmetric Multidimensional Scaling (NMS)

Results – Two communities, prairie and old field, were recognized by field observation and confirmed with cluster analysis. 48 species were non-random indicators of the prairie community while only 6 species were found to associate non-randomly with the old field

community. Mean comparison tests determined that native species density, native richness, vegetative cover, visible sky, and floristic quality indices were all significantly greater in prairie plots compared to the old field plots. Mean comparison tests indicate that bare ground was higher in the old field plots as opposed to the prairie plots. Shrub density was greater in the prairie plots but the differences were not significant. *Rhamnus cathartica*, *Cornus racemosa*, *Lonicera* X *bella*, *Viburnum lentago*, and *Rhamnus frangula* were the most abundant shrub species in both the old field and the prairie plots. Trees were uncommon at the site, and were found in only four plots. A graphical ordination of transect plots grouped by perceived community type supports the 2 community classification from cluster analysis, and suggests that the variation in community affiliation is driven by native richness and percent bare ground.

Discussion - Regardless of community type, *Rhamnus cathartica* was the most abundant shrub species at the site. Areas of high shrub density and low canopy cover in the prairie plots may be representative of recently invaded communities. Furthermore, the species composition in these plots is intermediate between the prairie and old field plots, even though they were classified as prairie by cluster analysis. Previous studies suggest shrub species have increased in density three fold in the past fourteen years. Results exemplify the need for management in this shrub encroached ecosystem.

2.1 Introduction

Chief goals of this portion of the study were to collect and quantify species density, species richness, bare ground, and total cover in the ground-layer vegetation and to quantify composition, stem density, and percent canopy cover in the shrub stratum. These measures are common in other descriptive studies and will provide the necessary data to complete the objectives for this chapter outlined in Chapter 1. These goals are relevant to the rest of the study because it identifies the general vegetation patterns within the study area, providing a base from which firm inferences can be made regarding the remaining sections of this thesis. Furthermore, general vegetation patterns including density, richness, and composition are useful parameters for comparisons with other studies.

This study is significant because results will be used as a baseline reference for monitoring vegetation change with planned habitat management. As mentioned above, the descriptive vegetation parameters sampled in this study will prove essential to track the changes in vegetation across the temporal extent of the project. Current project goals dictated by the ISTHA and IDOT require a resampling of the vegetation every year for five years. The vegetation sampling will include one year of baseline monitoring followed by 4 years of post management monitoring. The post management surveys will allow comparisons to this baseline study, so that any changes or effects of management can be dutifully reported to the ISTHA and IDOT. If change is significant, the ISTHA and IDOT will receive credit for restoring the area for the purpose of compensating for the unavoidable negative impacts to aquatic resources elsewhere in the state. Proposed habitat management includes removal of invasive species and localized seeding of native prairie and wetland species followed by habitat management involving prescribed fire.

Site History

See Chapter 1.2 Site History

Study Questions

This study was designed to analyze the structure of the upland plant communities at the North Chicago Wetland Mitigation Site (NCWMS) as part of a baseline monitoring program.

Question A – What communities can be identified at the site based on species composition data?

Prediction – Based on field observations, there will be two main community types, prairie and old field. Differences in these community types will be discussed below.

Question B – What are the compositional patterns between the perceived community types and which species are responsible for these patterns?

Prediction – Vegetation patterns represent an inferred gradient of disturbance due to shrub encroachment and agricultural practices. Prairie plots will be characterized by lower percent bare ground, greater species richness, greater herbaceous cover, and higher floristic quality. Old field plots will be characterized by higher percent bare ground, lower species richness, lower herbaceous cover, and lower floristic quality integrity.

Question C – What is the stem density and percent canopy cover in the shrub stratum, and does this vary depending on the community?

Prediction – Old field communities will have greater shrub canopy cover.

2.2 Methods

Sample Design

A stratified vegetation sampling design was utilized with 10 parallel transects running west to east, each separated by 152 m intervals. Five sample points were established on each transect separated by 76 m (the transect furthest to the north had four sample points). This array provided 37 terrestrial vegetation plots and 12 wetland plots (the latter not examined in current study). In addition, eight plots were established in reference prairie remnants in the far southern portion of the study, for a total of 45 vegetation sample plots. Specific plot location with the additional targeted sampling was determined randomly.

Vegetation Sampling

Vegetation was sampled from the first week in June until the third week of July. Spatially, the transects were sampled from north to south, with the sampling completed on each transect before moving to the next. Vegetation was sampled in 25-m^2 (5m x 5m) sampling plots with ground layer quadrats (1m^2) nested within. The baseline point for all sample plots was the southwest corner of the shrub/sapling plots. Plot sides were oriented along cardinal directions (the southern boundary runs W-E at 90^o). Composition and stem density of shrubs and saplings (all woody stems > 1-m tall and < 10 cm dbh) were sampled within the 25-m^2 plots. Percent shrub cover was determined using digital photography with a hemi-view lens oriented vertically in the plot center to photograph the canopy of the plot area (narrowed with a lens tube). Interference from herbaceous cover was minimized by placing the camera on a 70cm tall tripod. Percent visible sky was calculated from these images using HemiView Canopy Analysis Software, ver. 2.1. Percent canopy cover was calculated as 100 - % visible sky. Ground layer vegetation was sampled with 3 quadrats nested within each shrub plot, with quadrat placement in the southwest and northeast corners and one in the plot center. Data collected from each quadrat included species presence and percent cover for each species estimated with a modified Daubenmire cover-class scale (0-1 %, 1-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-100%). All species rooted within each quadrat frame were recorded to species including woody species < 1-m tall. Trees (woody stems > 10 cm dbh), scarce in the study area, were sampled in 200 m^2 (14.14 m x 14.14 m) sample plots (n = 4) anchored at the SW corner of the shrub plot.

Data Analysis

Question A- Cluster analysis in PC-ORD ver. 4.34 software package (McCune and Mefford 1999) was utilized to produce a hierarchical classification of sites from the quantitative sample data based on the Sørensen similarity distance measure and flexible Beta linkage method (ß = -0.25). The clustering algorithm based on Wishart (1969) and Post and Sheperd (1974) in PCORD, was used to produce a classification of plots from sample data. Flexible sorting with β set at -0.25 was used for its optimal grouping characteristics (Lance and Williams 1967) to construct a hierarchical dendrogram based on Sørensen distance measures. Results from the cluster analysis were confirmed with field observations. Communities were named based on field observations of the plots and the species data.

Question B, C, and D - Species abundance is measured by Importance Value (IV 200), calculated as the sum of relative frequency and relative cover for ground-layer samples; for the shrub/sapling stratum, IV is calculated as the sum of relative frequency and density; and for trees, IV is calculated as the sum of relative density and basal area. Indicator Species Analysis (Dufrene and Legendre 1997) was used to determine non-random group affiliation for species with probability determined from 1,000 Monte Carlo permutations of the data using the PC-ORD ver. 4.34 software package (McCune and Mefford 1999). Indicator Values were calculated for each species with the following formula: Indicator Value = 100 (RA x RF), with RA =relative abundance and RF = relative frequency. A perfect indicator (IV = 100) would be a species that is both faithful (complete fidelity to a particular community type) and reliable (always present).

Vegetation data include parameters calculated at both quadrat and plot spatial scales. Species richness was the only parameter summed among plot quadrats, all others were averaged. Parameters, defined below, include species richness (native and non-native), and metrics for Floristic Quality Assessment (FQA) including calculations based on both native and all species. FQA metrics include Mean Coefficient of Conservatism and the Floristic Quality Index (Taft et al. 1997). Species-level metrics included native species richness, mean coefficient of conservatism, floristic quality index (Taft et al. 1997), and mean wetness coefficient were calculated as follows:

Native Species Richness: Total number of native species in a sample unit

Native Species Density: Average number of native species in a sample unit

Mean Coefficient of Conservatism (Mean C): Σ Coefficient of Conservatism (CC) / S, where CC = Coefficient of Conservatism (Taft et al. 1997) and S = total species richness per sample unit (Swink and Wilhelm 1994; Taft et al. 1997). CC ranges from 0 to 10, 0 being assigned to all non-native species and native species with no affiliation to natural areas, whereas 10 is assigned to native species that almost always occur in high quality natural areas. Values for all species in this study can be found in Appendix 1.

Floristic Quality Index (FQI): Mean C * (√N) where N = native species richness

Mean Cn and **FQIn** are calculated using only native species.

Mean Wetness Coefficient: Σ Wetness Coefficient (WS) / S, where WC is the wetness coefficients for each species (Reed 1988) and S is the number of species per sample unit. This method was adapted for use in this project from the Federal Interagency Committee for Wetland Delineation (1989) to identify hydrophytic vegetation and to determine whether soil moisture was a confounding variable in this analysis. A listing of all species and their wetness confidents can be found in Appendix 1

All indices and parameters calculated from terrestrial vegetation samples were normally distributed. Comparisons of vegetation parameters among the vegetation types determined from cluster analysis were examined with means comparison tests (t-tests) using Systat ver. 10. The arrangement of sites, vegetation types, and species was examined with Nonmetric Multidimensional Scaling (NMS). NMS (Kruskal 1964; Mather 1976) was applied to assess the relationship between community types, species richness, and environmental variables. NMS has the advantage of not relying on a species response curve model and its optimal graphical representation of community relationships (McCune & Grace 2002). Using a random starting configuration, NMS was run in autopilot mode, comparing 40 runs with real data from one to six dimensions. A Monte Carlo test with 50 randomized runs was performed to assess whether resulting axes significantly reduced more stress than expected by chance. Plots that were highly dissimilar to others (standard deviation from the mean calculated distance of all plots > 2.3, < 3) were detected by outlier analysis in PC-ORD (McCune & Mefford 1999) and were excluded. Correlations between ordination axes and variables were evaluated by Pearson's correlation coefficient (r). Final NMS orientation figure produced with PCORD (Ver. 4.34). Botanical nomenclature follows Taft et al. (1997), a modification from Mohlenbrock (1986). Non-native species in the report will be indicated with an asterisk (*).

2.3 Results

Summary Vegetation Description

A total of 215 species were identified from the 29 transect plots and 16 prairie reference plots. This included 171 native species and 33 non-native species, with the remaining species unidentified to species. These individuals represented seedlings or sterile individuals unidentifiable to species and believed primarily to be seedlings or individuals of recorded species. Dominant species in the ground layer vegetation included *Rhamnus cathartica*, Cornus racemosa, Solidago juncea, Fragaria virginiana, Schizachyrium scoparium, Aster drummondii, Allium cernum Lonicera* X *bella*, Potentilla simplex, Andropogon gerardii,* and *Poa pratensis*.* Combined, all these species represent about 36% of the importance value among all species present. Refer to Appendix 1 for a listing of the common and scientific names for all species that were located within the ground layer.

Question A- What communities can be identified at the site based on species composition data?

Prairie and old field/shrubland were the two basic upland vegetation types perceived from field work and subsequently confirmed from hierarchical cluster analysis. 16 prairie plots and 29 old field/shrubland plots were identified from the analysis (Figure 5). The 16 prairie plots included 8 plots randomly placed in high quality prairie remnants in the southern portion of the site and 8 that were among the stratified transects.

Question B- What are the compositional patterns between the perceived community types and which species are responsible for these patterns?

Prairie has significantly higher native species density, native richness, vegetative cover, and lower percent bare ground (Table 1). Floristic quality indices were all significantly higher in the prairie plots. Additionally, visible sky was significantly greater in the prairie plots.

Several species had a non-random affiliation to prairie and old field communities. Only *Circea lutetiana, Lonicera* X *bella**, *Carex unbellata, Sanicula canadensis,* and *Rhamnus cathartica** are species that significantly associate with the old field plots (Table 2). Many more species are significant indicators of the prairie plots. *Achillea millefolium**, *Antennaria neglecta, Aster ericoides, Monarda fistulosa, Solidago juncea, Cerastium vulgatum**, *Helianthus rigidus, Ratibida pinnata,* and *Solidago nemoralis* are just of few of the most significant indicator species of the prairie plots (Table 2). Two C4 grasses were significant indicators of a prairie community in this analysis, *Schizachyrium scoparium* and *Andropogon gerardii*.

Question C- What is the stem density and percent canopy cover in the shrub stratum, and does this vary depending on the community?

Shrub density was greater in the prairie plots, but the differences were not significant. There were 24,125 stems/ha in the prairie plots and 22,220 stems/ha in the old field plots. Shrub canopy cover averaged 50% in the prairie plots and 75% in the old field plots. Overall, *Rhamnus cathartica*, *Cornus racemosa*, *Lonicera* X *bella*, *Viburnum lentago*, and *Rhamnus frangula* were the most important shrub species (Table 3) in both the old field and prairie communities. Three shrub species were found in the prairie plots that were not found in the transect plots, while 11 species were found in the old field plots that were not sampled in the prairie plots.

Question D - What is the structure and composition of forested plots?

Trees (woody stems > 10cm DBH) were uncommon at the site, and occurred in 4 out of the 45 plots sampled. *Populus deltoides* was the most important tree, as several large (>35cm dbh) specimens were present in one of the plots along the eastern edge of the site (Table 4). *Populus deltoides*, *Acer negundo*, *Crataegus pruinosa*, *Prunus serotina*, *Quercus macrocarpa*, and *Rhamnus cathartica* were the only tree species found in the sampling units. For those plots with trees, average basal area at the site was $12m^2$/ha and average density was 250 trees/ha,

Ordination

The NMS ordination graphically represents the structure of the community while allowing for further interpretation of community attributes such as percent bare ground, percent shrub canopy cover, mean wetness coefficient, native species richness, non-native species richness and shrub density (Figure 6). As identified earlier with cluster analysis, the ordination clearly supports two distinct community types derived from vegetation sample data mostly separated by variation in the first axis. Combined, axes one and two explain 77% of the variation in the original dataset. Variation in the first axis can be attributed to a gradient of native species richness (r = -0.81) and percent bare ground (r = 0.83), with a smaller contribution from % canopy cover (r = 0.73) and mean wetness coefficient (r = -.54). The gradient on axis two cannot be sufficiently explained by any of the environmental variables included in the model. Plot Pr8 has high ground layer cover, little shrub canopy cover, and high native density, FQI, and Mean C. The abundant species present in this plot are rare in other plots, even those classified as prairie. As a result, this plot was recognized as an outlier and removed from the graphical ordination.

2.4 Discussion

Prairie and old field plots differ in species richness, species density, herbaceous cover, and percent bare ground. A trend in the data is that fewer species associate non-randomly with the old field plots. One explanation is that few herbaceous species can compete with shrubs in the old field plots, due to the significantly higher canopy cover. Accordingly, the results indicate that bare ground increases significantly under high canopy cover. Very few shade tolerant woodland species occurred at the site, and when they did their distribution was highly localized. The exception would be the species that were significant indicators for the old field. All are common in savanna communities characterized by sparse to dense canopy cover. The lack of common woodland or transitional species may be partially explained by the presence of dispersal barriers or a lack of adjacent woodland habitat that discourages migration of shade tolerant species to the site. Present day dispersal barriers at the site include the surrounding matrix of urban developments including large industrial parks and residential developments. Past dispersal barriers likely included the immense agricultural landscapes that existed prior to industrial and residential development.

Another interesting pattern identified by this study is the slightly higher density of shrubs within prairie plots. However, canopy cover is significantly greater in the old field plots, indicating that prairie plots are dominated by young shrubs that have yet to form a dense canopy. Further evidence of shrub invasion is the intermediate composition of the vegetation in plots heavily infested by shrubs. For example, plots 10D and 9A or 7d and 1A are similar to one another in ordination space, because they share many of the same species with similar herbaceous cover, even though they are classified as different communities. Intermediate plots commonly had species that were significant indicators of both the old field and prairie plots. Furthermore, previous studies at the site (Plocher et al 1996) indicate a three fold increase in shrub density per hectare over a 14-year period (Taft et al 2010). This indicates that shrub dominance is a relatively recent phenomenon requiring immediate action to maintain prairie community structure. Shrub removal and prescribed fire may shift the ground layer species composition of the plots intermediate between prairie and old field towards that of prairie plots, but without management those plots intermediate in composition will likely resemble old field plots in the future.

The mean wetness coefficient indicates that no terrestrial plots were dominated by wetland vegetation. However, NMS ordination revealed that there was a positive relationship between mean wetness coefficients and community type. Prairie communities are represented by a higher mean wetness coefficient and the old field plots by a lower mean wetness coefficient. This indicates that ground layer vegetation in prairie plots is more affiliated with uplands, while those in the old field plots are more affiliated with mesic habitats. However, any relationships should be interpreted with caution as wetness coefficients assigned to species were done so to differentiate between wetland and non-wetland habitats, and not to identify a moisture gradient based solely on species distribution patterns.

Tree/forest cover was insignificant at the site, as trees occurred sporadically. Soil surveys indicate that the far northwest area of the site was dense forest at one time (Paschke and Alexander 1970), but has since been degraded into a matrix of grassland and shrub communities. Aerial photographs of the area from 1941 show no forest cover in the northeast area of the site (Chapter 1, Figure 1). The woodland flora that likely formed under the forest canopy did not persist to the time of sampling, as it was most likely degraded as a result of forestry and agricultural practices. Other work determined that the study area existed within a mosaic of mesic prairie, wet prairie, and savanna vegetation (Moran 1976). Consequently, it is possible that trees could have been locally dense in the northeast corner of the study area, accounting for the formation of the forest soil observed in soil surveys.

2.5 References

Dufrene, M. and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs* 67(3):345-366.

Federal Interagency Committee for Wetland Delineation. 1989. *Federal manual for identifying and delineating jurisdictional wetlands*. U.S Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and U.S.D.A Soil Conservation Service, Washington, D.C. Cooperative technical publication. 76 pp. plus appendices.

Kruskal, J.B. 1964. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. *Psychometrika* 29: 1-27.

Lance, G.N. and W.T. Williams. 1967. A general theory of classificatory sorting strategies. 1. Hierarchical systems. *Computer Journal* 9:373–380.

Mather, P.M. 1976. *Computational methods of multivariate analysis in physical geography*. J. Wiley and Sons, London. 532 pp.

Mohlenbrock, R.H. 1986. *Guide to the vascular flora of Illinois*. Revised and enlarged edition. Southern Illinois University Press, Carbondale. viii + 507 pp.

Moran, R.C. 1976 Presettlement vegetation of Lake County, Illinois. *Proceedings of the Fifth Midwest Prairie Conference.* Iowa State University, Ames, Iowa.

McCune, B. and J.B. Grace. 2002. *Analysis of ecological communities*. MjM Software Design, Gleneden Beach, OR, US.

McCune, B. & M.J. Mefford. 1999. PC-ORD. *Multivariate analysis of ecological data*. Version 4.34. MjM Software, Gleneden Beach, OR, US.

Paschke, J.E., and J.D. Alexander. 1970. *Soil survey, Lake County, Illinois*. Illinois Agricultural Experiment Station Soil Report No. 88. United States Department of Agriculture, Soil Conservation Service in cooperation with Illinois Agricultural Experiment Station.

Plocher, A., P. Tessene, and J. Olson. 1996. Wetland mitigation site assessment of the US 41/IL 137 Illinois Department of Transportation project area. Technical report submitted to the Illinois Department of Transportation, Bureau of Design and Environment, Springfield.

Post WM, and J.D. Sheperd. 1974. *Hierarchical agglomeration*. University of Wisconsin, Madison

Reed, P.B., Jr. 1988. *National list of plant species that occur in wetlands*: 1988 Pennsylvania. U.S. Fish&Wildlife Service, National Wetlands Inventory.

Taft, J.B., G.S. Wilhelm, D.M. Ladd, and L.A. Masters. 1997. Floristic Quality Assessment for vegetation in Illinois, a method for assessing vegetation integrity. *Erigenia* 15: 3-95.

Taft, J.B., C. Hauser, and K.R. Robertson. 2006. Estimating floristic integrity in tallgrass prairie. *Biological Conservation* 131:42-51.

Taft, J.B., Z. Kron, & A. Plocher. 2010. Baseline quantitative vegetation monitoring in terrestrial and wetland communities in the North Chicago wetland mitigation site, Lake County, Illinois. Technical report submitted to the Illinois Tollway Authority, Downers Grove.

Whittaker, R.H. 1975. *Communities and Ecosystems*, second edition Macmillan Publishing Co., Inc., New York, New York.

Wishart, D. 1969. An algorithm for hierarchical classifications. *Biometrics* 25:165–170.

2.6 Tables and Figures

Table 1. Results of mean comparison tests between the old field and prairie communities identified from cluster analysis at the North Chicago Wetland Mitigation site. Significance was corrected for multiple comparisons with the Bonferonii correction (0.05/N where N is the number of comparisons made). Significant variables are bolded. Native species density, total density, native richness, % ground layer cover, Native Mean C, Mean C, FQI, FQIn, and visible sky were all significantly greater in prairie plots. % Bare ground was significantly greater in the old field plots.

	Prairie		**Old Field**			
	Mean	SE	Mean	SE	t-stat	*P*
Ground layer structure						0.008333
Native spp. density/quad	23.92	0.95	13.66	1.76	5.59	**0.000002**
Adventive spp. density/quad	5.98	0.46	3.93	0.46	2.87	0.008338
Total density/quad	29.90	1.09	17.59	2.07	5.8	**0.000001**
Native Richness/plot	38.00	1.29	24.69	2.87	4.84	**0.000018**
Adventive Richness/plot	8.63	0.69	5.72	0.78	2.64	0.013740
% Vegetative cover	206.72	13.7	78.04	9.90	6.49	**0.000003**
% BG	9.03	1.59	34.34	4.44	-6.4	**0.000000**
Floristic Quality Assessment						0.012500
Native Mean C	3.62	0.14	2.74	0.13	4.03	**0.000529**
Mean C	2.94	0.16	2.09	0.14	3.58	**0.001598**
FQI	14.48	0.93	7.86	0.88	4.68	**0.000100**
FQIn	17.78	0.96	10.06	0.99	5.21	**0.000022**
Shrub Stratum						0.025000
Shrub Density	60.31	7.03	55.55	8.11	0.42	0.674544
Visible sky	0.50	0.05	0.24	0.02	3.76	**0.001542**

Table 2. Species with a non-random affiliation to the given community type determined by 1000 Monte Carlo permutations. Only significant results are shown (P < .05). Indicator Value = 100 (RA x RF), with RA =relative abundance and RF = relative frequency. A perfect indicator (IV = 100) would be a species that is both faithful (complete fidelity to a particular community type) and reliable (always present). Many more species were significant indicators of prairie communities

Prairie

Species	Indicator Value	P
Achillea millefolium *	83.7	0.0001
Antennaria neglecta	61.4	0.0001
Aster ericoides	89.5	0.0001
Monarda fistulosa	74.1	0.0001
Solidago juncea	86.3	0.0001
Cerastium vulgatum *	62.3	0.0002
Helianthus rigidus	43.6	0.0002
Ratibida pinnata	84.8	0.0002
Schizachyrium scoparium	43.7	0.0002
Solidago nemoralis	71.4	0.0002
Agrostis alba	69.7	0.0003
Erigeron strigosis	60.1	0.0003
Liatris spicata	48.5	0.0003
Daucus carrota *	65.4	0.0005
Hieracium caespitosum *	55.2	0.0006
Lithospermum canescens	37.5	0.0006
Solidago rigida	47.3	0.0006
Sorghastrum nutans	37.5	0.0006
Vicia americana	37.5	0.0006
Sysyrinchium albidum	42.5	0.0007
Aster azureus	37.5	0.0008
Parthenium integrifolium	37.5	0.0008
Leucanthemum vulgare *	63	0.0011
Andropogon gerardii	37.4	0.0012
Rudbeckia hirta	66.2	0.0012
Commandra umbellata	31.2	0.003
Silphium terebinthinaceum	31.2	0.003
Euthamia graminifolia	35.6	0.0074
Rosa caralina	55.6	0.0086
Melilotus alba *	36.3	0.0097
Krigia biflora	25	0.0109
Gentiana andrewsii	25	0.0116
Helianthus grosseseratus	39.4	0.0134
Rubus pensilvanicus	56.6	0.0163
Aster novae-angliae	27	0.0166
Juncus interior	24.6	0.0307
Cornus racemosa	63.1	0.0319
Prunella vulgaris v. *elongata*	53.2	0.0319
Gentiana alba	24.4	0.0354

Old Field

Species	Indicator Value	P
Circea lutetiana	37.9	0.0136
Lonicera X bella	57	0.0295
Carex unbellata	31	0.0297
Sanicula canadensis	40.2	0.0307
Rhamnus cathartica	59.2	0.0471

Table 2. continued

Prairie			Old Field		
Species	Indicator Value	P	Species	Indicator Value	P
Gentiana quinquefolia	23.6	0.0375			
*Poa pratensis**	51.4	0.0387			
Bromus kalmii	18.7	0.0393			
Asclepias tuberosa	18.7	0.0396			
Liatris aspera	18.7	0.0396			
Ulmus americana	18.6	0.0399			
Viola peditifida	28.1	0.0405			
*Medicago lupulina**	18.7	0.0412			

Table 3. Shrub Importance values (IV) calculated from all prairie and old field plots. IV was calculated as the sum of relative frequency and relative density per $25m^2$ plot. *Rhamnus cathartica*, *Cornus racemosa*, *Lonicera* X *bella*, *Viburnum lentago*, and *Rhamnus frangula* were the most important species regardless of community type and together accounted for 87.82% and 82.22% of the IV in prairie and old field, respectively. Shrubs were defined as wood plants > 1m tall with a DBH < 10cm.

Species	**All plots** % IV	**Prairie** % IV	**Old Field** % IV
Rhamnus cathartica *	38.67	41.62	37.44
Cornus racemosa	22.48	26.06	20.40
Lonicera X *bella* *	10.83	11.30	10.90
Viburnum lentago	7.58	4.71	9.08
Rhamnus frangula *	4.31	4.14	4.40
Crataegus pruinosa/coccinea	3.63	1.99	4.39
Prunus virginiana	1.54	1.00	1.79
Vitis riparia	1.50	2.09	1.25
Cornus stolonifera	1.48	1.00	1.74
Zanthoxylum americanum	1.03	2.96	0.00
Crataegus sp.	0.92	0.00	1.31
Malus ioensis	0.90	0.00	1.28
Crataegus calpodendron	0.66	0.00	0.96
Cornus obliqua	0.64	1.05	0.48
Viburnum opalus *	0.60	0.00	0.86
Crataegus punctata	0.59	0.00	0.83
Populus tremuloides	0.53	0.00	0.79
Amelanchier sanguinea	0.33	1.10	0.00
Rhus glabra	0.31	0.00	0.45
Crataegus mollis	0.29	0.00	0.42
Fraxinus pennsylvanica subintegerrim	0.29	0.00	0.42
Malus pumila *	0.29	0.00	0.42
Prunus americana	0.29	0.00	0.42
Viburnum recognitum	0.29	1.00	0.00
Mean density / plot	57.24	60.31	55.55
Density / ha	22897.78	24125.00	22220.69

Table 4. Tree importance values (IV) are calculated as the sum of relative density and basal area. Trees were uncommon at the North Chicago Wetland Mitigation site and occurred in only 4 out of 45 plots.

Species	Basal Area / ha	Density / ha	% IV
Populus deltoidies	7.52	50.02	40.83
Rhamnus cathartica *	1.00	75.02	19.11
Crataegus pruinosa/coccinea	0.52	50.02	12.13
Quercus macrocarpa	1.69	25.01	11.92
Acer negundo	0.81	37.51	10.81
Prunus serotina	0.66	12.50	5.20
	12.20	250.08	100.00

mean tree density/200m^2 plot	5
mean tree spp./200m^2 plot	2.75

Figure 5. Hierarchal cluster analysis using a Sørensen distance measure with a flexible ßeta linkage (-0.25). Results indicate two basic groups of plots can be found at North Chicago Wetland Mitigation site. In combination with field work, these two communities were determined to be prairie (red plots) and old field (Green Plots). There were a total of 16 prairie plots and 29 old field plots.

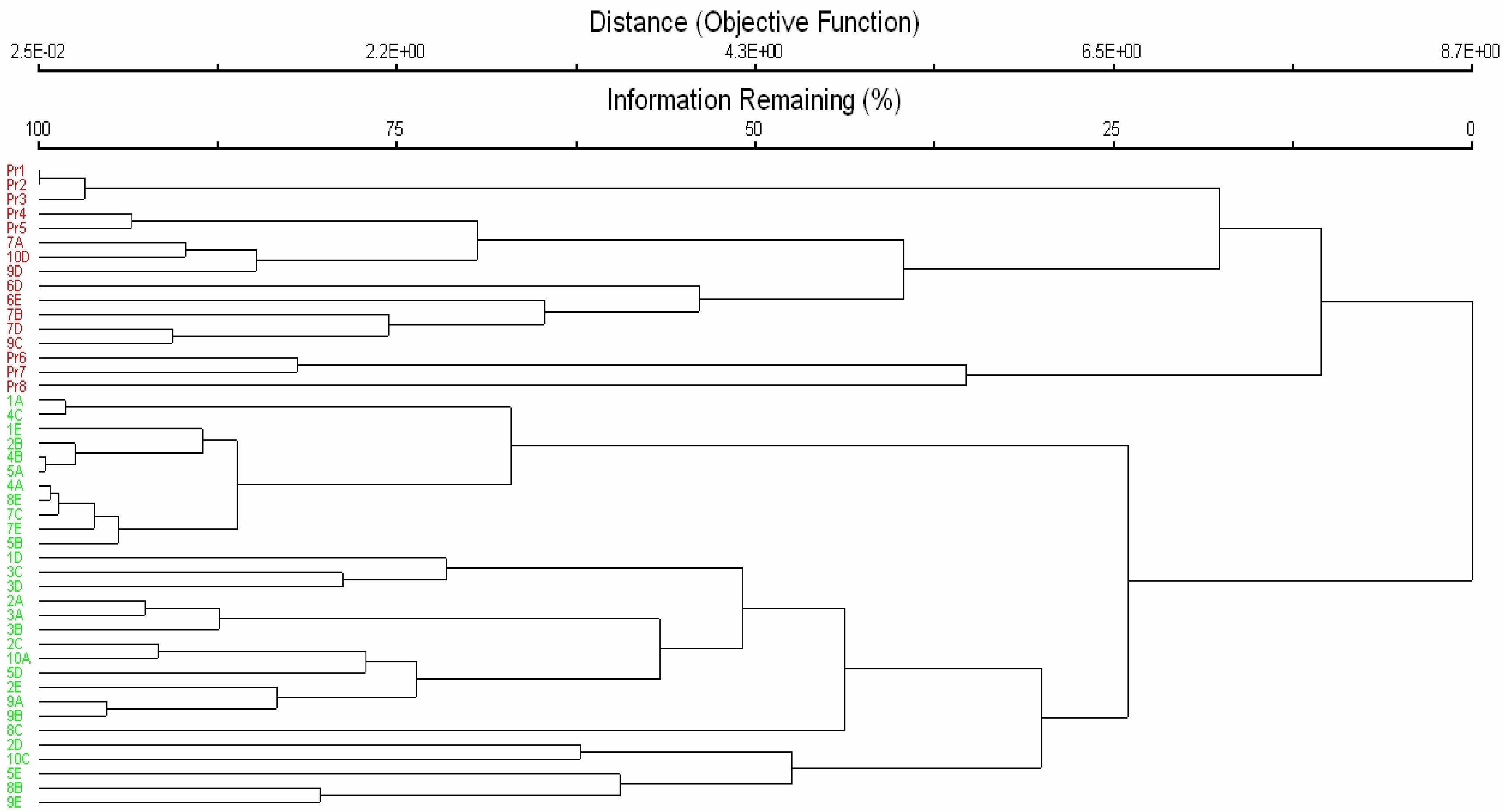
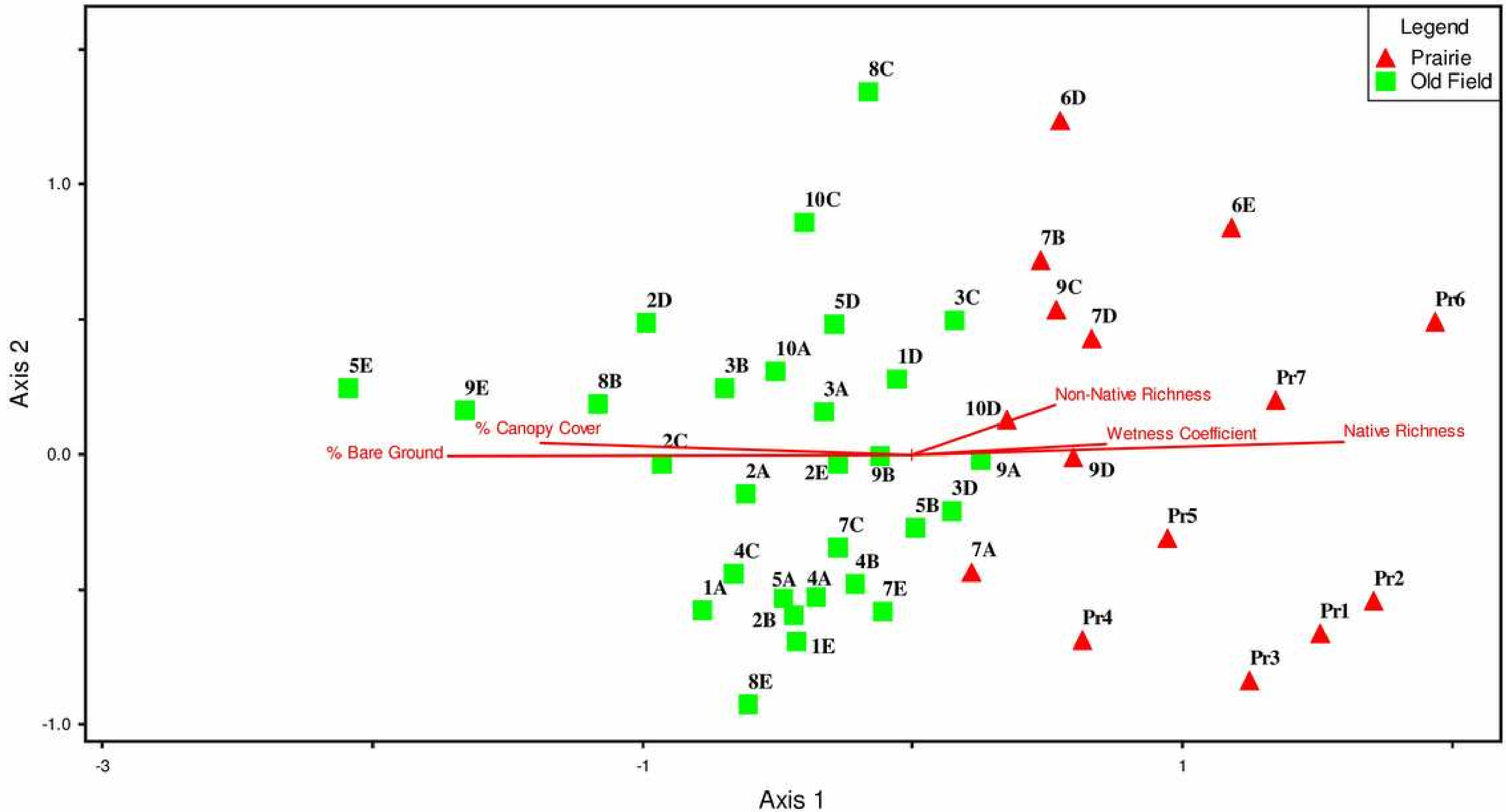


Figure 6. Two dimensional NMS ordination of variables and plots categorized by community type that explained 77% of the variation in the original data. Final Kruskal stress was 16.13 and final instability = 0.00001. The ordination was rotated until Axis 1 explained the most variation in variables. Variables included within the model and explaining the most variation on Axis 1 are % bare ground (r = 0.83), % shrub canopy cover (r = 0.73), native richness (r = -0.81), mean wetness coefficient (r = -0.54), and non-native richness (r = -0.48). Shrub density was included within the model but excluded from the graphical ordination because it explained little variance (r < 0.1) in the original data. Plot Pr 8 was removed from the graphical depiction because it was identified as an outlier (> 2 standard deviation from the mean).



Chapter 3

Soil seed bank

Abstract

Questions - Does heat shock significantly alter the species germinating from the seed bank? Is the seed bank representative of the standing vegetation at the plot level? Is there any evidence that refugia were responsible for the recolonization of former agricultural lands? If so, are there differences in plant distributions based on their dispersal mechanisms?

Location – 65 ha tallgrass prairie and old field mosaic at the North Chicago Wetland Mitigation Site in Lake County, IL.

Methods – The vegetation and germinable seed bank were sampled along stratified transects to determine composition. Similarity of species composition was compared between heat treated and control soil seed bank samples germinated in flats on a greenhouse mist bench. Similarity was determined using the Sørensen similarity index. Sørensen similarity also determined the extent to which standing vegetation matched the seed bank composition. To determine if prairie remnants acted as refugia for the spread and colonization of prairie species, prairie plants were identified in the standing vegetation. They were classified into dispersal categories (animal, unassisted, water, wind) to evaluate patterns of colonization. Patterns of colonization were determined by comparing species occurrence data on a distance gradient to the nearest remnant.

Results – Heat shock had a variable effect on germination. 11 species germinated only after heat shock. Conversely, 8 species germinated exclusively in the unheated control. Seed banks commonly had 1 to 2 species in common with the standing vegetation. Of the 50 most common species found in local remnants, only 6 were found in the seed bank. Overall species richness,

proportion of prairie species, and Floristic Quality Index had no relationship with distance to remnants.

Discussion – Heat shock has negative, positive and indifferent effects on the germination of several native midwestern species. The extent to which most North American grassland species benefit from heat shock remains unknown. This study suggests that it may be a significant factor for only some species. Seed banks do not appear to provide a refuge for prairie species because few prairie specialists were present in the seed bank. Dispersal types among species had no relationship to distribution patterns at the study site. One limitation of this study is the size of the samples taken from the soil seed bank.

Conclusions – The study suggests that few species were found in the seed bank and there was very little similarity between the species found in the seed bank and the standing vegetation. Possible causes of seed bank limitation are probably attributable to the past history of rigorous cultivation at the site and the recent history of shrub encroachment. Results suggest that at least some of the North Chicago Wetland Mitigation site should be supplemented with native grassland seed because seed limitation may be a restrictive factor determining local patterns of species richness and composition.

3.1 Introduction

This portion of the study represents a rapid assessment of the state of the soil seed bank to determine its potential role in the restoration of the vegetation at the North Chicago Wetland Mitigation Site (NCWMS). It needs to be determined the extent to which the soil seed bank at NCWMS provides a refugium for prairie species and whether local prairie remnants provide resources for recolonization. Refugia of plant species diversity such as soil seed banks and remnants can be vital to recovery of degraded plant communities. For example, soil seed banks can provide a valuable resource for recolonizing habitats following disturbance (Thompson and Grime 1979) and local remnants may be sources for colonizing species. Some community types such as boreal forests have a rich seed bank including many species found in standing vegetation (Grandstrom 1982). However, there has been less evidence that soil seed banks provide this resource in grasslands, particularly tallgrass prairie (Abrams 1988).

Seed limitation has recently received a great deal of attention in the ecological literature (Svenning and Wright 2005; Ehrlen et al. 2006; Orrock et al. 2006; Stien et al 2008; Leng et al. 2009; Jacquemyn et al. 2010), and it could be a contributing factor to plant distribution patterns at the site. The distributional patterns in both the soil seed bank and the standing vegetation will be scrutinized for patterns of seed limitation. Seed limitations may impose strict limits on habitat recovery following disturbance, (Zobel et al. 2000; Wilsey and Polley 2003; Foster et al. 2007) making seed banks and habitat remnants potentially important components to restoration.

In addition to the removal of invasive shrubs and prescribed fire, the management plan for the site includes the application of native grassland seed to degraded areas. It needs to be determined the extent to which this is necessary and where augmentation may be most justified based on existing patterns and evidence for recovery.   By analyzing the seed bank and the standing vegetation for distributional patterns and evidence of limitation, the results of this portion of the study could directly inform management activities at the site.

Site History

See Chapter 1.1 Site History

Seed Dispersal

Mechanisms of seed dispersal have been classified into six dispersal categories (Thomsan et al. 2010): wind, unassisted, water, ant, vertebrate-ingestion and vertebrate-attachment. Dominant prairie vegetation seed dispersal types can be catagorized into the wind, unassisted, water, vertebrate-ingestion and vertebrate-attachment categories. These categories were adapted for this study by combining the two vertebrate categories into the single animal assisted dispersal category. Myrmecochory was not evaluated for the plant taxa used in this study, and was excluded as a possible dispersal type because no known myrmecochorous plants species are known from NCWMS.

Study Questions

This study provides a rapid assessment of seed bank characteristics examining existing patterns of species composition and diversity in seed banks and standing vegetation for evidence of species persistence in soil seed banks and colonization from prairie remnants into former agricultural lands.

Question A - Is the seed bank representative of the standing vegetation at the plots?

Prediction – Similar studies examining prairie seed banks have found a poor correlation between standing vegetation and seed banks. It is expected that similar results will be found in this study.

Question B - Does simulated fire (heat shock) significantly alter the species germinating from the seed bank?

Prediction – Heat will significantly affect both the identity of species germinating and the number of species germinating from the seed bank. It is possible that some species will be unaffected by the heat treatment and will therefore show no differences in germination between treatments.

Question C - Is there any evidence that seed bank refugia were responsible for the colonization of former agricultural lands?

Prediction – As suggested by the literature, there should be little evidence that characteristic grassland species are common in the seed bank. The seed bank is expected to be depauperate in general and lacking the most important species found in the standing vegetation in the nearby prairie remnants.

Question D – What are the patterns of recolonization relative to the remnants?

Prediction – Prairie plants present in the remnants colonized the old agricultural fields post agricultural use. Therefore species richness, FQI, and proportion of species that are prairie species per plot should be greatest near remnants. The highest diversity should appear near remnants and any landscape features that could have once acted as a windbreak or shelter in the previously agricultural landscape.

Plants with water dispersed seeds will be the most restricted category at the site because it consists mostly of upland habitats. It is possible that water dispersed seeds will be locally common to microhabitats, but it is unlikely that they will be abundant throughout the non-wetland habitats on site. Unassisted seeds should be the most locally restricted seeds, second only to water dispersing seeds. Animal dispersed plant species are expected to occur throughout the site. Wind dispersed seeds, with their large surface area relative to their weight, are expected to be found throughout the site.

3.2 Methods

Sample Design

See Sample Design, Chapter 2.2.

Vegetation Sampling

See Vegetation Sampling Chapter 2.2

Soil sampling

Using a soil probe, five soil samples 2 cm in diameter and 15 cm in length were obtained at each 5 X 5m plot, for a total soil volume of 4946cm^3. Samples were taken at the corners of the plot and in the center, including one within each ground-layer sample quadrat. The low number and volume of samples taken at each plot reflect the intention to minimize disturbance while providing a rapid assessment of the site which is currently undergoing restoration. Surface debris such as twigs and leaves were removed from the samples. Prairie reference plots were excluded from the soils analysis. In 2009 soil samples were collected from transects 1-6 and in 2010 soil samples were collected from transects 7-10, however 2010 samples were excluded from the analysis due to poor germination and only 2009 data were analyzed.

Collection of soil samples began in July 2009 and ended by the end of that month. Samples were collected at this time to avoid transient species in the seed bank that could germinate soon after winter cold stratification. Soil samples were air-dried at room temperature for two weeks. They were then cold stratified at 2^oC for one month and at -4^oC for an additional month. Individual cores taken from the same plot were mixed to ensure a homogenized sample, and then divided evenly by weight into two treatments, heat treated and an unheated control. Heat treated samples were warmed to 80^{o}C for a period of 10 minutes in a drying oven to mimic effects of grassland fires on surface soils, and is within the range tested by other studies (Herranz et al. 1998; Hanley et al. 2001; Thomas et al. 2003; Bolin 2009). This temperature is also known to break dormancy in hard seeded species (Keeley 1994) and has an affect similar to fire on the temperature of the near-surface soil (Herranz et al. 1998; Hanley et al. 2001; Thomas et al. 2003). Samples were then spread on sterile media composed of peat and vermiculite on a greenhouse mist bench. Soil sample depth never exceeded 5mm when placed over the sterile media (30mm depth). Soil was kept moist but not wet by the mist bench, which provided a 20 second mist every 5 minutes for a 2 hour interval starting at 1pm. Flats were rotated often to lessen any bench effect. Flats remained under natural light conditions from the period beginning in March, 2010. Control flats were placed randomly on the bench to assure that the soil was not contaminated with seed, and no contamination was detected in the control flats. Seedlings remained in the flats until they were identified to species. Unidentified flowering individuals were removed and preserved for identification at a later time. After 5 months, it was assumed the germinable seed bank was exhausted since no new plants or taxa had emerged for several weeks and the experiment was terminated.

Assignment to Dispersal Categories

The pattern of recolonization was assessed by grouping species together by dispersal classes. The study concentrated on the 50 most common native species located within the prairie reference plots, based on Importance Value (IV 200= relative cover + relative abundance). Of these, 37 species were selected that were present at least once in the transect plots. Table 5 lists the life history and characteristics of the seeds for each species selected for the analysis. Plant species were categorized into one of four dispersal categories based on their fruit and or seed morphology. Dispersal categories were unassisted (i.e. gravity), wind, water, and animal assisted dispersal and were determined visually by the author based on herbarium specimens.

Data Analysis

Question A – Results from seed bank treatments were compared using the qualitative Sørensen similarity index (Sørensen 1957) based on presence-absence data for each species. The method is based on the formula (2A)/(B+C) x 100 where A is the number of species common between treatments and B and C are the total number of species in the treatments being compared. Sørensen's index is a suitable similarity measure because it retains sensitivity in heterogeneous data and gives less weight to outliers (McCune and Grace 2002). Furthermore, a Poisson distribution was used to determine whether there was a significant difference in the mean number of species germinating between treatments because of the discrete nature of the data.

Question B – Sørensen similarity index also was used to compare species occurring in the seed bank to species occurring in the standing vegetation. The analysis combined data from both the control and the heat treatment for each plot to represent the total germinable seed bank.

Questions C and D –The distance from each plot to a known remnant prairie was measured with GIS, to 5 meter accuracy. Remnant locations were determined from previous vegetation surveys at the site (Figure 7). The 50 species with the highest importance values in the prairie plots (Appendix 1) were selected for this analysis. Patterns of selected prairie species richness were compared to the distance of the nearest remnant to determine any relationships. Additional relationships of distance to remnants were tested including proportion of species richness of selected prairie species (species richness of select prairie species per plot / total species richness per plot) and Floristic Quality Index (FQI). The relationship of seed bank and standing vegetation similarity to distance were explored using linear regression. Binary Logistic regression of presence-absence data for each of the 50 prairie specialist species assessed the probability that they occur near remnants. The BASE package in the R statistical platform was used for analysis and graphic production (R Development Core Team 2009). A General Linear Model was specified for each species and each dispersal group for separate analyses. Since data could take on only two values (0 = absent, 1 = present), the regression used a binomial distribution with a "logit" link to determine the probability.

3.3 Results

Question A **–** Does heat shock significantly alter the species germinating from the seed bank?

In all, 27 species were identified from the 21 soil samples, with each sample divided into a control flat and a heat treatment flat (Table 6). The average number of new species with each additional sample unit does not near an asymptotic state with 21 plots (Figure 8). Conversely, the average similarity between plots increases dramatically until there is little distance between plots. 12 species were present only once in the study, while six were present at least twice. 11 species (40%) germinated only in heat treated samples while 8 (30%) species were found only in the control. The other 8 (30%) species were found in both treatment and control samples. On average, species that germinated in both the treatment and control flats were more abundant than those that only germinated in one or the other treatment.

Treatments most frequently had little to no similarity between them (Figure 9). Seed flats with high similarity suggest that the heat treatment had little to no effect on the species that germinated. Flats with little to no similarity suggest that a heat treatment had some effect. 11 out of 42 flats had no similarity between treatment and control. There was a slightly higher mean species density in control flats compared to heat-treated flats but the difference was not significant. Overall, there was a 15% increase in the number of species that germinated in the control when compared to the heat treatment.

Question B - Is the seed bank representative of the standing vegetation at the plots?

Only 16 species were found that were present in both the soil seed bank and the standing vegetation of individual sample plots (Table 7). 31% of those species are non-native, and 25% are annuals. *Oxalis stricta* was the most frequently found species in both the standing vegetation and the seed bank.

Overall, 16% of species in the standing vegetation were found in the seed bank, and 89% of species found in the seed bank were also found in the standing vegetation. Two species not found in the vegetation sampling but identified from the seed bank were *Cardamine* cf. *pensylvanica* and *Leucospora multifida.* 9 of the 27 species found in the seed bank were consistently found in the local prairie remnants, while 6 species were ranked among the top fifty species in terms of importance values in prairie remnants. However, the most abundant species in the remnant prairies are absent from the seed bank, including *Schizachyrium scoparium*, *Parthenium integrifolium*, *Sorghastrum nutans*, *Andropogon gerardii*, and *Silphium terebinthinaceum*.

Most frequently there was little similarity between the seed bank and standing vegetation (Figure 10). There was no correlation between Sørensen similarity index and species richness per plot; however, the two plots lowest in richness had no similarity between seed banks and vegetation. The relationship between similarity and richness is decidedly non-linear (Figure 11).

This indicates an initial increase in Sørensen similarity with increasing richness, then a subsequent decrease in similarity with increasing species richness.

Question C and D – Is there any evidence that seed bank refugia were responsible for the colonization of former agricultural lands? What are the patterns of recolonization relative to the remnants?

There was no significant relationship between FQI or proportion of prairie species and the distance to the nearest remnant. In addition, no relationship was identified between richness within a dispersal category and distance to remnant. The relationship between Sørensen similarity of standing vegetation to seed bank and distance to the nearest remnant is not significant. No individual prairie species had a significantly higher probability of occurring nearer a remnant. *Viola pedatifida*, a prairie species, had a decreasing probability of occurrence further from remnants, and the pattern was nearly significant (P = .074).

3.4 Discussion

<u>The significance of heat treatment</u>

Multiple studies have shown that plant species with physical dormancy that are native to fire-adapted ecosystems respond with increased germination rates following heat shock treatments (Auld 1986; Portlock et al. 1986; Bolin 2009). Other aspect of fire, such as the smoke and the chemicals it contains, may aid in the release of dormancy and subsequently improve germination rates (Jefferson et al. 2007; Moreira et al. 2010). Additional work suggests that the frequency and intensity of fire may represent a significant effect on the germination rates of several shrub species from southern Australian (Teiu et al. 2010). Very few studies have examined the role of heat shock on the germination of temperate grassland plants. Since prairies are fire adapted ecosystems, it seems plausible that heat treatments may have an effect on the germinable seed bank. For example, Bossuyt and Honnay (2008) found that heat shock increased the richness and density of seed banks in a study of calcareous temperate grasslands. Species affiliated with old field and prairie communities responded positively, negatively, and indifferently to the effect of heat shock. The 11 species that germinated only in the heat treated flats may have been positively affected by the heat treatment, perhaps through the release of dormancy. The eight species found to germinate only in the control flats were interpreted to be negatively effected by the heat treatment, under the assumption that seed was distributed randomly and evenly for each species within the samples taken from the site. No effect of heat treatment was identified for an additional eight species that germinated in both heat treated flats and control flats. Heat treatment resulted in a net gain of four species compared to control flats. However, most of these species were found only once and do not represent a significant treatment effect.

Seed bank vegetation comparison

The result of low similarity between species germinating in the soil seed bank and vegetation sampled in plots is consistent with other grassland studies (Thompson and Grime 1979; Johnson and Anderson 1988; Perez et al. 1998; McNicoll and Augspurger 2010); however, the finding in this study was due primarily to large differences in species richness in the soil seed bank and the standing vegetation. Only two species occurring in the seed bank did not also occur in the standing vegetation. This is uncommon, as most grassland ecosystems have a much higher proportion of species novel to the seed bank (Abrams 1988; McNicoll and Augspurger 2010). This suggests that the seed bank at this site, from the limited sample volume in this study, appear to be very species poor even when standing vegetation richness is very high. One possible explanation for this is the combination of past cultivation and recent and intense woody encroachment on the site. Previous work has shown that seed banks swiftly switch in composition following shrub and tree encroachment in temperate grasslands (D'Souza and Barnes 2008). In addition, most of the northern half of the study area was cultivated in row crop agriculture for a minimum of 30 years (Chapter 1), which may have been long enough to deplete whatever native seed bank existed in the soil prior to shrub invasion. Therefore the seed bank may be impeded by shrub encroachment and its inhibitory effects on grassland soil seed bank maintenance.

Seed bank refugia

These results suggest that the soil seed bank did not act as a refuge for prairie species following disturbance. This comes as no surprise, as prairie community dominants such as C4 grasses are often absent or low in abundance in prairie soil seed banks (Abrams 1988; Laughlin 2003; McNicoll and Augspurger 2010), and they rely heavily on vegetative means for maintaining dominance (Benson and Hartnett 2006) even though they produce substantial amounts of seed. Oftentimes, germinable seed banks tend to be dominated by transient or ruderal species in grassland communities, as was found in this study.

There are several possible explanations for the seed limitation observed in this study. The probability of Type I error is high, since the sample size for the seed bank work was relatively small compared to other seed limitation studies (Svenning and Wright 2005; Ehrlen et al. 2006; Orrock et al. 2006; Stien et al 2008; Leng et al. 2009; Jacquemyn et al. 2010), and may not be representative of the heterogeneity and richness present within the soil seed bank at each plot. As shown in the results, a species-area curve indicates that sampling has not yet identified all species present within the seed bank. Additionally, no seed addition or transplants were planted to rule out establishment limitation as a possible limiting factor. As mentioned in the introduction, this seed bank study was designed as a rapid assessment to inform managers of the current state of the seed bank. Results would then be used to aid in designing a seed mix and a seed planting plan, including how many species should be included, which species should be included, and the rate of seeding. Since relatively little prairie specialist species were present within the seed bank, seed augmentation with a general prairie mix is deemed to be prudent and appropriate in some areas.

Colonization

Little spatial evidence was found to suggest remnant patches of prairie significantly contributed to the recolonization of the formally cultivated areas within the site. However, many factors could account for the unexplained variance in this insignificant relationship as many covariates such as soil moisture, soil type, and local competitive interactions are not accounted for. Several uncommon prairie specialist species had a scattered distribution across the site, including *Gentiana alba*, *Viola peditifida*, *Zizia aptera*, *Anemone cylindrica*, *Oenothera perennis* (state threatened), *Allium cernuum*, *Asclepias purpurascens*, *Liatris aspera*, *L. spicata*, *Oxypolis rigidior*, *Phlox pilosa*, *Rosa carolina*, *Rudbeckia hirta*, *Ratibita pinnata*, *Lobelia spicata*, *Solidago juncea*, *Comandra umbellata*, *Hypoxis hirsuta*, *Sisyrinchium* spp., *Veronicastrum virginicum*, *Zizia aurea*, *Asclepias tuberosa*, *Aster ericoides*, *Monarda fistulosa*, and *Carex pellita*. It is possible that some prairie species existed along the fencerows or the perimeter of the agricultural disturbance, and were able to colonize open habitat after the disturbance ended. This remains speculation as the exact layout and vegetative composition of the fencerows were not historically determined. Nevertheless, prairie plants dispersing from remnant patches scattered throughout portions of the site to colonize previously cultivated areas still remains the most likely explanation, as soil seed banks were found to be poor refugia for prairie species.

3.5 References

Arnold, G.W. 1983. The influence of ditch and hedgerow structure, length of hedgerows, and area of woodland and garden on bird numbers on farmland. *Journal of Applied Ecology*, 20(3): 731-750.

Auld T.D. 1986. Dormancy and viability of *Acacia sauveolens* Sm.Willd. *Australian Journal of Botany* 34: 463-472.

Benson, E.J. and D.C. Hartnett. 2006. The role of seed and vegetative reproduction in plant recruitment and demography in tallgrass prairie. *Plant Ecology* 187 (2): 163-177.

Bolin, J.F. 2009. Heat shock germination responses of three eastern North American temperate species. *Castenea* 74(2): 160-167.

Bossuyt, B. and O. Honnsy. 2008. Heat shock increases the reliability of a temperate calcareous grassland seed bank study. *Plant Ecology* 199: 1-7.

Bullock, J.M., I.L. Moy, S.J. Coulson, and R.T. Clarke. 2003. Habitat-specific dispersal: Environmental effects on the mechanisms and patterns of seed movement in a grassland herb *Rhinanthus minor*. *Ecography*, 26(5): 692-704.

Dahl, E. 1946. On different types of unglaciated areas during the Ice Ages and their significance to plant geography. *New Phytologist*. 45: 225-242.

D’Souza, L.E. and P.W. Barnes. 2008. Woody plant effects on soil seed banks in a central Texas savanna. *Southwestern Naturalist* 53(4): 495-506.

Ehrlen, J., Z. Munzbergova, M. Diekmann, and O. Eriksonn. 2006. Long-term assessment of seed limitation in plants: results from an 11-year experiment. *Journal of Ecology* 94(6): 1224-1232.

Foster, B.L., C A. Murphy, K. R. Keller, T.A. Aschenbach, E. J. Questad, and K. Kindscher. 2007. Restoration of prairie community structure and ecosystem function in an abandoned hayfield: A sowing experiment. *Restoration Ecology* 15(4): 652-661.

Grandstrom, A. 1982. Seed banks in five boreal forest stands originating between 1810 and 1963. *Canadian Journal of Botany* 60(9): 1815-1821.

Harvey, C.A. 2000. Windbreaks enhance seed dispersal into agricultural landscapes in Monteverde, Costa Rica. *Ecological Applications* 10(1): 155-173.

Hanley M.E., M. Fenner, and G. Ne'eman. 2001. Pregermination heat shock and seedling growth of fire-following Fabaceae from four Mediterranean-climate regions. Acta Oecologica 22: 315–320.

Herranz J.M., P. Ferrandis, and M. Martınez-Sanchez. 1998. Influence of heat on seed germination of seven Mediterranean Leguminosae species. Plant Ecology 136: 95–103.

Hickman, K.R., D.C Hartnett, R.C. Cochran, and C.E. Owensby. 2004. Grazing management effects on plant species diversity in tallgrass prairie. *Journal of Range Management* 57(1): 58-65.

Holden, C. 2006. Migration and dispersal. Inching toward movement ecology. *Science* 313(5788): 779-782.

Jacquemyn, H., R. Brys, and E. Jongejans. 2010. Seed limitation restricts population growth in shaded populations of a perennial woodland orchid. Ecology 91(1): 119-129.

Jefferson, L.V., M. Pennacchio, K. Havens, B. Forsberg, D. Sollenberger, and J. Ault. Ex situ germination responses of midwestern USA prairie species to plant-derived smoke. *American Midland Naturalist* 159:251-256.

Johnson, R.G. and R.C. Anderson. 1986. The seed bank of a tallgrass prairie in Illinois. *American Midland Naturalist* 115(1): 123-130

Laughlin, D.C. 2003. Lack of native propagules in a Pennsylvania, USA, limestone prairie seed bank: Futile hopes for a role in ecological restoration. *Natural Areas Journal* 23(2): 158-164.

Leng, X., C.J.M. Musters, and G.R. de Snoo. 2009. Restoration of plant diversity on ditch banks: Seed and site limitation in response to agri-environment schemes. *Biological Conservation* 142(7): 1340-1349.

McCune, B. and J. Grace. (2002) Analysis of Ecological Communities. Mjm Software Design.

McNicoll, M. B., and C.K. Augspurger. 2010. A comparison of vegetation and seed bank community structure in a sand prairie in Illinois, U.S.A. *American Midland Naturalist* 164(1): 136-150.

Moreira, B., J. Tormo, E. Estrelles, and J.G. Pausas. 2010. Disentangling the role of heat and smoke as germination cues in Mediterranean Basin flora. *Annals of Botany* 105: 627-635.

Orrock, J.L. D.J. Levey, B.J. Danielson, and E.I. Damschen. 2006. Seed predation, not seed dispersal, explains the landscape-level abundance of an early-successional plant. *Journal of Ecology* 94(4): 838-845.

Pérez, C.J., S.S. Waller, L.E. Moser, J.L. Stubbendieck and A.A. Steuter. 1998. Seed bank Characteristics of a Nebraska Sandhills Prairie. *Journal of RangeManagement* 51(1): 55-62.

Portlock C.C., S.R. Shea, J.D. Majer, and D.T. Bell. 1989. Stimulation of germination of *Acacia pulchella*: Laboratory basis for forest management options. *Journal of Applied Ecology* 27: 319-324.

R Development Core Team (2009). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Schott, G.W., and S.P. Hamburg. 1997. The seed rain and seed bank of an adjacent native tallgrass prairie and old field. *Canadian Journal of Botany* 75(1): 1-7.

Schurr, F.M., O. Steinitz, and R. Nathan. 2008. Plant fecundity and seed dispersal in spatially heterogeneous environments: Models, mechanisms and estimation. *Journal of Ecology* 96(4): 628-641.

Sørensen, T. (1957) A method of establishing groups of equal amplitude in plant sociology based on similarity of species and its application to analyses of the vegetation on Danish commons. *Biologiske Skrifter / Kongelige Danske Videnskabernes Selskab* 5(4): 1–34.

Stein, C., H. Auge, M. Fischer, W.W. Weisser, and D. Prati. 2008. Dispersal and seed limitation affect diversity and productivity of montane grasslands. *Oikos* 117(10): 1469-1478.

Svenning, J.C. and S.J. Wright. 2005. Seed limitation in a Panamanian forest. *Journal of Ecology* 93(5): 853-862.

Swink, F. and G. Wilhelm. 1994. *Plants of the Chicago Region*. 4th ed. Indiana Academy of Sciences, Indianapolis, 921 pp.

Taft, J. 1996. Floristic survey and assessment of the Illinois Department of Transportation North Chicago (US Route 41/IL Route 137) Wetland Mitigation Site in Lake County. Technical Report 1996(29) submitted to the Illinois Department of Transportation, Springfield.

Taft, J. B. 2006. Floristic Survey and Assessment of the North Chicago Wetland Mitigation Site, Lake County, Illinois. Center for Wildlife and Plant Ecology. Illinois Natural History Survey Technical Report. Submitted to the Illinois Department of Transportation, Bureau of Location and Environment, 28 September 2006

Taft, J. B., G.S. Wilhelm, D.M. Ladd, and L.A. Masters. 1997. Floristic Quality Assessment for vegetation in Illinois, a method for assessing vegetation integrity. *Erigenia* 15: 3-95.

Taft, J. B., C. Hauser, and K. R. Robertson. 2006. Estimating floristic integrity in tallgrass prairie. *Biological Conservation* 131: 42-51.

Taft, J.B., Z. Kron, and A. Plocher. 2010. Baseline quantitative vegetation monitoring in terrestrial and wetland communities in the North Chicago wetland mitigation site, Lake County, Illinois. Technical report submitted to the Illinois Tollway Authority, Downers Grove.

Thomas, P.B., E.C. Morris, and T.D. Auld. 2007. Response surfaces for the combined effects of heat shock and smoke on germination of 16 species forming soil seed banks in southeast Australia. Austral Ecology 32: 605–616.

Thomson, F. J., A.T. Moles, T.D. Auld, D. Ramp, S. Ren, and R.T. Kingsford. 2010. Chasing the unknown: Predicting seed dispersal mechanisms from plant traits. *Journal of Ecology* 98(6): 1310-1318.

Van Dorp, D., W.P.M. Van den Hoek, and C. Daleboudt. 1996. Seed dispersal capacity of six perennial grassland species measured in a wind tunnel at varying wind speed and height. *Canadian Journal of Botany* 74(12): 1956-1963.

Wilsey, B.J., and H.W. Polley. 2003. Effects of seed additions and grazing history on diversity and productivity of subhumid grasslands. *Ecology*, 84(4): 920-931.

Zobel, M., M. Otsus, J. Liira, M. Moora, and T. Möls. 2000. Is small-scale species richness limited by seed availability or microsite availability? *Ecology* 81(12): 3274-3282.

3.6 Tables and Figures

Table 5. The 50 common prairie species organized by descending rank order of IV data calculated from plots within prairie remnants. The table includes characteristics for selecting a dispersal category and the resulting dispersal category for each species. Prairie remnants ranged from mesic to wet mesic and was composed of a range of species.

Species	IV	Characteristics	Dispersal Category
Schizachyrium scoparium	13.47	hairs	Animal
Parthenium integrifolium	9.13	achene	Unassisted
Sorghastrum nutans	7.75	hairs	Animal
Andropogon gerardii	7.71	hairs	Animal
Silphium terebinthinaceum	7.23	winged seeds	Wind
Cornus racemosa	6.14	drupe	Animal
Solidago juncea	5.40	pappus	Wind
Allium cernuum	4.24	spherical seed	Unassisted
Carex buxbaumii	4.18	perigynia	Water, Unassisted
Helianthus rigidus	4.17	flattened seed	Animal
Carex granularis	3.64	perigynia	Water, Unassisted
Helianthus grosseserratus	3.25	pappus	Wind
Rubus pensilvanicus	3.21	aggregate fruit	Animal
Aster azureus	2.62	pappus	Wind
Monarda fistulosa	2.57	small cylindrical	Unassisted
Erigeron annuas	2.50	pappus	Wind
Anemone virginiana	2.47	pappus	Wind
Calamagrostis canadensis	2.44	small grain	Unassisted
Rudbeckia hirta	2.42	small cylindrical	Unassisted
Carex pellita	2.42	perigynia	Water, Unassisted
Aster ericoides	2.41	pappus	Wind
Potentilla simplex	2.28	rounded	Unassisted
Solidago canadensis	2.11	pappus	Wind
Lithospermum canescens	2.06	small ovoid	Unassisted
Solidago rigida	2.01	pappus	Wind
Antennaria neglecta	1.91	pappus	Wind
Spartina pectinata	1.91	achenes with low viability	Animal
Ratibida pinnata	1.81	small cylindrical	Unassisted
Dichanthelium villosissimum	1.73	oval grain	Unassisted
Viola pratincola	1.73	round seed	Unassisted
Fragaria virginiana	1.71	aggregate fruit	Animal
Lespedeza capitata	1.67	small ovoid/reniform	Unassisted
Pycnanthemum virginianum	1.56	small cylindrical	Unassisted
Liatris cf spicata	1.54	pappus	Wind
Geum aleppicum	1.45	hooked spur	Animal
Rosa carolina	1.44	aggregate fruit	Animal
Zizia aptera	1.43	small rounded	Unassisted
Solidago gigantea	1.39	pappus	Wind
Euthamia graminifolia	1.33	pappus	Wind
Prunella vulgaris v. elongata	1.31	small rounded/ovoid	Unassisted
Viola pedatifida	1.31	Small spherical	Unassisted
Krigia biflora	1.30	pappus	Wind

Table 5 (cont.)

Species	IV	Characteristics	Dispersal Category
Vitis riparia	1.29	berry	Animal
Vicia americana	1.25	spherical	Unassisted
Hypoxis hirsuta	1.20	small spherical	Unassisted
Juncus tenuis	1.02	small spherical	Unassisted
Aster lateriflorus	0.98	pappus	Wind
Comandra umbellata	0.96	berry	Animal
Cacalia tuberosa	0.91	pappus	Wind
Galium obtusum	0.88	small rounded	Unassisted

Table 6. The 27 species found in the germinable seed bank, organized by the positive, negative, or indifferent effect of heat treatment and there general habitat. A positive effect is defined as the species germinating only in heat treatments. A Negative effect is defined as species only germinating in the control flats. An indifferent effect is when a species germinates in both heat treatment and control flats. An asterisk denotes a non-native species (N = 8) and a + indicates that this species was one of the highest ranking species in terms of importance values in the local remnant prairies (N = 7).

Positive	Negative	Indifferent
Ruderal	Ruderal	Ruderal
Cardamine cf. *pensylvanica*	*Taraxacum officinale**	*Juncus tenuis*
*Cerastium vulgare**	*Leucanthemum vulgare**	*Oxalis stricta*
Carex granularis +	*Solidago canadensis +*	*Hypericum perforatum**
Dichanthelium implicatum		*Erigeron annuus+*
Lonicera X *bella**		*Poa pratensis**
		*Rhamnus cathartica**
Prairie/Savanna	Prairie/Savanna	Prairie/Savanna
Lobelia spicata	*Juncus dudlyei*	*Allium cernuum +*
Euthamia graminifolia +	*Solidago nemoralis*	*Rudbeckia hirta +*
Fragaria virginiana +	*Potentilla simplex*	
Carex blanda		
Wetland	Wetland	Wetland
Glyceria striata	*Lythrum salicaria**	
Lythrum alatum	*Leucospora multifida*	

Table 7. The number of times an individual species was present in both the soil seed bank and the standing vegetation of individual sample plots. An asterisk denotes a non-native species.

Species	N
Oxalis stricta	7
*Poa pratensis**	4
Juncus tenuis	3
*Taraxacum officionale**	3
Allium cernum	2
*Cerastium vulagare**	2
Erigeron annuas	2
*Leucanthemum vulgare**	2
Potentilla simplex	2
*Rhamnus cathartica**	2
Rudbeckia hirta	2
Carex granularis	1
Fragaria virginiana	1
Lobelia spicata	1
*Lonicera X bella**	1
Solidago canadensis	1

Figure 7. Adapted from Taft et al 2010. Remnant prairies are indicated by the green polygons on the map below. Transects are indicated by a solid black line, and the plots by green dots. In general, remnants were spatially concentrated in the southern half of the site and no transect samples were located within the boundary of a remnant. The inset to the right of the main figure shows the plots sampled in the targeted remnant prairies.

Figure 8. Species area curve of the soil seed bank at the NCWMS. The total volume of soil sampled is 4926cm^3. The Sørensen distance measure was used to calculate the distance between subplots. Dashed lines represent the 95% confidence interval around the data.

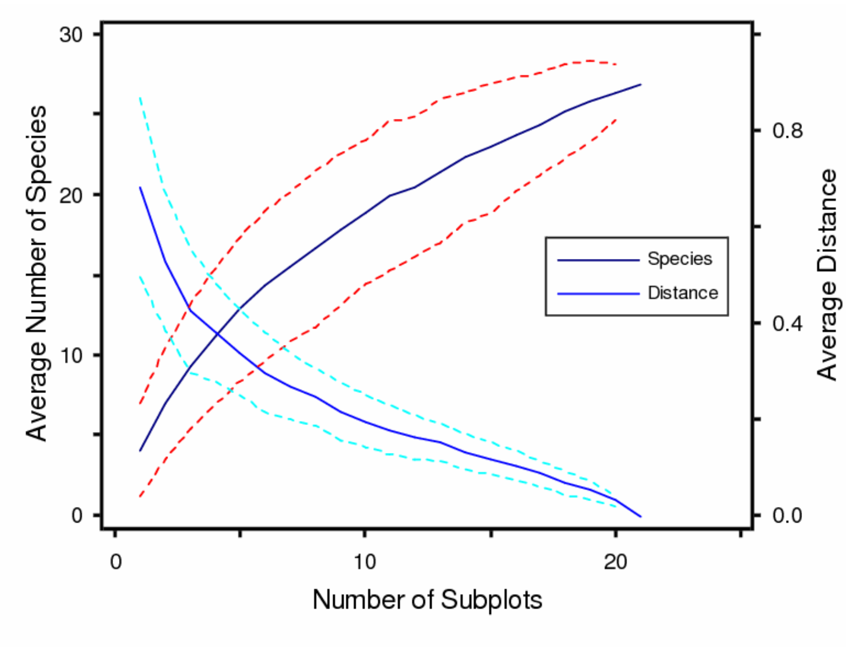


Figure 9. Histogram of the Sørensen index of similarity (SIS) comparing the species germinating in the heat treatment and control flats. Index was calculated as 2A / (B + C) X 100 where A is the number of species in common and B and C are the number of species in each respective sample, expressed as a percent. 11 Plots had no similarity while 10 plots had > 22% similarity.

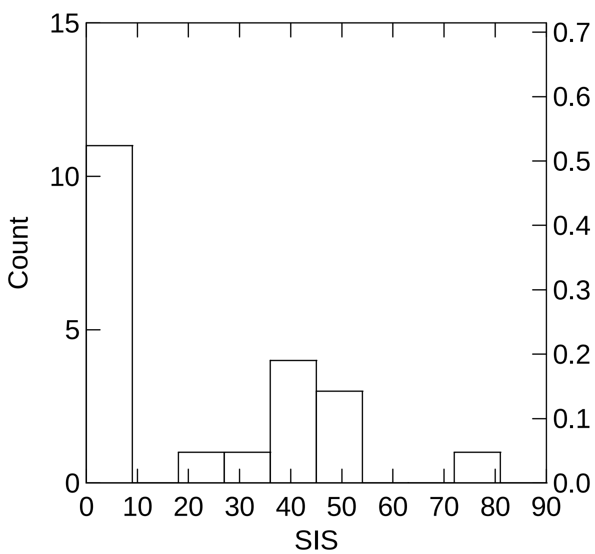


Figure 10. Histogram of the Sørensen index of similarity (SIS) comparing the soil seed bank to the standing vegetation for each plot. Index was calculated as 2A / (B + C) X 100 were A is the number of species in common and B and C are the number of species in each respective sample. Two plots had no similarity between the soil seed bank and the standing vegetation.

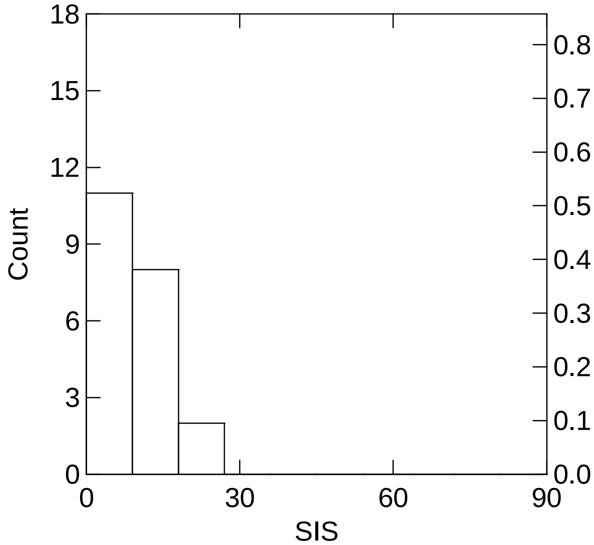
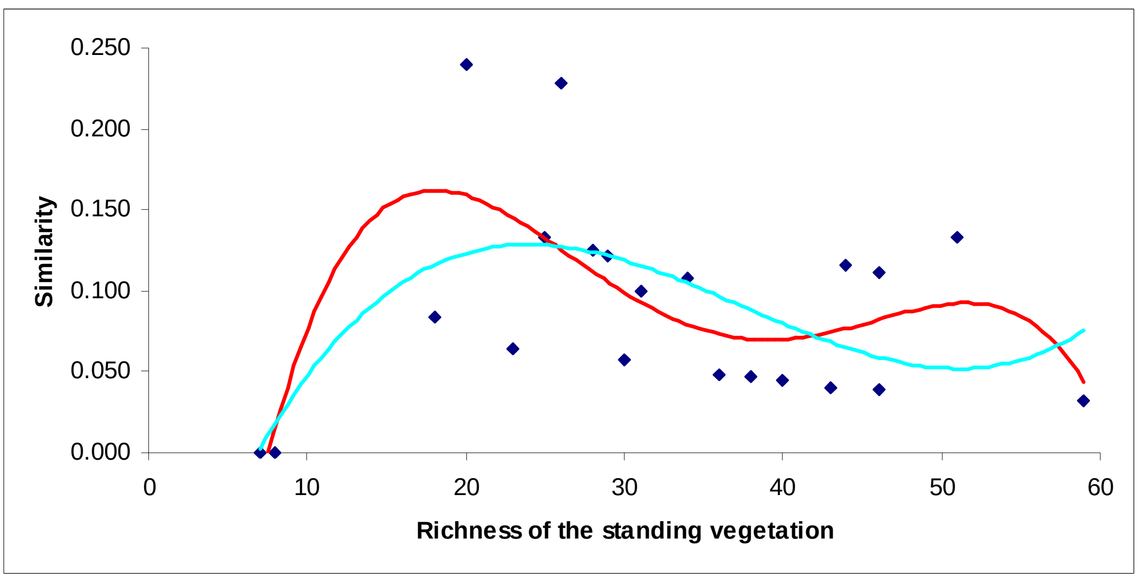


Figure 11. Graphical representation of the relationship between similarity and richness. The relationship is strictly non-linear in nature. The 3rd and 4th (R^2 of 0.34 and 0.4 respectively) order polynomials provide the most significant fit ($P<.05$) with the highest account of the variance (blue line and red lines respectively).



Chapter 4

Inferred patterns of functional group attrition in shrub encroached tallgrass prairie

Abstract

Introduction: The purpose of this study was to determine whether nonrandom ordered patterns of plant functional group losses could be detected with increasing woody invasion in native grassland habitats. Additionally the study sought to identify the relationship between diversity, richness, evenness, and dominance within the vegetation to shrub canopy cover. Functional groups are species assemblages with shared characteristics that include factors such as morphology, ecophysiology, ecological roles, resource use, or response to disturbance.

Questions: What is the relationship between functional groups, richness, diversity, dominance, and evenness to shrub canopy cover? Are patterns of functional group cover and richness associated with particular classes of shrub canopy cover? Are there ordered patterns of functional group losses in shrub encroached tallgrass prairie?

Location: Tallgrass prairie and old field mosaic at the North Chicago Wetland Mitigation Site in Lake County, Illinois.

Methods: Ground layer and shrub canopy data were collected from 45 sample plots including 37 located on stratified transects and eight located randomly in high-quality reference prairie habitat. Species data were converted to plant functional groups based on species traits. The relationships between functional group richness and percent cover and shrub canopy cover were examined with linear regression. The associations of cover and richness of particular functional groups to shrub canopy cover classes were determined with discriminant analysis. Differences of functional group cover and richness among canopy cover classes were tested with ANOVA followed by Tukey post-hoc tests. Nonmetric Multidimensional Scaling (NMS) was used to graphically illustrate patterns of functional group association among canopy cover classes.

Results: Species diversity and richness are indirectly related to percent shrub cover while species dominance was directly related to shrub cover. Percent cover of the ground layer is inversely correlated with shrub canopy cover. Cover and richness of C4 grass, perennial legume, perennial forb, perennial sedge, and annual forb functional groups follow ordered decline with increasing shrub canopy cover and differences among canopy cover classes were significant. NMS provides a graphical summary indicating functional groups most commonly dominant in prairie communities are associated with low canopy cover plots compared with closed canopy plots.

Conclusions: The results indicate that shrub canopy cover affects grassland diversity patterns and highlights ordered patterns of loss in the cover and richness of plant functional groups that can be used as a guideline to evaluate sites undergoing shrub encroachment. These results have important management implications for restoration and management of grassland ecosystems.

4.1 Introduction

The main research questions I am exploring involve determining whether ordered patterns of change can be detected in prairie species and particularly plant functional groups that correspond to degree of encroachment by woody species. Such results should help interpret site conditions at prairies where shrub encroachment has occurred to provide a framework for restoration and recovery potential. To explore these questions, this study concentrates on the patterns of shrub and small tree invasion into natural (tallgrass prairie) and semi-natural (old field with prairie species) grasslands at a 65ha mosaic of prairie, old field, and wetlands in northeastern Illinois that has been invaded by native and adventive woody species.

Recent history has seen shrub abundance increase significantly in savanna and grassland communities around the world (Bragg and Hurlbert 1976; Knight et al. 1994; Archer et al. 1995; Wilson and Kleb 1996; McPherson 1997; Hoch and Briggs 1999; Brown and Archer 1999; Price and Morgan 2008). Shrub encroachment effects have included reduced richness in the herbaceous layer (Lett and Knapp 2005; Price and Morgan 2008), reduced annual net primary productivity of dominant C4 prairie flora (Heisler et al. 2004), and reductions in biomass and density of herbaceous vegetation (Brown and Archer 1999). The postulated causes of shrub encroachment include repressed fire (Gibson and Hulbert 1987), climate change (Archer et al. 2001), disturbance (Schlesinger et al. 1990) and grazing (Van Auken 2000; Briggs et al. 2005).

Changes associated with woody encroachment in grassland habitats can be likened to a pattern of community disassembly. Zavaleta et al. (2009) define community disassembly as the nonrandom process of progressive species loss and decline and predict that interacting traits and ecological drivers cause the non-random decline and loss of species. Individual species traits make them vulnerable to the effects of the driver, directly causing a reduction or loss of the vulnerable species. Many traits have been shown to increase vulnerability in certain species of plants such as characteristics of geographic range (Sakai et al. 2002; Williams et al. 2005), demography (Duncan and Young 2000; Turner et al. 1996), phenotype (Duncan and Young 2000; Leach and Givnish 1996), life history (Walker and Preston 2006; Sakai et al. 2002), and taxonomy (Schwartz and Simberloff 2001). Causes of vulnerability are mostly but not exclusively anthropogenic in nature and include habitat destruction, biological invasion, and climate change in addition to stochastic events (Zaveleta et al. 2009).

It is essential to understand how composition and diversity of grassland habitats are effected by woody encroachment, so that the information can be used in restoration and rehabilitation of these once extensive grassland habitats. Plant functional groups, defined below, will be used in this study to help connect plant traits to variation in structure and diversity with woody encroachment of natural and semi-natural grasslands.

Plant Functional Groups

Functional groups are species assemblages with shared characteristics, and can include factors such as morphology, ecophysiology, ecological roles, resource use, or response to disturbance (Symstad 2002). Functional group metrics are increasingly being used in ecological studies to explore new aspects of plant communities. For example, functional group density discriminated between prairies of differing quality in Illinois (Sivicek and Taft 2011). In addition, functional group removal studies have examined the role functional groups play in determining abiotic ecosystem properties and the growth response of remaining functional groups (McLaren and Turkington 2010). Furthermore, studies have examined the effects of graminoid and woody invaders on native plant functional groups (Mason et al. 2009).

Site History

See Chapter 1.1, Site History.

Study Questions

The purpose of this study was to determine whether nonrandom ordered patterns of species and plant functional group losses could be detected with increasing woody invasion in native grassland habitats.

Question A – What is the relationship between shrub canopy cover and: a) species diversity patterns, b) functional group richness and c) functional group cover?

Prediction – Studies examining shrub encroachment in tallgrass prairie have noted dramatic declines in herbaceous diversity (Brown and Archer 1999; Lett and Knapp 2005; Price and Morgan 2008) with increasing shrub canopy cover. I predict ground layer richness and cover will have a negative relationship with shrub canopy cover. Conversely, low shrub canopy cover will correspond to increased richness and cover within functional groups.

Question B - Are particular classes of shrub canopy cover associated with patterns of functional group cover and richness?

Prediction – Overall, plots with intermediate levels of canopy cover may have greater richness than open plots, as shade intolerant species compete with shade tolerant ones. However, as canopy cover increases, shade intolerant species will eventually be competitively displaced.

The characteristic C4 grasses that are among the dominant species in tallgrass prairie communities in the Midwest are adapted to full-sun conditions and decline in abundance with increasing shade (Heisler et al. 2004). It is predicted that C4 grass cover would be a good predictor and is expected to decline with increasing canopy cover. In addition to C4 grasses, I predict that C3 grasses, perennial prairie forbs, and perennial legumes will be reliable indicators for distinguishing canopy cover classes. Based on field observations, these three functional groups were absent or occurred in suppressed, diminutive condition when present beneath a dense shrub canopy. Annual forbs, annual legumes, and biennial forbs are predicted to contribute little to the separation of canopy cover classes because of their sporadic and primarily ruderal lifestyle. Ferns, trees, and vines also are predicted to be neutral with regard to woody encroachment because of their uncommon and sporadic distribution across the site. Shrubs (< 1 m tall) occurred in almost every ground layer sample plot; consequently, the pattern of total shrub cover is expected to be indifferent to the degree of overstory shrub cover. To summarize, perennial forbs, perennial legumes (nitrogen fixing forbs), C4 grasses, and C3 grasses are predicted to be the most reliable predictors of canopy cover classes.

Question C – Are there ordered patterns of functional group losses in shrub encroached tallgrass prairie?

Prediction **–** Because this site is a grassland habitat fragment isolated from woodland or forest habitats, there should be few shade-tolerant species to replace lost or declining prairie species leading to the expected patterns of attrition of plant functional groups. Consequently, functional groups except shade-tolerant shrubs and ferns are expected to decrease in cover individualistically with increasing shrub canopy cover, with some groups unable to persist under the greatest shrub canopy cover. It is expected that most functional groups also will decrease in richness individualistically with increasing shrub canopy cover. Identifying whether an ordered pattern of attrition of functional group cover and richness occurs may help determine site restoration potential.

4.2 Methods

<u>Sample Design</u>

See Sample Design, Chapter 2.2.

Vegetation Sampling

See Vegetation Sampling Chapter 2.2

Assignment of Functional Groups

Species were assigned to the following plant functional groups based on growth form, life history, ecophysiology, and taxonomy: annual forb, annual legume, biennial forb, fern, perennial forb, perennial legume, perennial sedge, shrub, tree, and vine. Similar groups were followed by Kindsher and Wells (1995) and Sivicek and Taft (2011). However, in the current study, no differentiation was made between native and nonnative groups See Appendix A for a full listing of species and their corresponding functional group.

Canopy Cover Classes

Data on canopy cover were collected using a digital camera oriented vertically at about 70 cm height using a hemispherical lens. Images were analyzed with HemiView analytical software (Ver. 2.1 SR2). A lens tube was used to restrict canopy image to an area roughly the size of the shrub plot (25 m^2). Percent canopy cover was determined by subtracting the calculated value from each plot for total percent visible sky from 100. These canopy cover data were used to construct classes of canopy cover for each plot. The classes were constructed as increments of 25% canopy cover: 1 (0-25%), 2 (25-50%), 3 (50-75%), 4 (75%-100%). Canopy cover classification has been used for other purposes such as studies of oak regeneration (Stan et al. 2006) in forests or for community classification (White and Madany 1978).

Data Analysis

Question A – The relationship between % shrub canopy cover (100 - % percent visible sky) and measures of species diversity (species richness, dominance, evenness, and Shannon-

Weiner index) were examined with correlation analysis. Functional group richness and ground layer cover were regressed against % shrub canopy cover to asses the relationship between the variables. Differences in ground layer cover and the number of functional groups among shrub canopy cover classes were assessed with ANOVA.

Question B – Complete and automatic forward stepping discriminant analysis were used to determine the differences between classes of canopy cover, and to determine which functional groups best discriminated between canopy cover classes. Cover and richness per functional group were used as dependent variables in separate analyses. Canopy cover classes, described above, were used as the grouping variable. F-to-remove statistics determined the relative importance of functional groups separating canopy cover classes. The forward stepping analysis used variables with default 0.15 probability to enter the model. A between-groups F-matrix was used to determine the similarity among canopy cover classes based on the dependant variable used. For each pair of groups, these F-statistics test the equality of group means and are proportional to distance measures. A separate ANOVA was used for each functional group to determine the differences of its mean cover and mean richness among shrub canopy cover classes. Tukey post-hoc tests determined which means within each shrub category differed significantly and the probability was corrected for multiple comparisons with the Bonferroni correction (0.05/n where n = the number of comparisons). All discriminant analysis and ANOVA were performed with SYSTAT ver 9 (SPSS 1998).

Question C – Proportions of functional groups by shrub cover class were examined graphically in Excel to characterize the basic ordered patterns. Nonmetric Multidimensional Scaling (NMS) was used with a Sørensen distance measure, to graphically represent the observed community structure and to further assess the relationship between canopy cover classes and functional group richness and cover. NMS was used for its independence from species response models, optimal graphical representation of community relationships, and its preservation of the order of among-sample dissimilarities in the rank order of distances (Kruskal 1964; Mather 1976; Clarke 1993; McCune & Grace 2002). Plots that were highly dissimilar to others (standard deviation from the mean calculated distance of all plots > 2.3, < 3) were detected by outlier analysis in PC-ORD (McCune & Mefford 1999) and were excluded. Using a random starting configuration, NMS was run in autopilot mode, comparing 40 runs with real data from one to six dimensions. A Monte Carlo test with 50 randomized runs was performed to assess whether resulting axes significantly reduced more stress than expected by chance. Correlations between ordination axes and variables were evaluated by Pearson's correlation coefficient (r).

4.3 Results

Question A – What is the relationship between shrub canopy cover and: a) species diversity patterns, b) functional group richness and c) functional group cover?

Percent shrub canopy cover was negatively correlated with species richness and Shannon-Weiner Diversity index, positively correlated with Dominance ($P < 0.05$), and had no correlation with Evenness. The correlation with the best fit was between species richness and percent canopy cover (Figure 12).

Total ground layer cover decreases significantly with increasing shrub canopy cover (Figure 13). Regression of individual functional group cover shows a significant decline in annual forbs, perennial forbs, perennial legumes, cool-season grasses, warm-season grasses, and perennial sedges (Table 8). Richness significantly declines with increasing canopy cover in the C4 grasses, perennial legumes, perennial forbs, and C3 grasses (Table 9). Conversely, vine richness significantly increases with increasing canopy cover. Ground layer cover of all functional groups decreases significantly within the third and fourth canopy cover classes (Figure 14). Furthermore, there is a reduction in the mean number of functional groups within the third and fourth shrub canopy cover classes; however, the differences are not significant (Figure 15).

Question B - Are particular classes of shrub canopy cover associated with patterns of functional group cover and richness?

Discriminant analysis indicates that canopy cover classes one and four are the most different from one another based on both functional group ground-layer cover (Table 10) and functional group richness (Table 11). Additionally, canopy cover classes three and four are the most similar to one another based on both functional group ground layer cover and functional group richness.

Discriminant analysis using functional group ground layer cover data indicated that perennial forbs, perennial legumes, perennial sedges, annual forbs, annual legumes, biennial forbs, and ferns were the variables that best distinguished between shrub canopy cover classes (Table 12). Additional analysis incorporating functional group richness data suggests that C4 grasses, perennial forbs, and annual forbs were variables that best separated between cover classes (Table 13). Warm-season grass richness was the variable that best separated the shrub canopy cover classes relative to the other variables in the model.

ANOVA of the individual functional groups indicates that ground-layer cover of functional groups decreases with increasing shrub canopy cover classes in annual forbs, perennial forbs, perennial legumes, C3 grasses, C4 grasses, and sedges (Figure 16). Though not statistically significant ($P < .05$), ground layer cover of vines and ferns is greater in the higher shrub canopy cover classes. Mean richness within each canopy cover class is significantly different for select groups (Figure 17). Perennial forbs, perennial legumes, and C4 grasses show an overall significant decrease in richness for the high shrub canopy cover classes. Vines show the opposite pattern and increase in richness with increasing shrub canopy cover class.

Question C – Are there ordered patterns of functional group losses in shrub encroached tallgrass prairie?

Ordered patterns among functional groups and canopy cover classes (Table 14, Figure 18) indicate that perennial forbs, C4 grasses, and sedges are the most dominant functional groups in low canopy cover classes. At higher canopy cover classes, the ground vegetation layer is dominated by shrub seedlings and saplings, in addition to C3 grasses and vines.

The NMS ordination shows ground layer cover of C4 grasses, perennial legumes, perennial sedges, and annual legumes groups closely associated with plots under 50% shrub canopy cover (Figure 19). Perennial forbs and annual forbs tend to associate with a decrease in canopy cover but are plotted in intermediate space because they occur in lower light situations as well. Fern, biennial forb, shrub and tree cover dominates the plots in denser shade. Vines were more often present in the plots with highest canopy cover. Outlying plots such as 9E and 5E represent communities that were dissimilar from most others samples. Plots 9E and 5E are different from all other plots but similar to one another. They had very high canopy cover with low ground layer cover, native richness, and native FQI. As a result of their dissimilarity, the plots 5E and 8E were removed from the graphical ordination following outlier analysis in PCORD (McCune and Mefford 1999). The first axis represents 84% of the proportion of variance, based on the r^2 between distance in the ordination space and distance in the original space. The second axis represents 7%, for a total of 91% of variance represented by the ordination axes

The same general patterns observed in the cover data ordination using NMS can be seen in the ordination based on the richness of functional groups (Figure 20). The plots lowest in richness are 8E, 9E, 5E, and 1A. As a result, those plots were excluded from the ordination following the procedure for outlier analysis in PCORD (McCune and Mefford 1999). An interesting result of this ordination is that Pr7 groups well with other prairie plots, even though it falls in canopy cover class 3 (50-75% shade). Plot Pr8 groups with high canopy cover plots because of its low richness, even though the plot is representative of a high quality wet prairie habitat and has relatively little canopy cover (16.1%) compared to plots with similar species richness. The first axis represents 86% of the proportion of variance, based on the R^2 between distance in the ordination space and distance to the original space. The second axis represents 12% of the variance, for a cumulative total of 98%. Variable and functional group correlations with ordination axes can be found in Table 15 (cover) and Table 16 (species richness).

4.4 Discussion

Functional groups

Functional group data were utilized in this study to understand their relationship to canopy cover and whether there were patterns of decline related to increasing woody encroachment that might suggest loss of ecosystem functions with fire absence. Selective or complete loss of species within these groups will have lasting effects on community structure and function (Hooper and Vitousek 1997). The loss of functionally unique species will likely affect ecosystem functioning because there is no species that can fill its role in the community (Walker 1995; Tilman et al. 1997).

Functional Group Patterns

The discriminant analysis results indicate that changes in perennial forb cover were largely responsible for discriminating between the canopy cover classes, and that several other functional groups such as perennial legumes, perennial sedges, annual forbs, annual legumes, biennial forbs, and ferns contributed to a lesser degree. Furthermore results of the discriminant analysis suggest that percent cover of functional groups in plots with 0-25% canopy cover is most different from cover values in plots with 75-100% cover. This indicates that plants underneath a dense shrub canopy will likely have significantly reduced cover compared to those underneath sparse shrub cover. The result of the linear regression reinforces these conclusions. Linear regression shows a significant decline in cover and richness for many of the functional groups with increasing shrub canopy cover, including the dominant warm season native grasses and perennial forbs of the prairie. Changes in functional group importance values among canopy cover classes illuminate further patterns of assemblage changes. Shrubs replaced perennial forbs as the dominant functional group in the ground layer at intermediate levels of shrub canopy cover (< 50% canopy cover). Additionally, C4 grasses and perennial legumes decreased in rank IV and were replaced by C3 grasses and vines above intermediate levels of canopy cover (> 50%). C4 grasses and perennial legumes were the least important species in the ranked IV of functional groups in high canopy cover (>50% canopy cover). Other studies also found grass and perennial forb (including legumes) functional groups to decrease in richness with increasing woody invasion (Mason et al. 2009).

Many individual species contributed to the observed variance in the relationships between functional group metrics and shrub canopy cover. The number of species within each functional group was not equal. As a result, some functional group patterns represented the averaged response among many species. Others, however, were dominated by the response of a handful of species. In the case of the annual forbs functional group, *Medicago lupulina** was the only species present within the sampled area. Furthermore, only two fern/fern ally species, *Botrychium dissectum* and *Equisetum arvense,* were recorded in the sample data. The importance of individual species depended largely on the habitat for the other functional groups. For instance, the annual forbs *Plantago rugelii*, *Ranunculus recurvatus* and *Dianthus armeria** were common in the old field community while *Gentianella quinquefolia*, *Castilleja coccinea*, and *Dianthus armeria** were common in the prairie. The C3 grasses *Agrostis alba**, *Danthonia spicata*, and *Dichanthelium oligosanthes* were important in the old field while *Agrostis alba**, *Poa pratensis**, and *Poa compressa** were important in the prairie plots. Dominant old field forbs included *Ratibida pinnata*, *Allium cernuum*, *Lobelia spicata*, *Aster drummondii*, and *Fragaria virginiana*. Dominant forbs in the prairie community were *Solidago juncea*, *Silphium terebinthinaceum*, *Parthenium integrifolium*, *Fragaria virginiana*, and *Ratibida pinnata*. Important sedges within the old field community were *Carex granularis, C. stricta*, and *C. umbellata*. Dominant sedges in the prairie community were *Carex pellita*, *C. granularis*, and *C. buxbaumii*. Important shrubs included *Rhamnus cathartica**, *Cornus racemosa*, and *Rubus pensilvanicus* in the prairie community and *Corylus americana*, *Viburnum lentago*, and *Rhamnus cathartica** in the old field plots. Common trees were *Crataegus* sp. (seedlings), *Prunus americana*, and *Fraxinus pennsylvanica subintegerrima* in the prairie plots and *Crataegus mollis*, *Prunus americana*, *Amelanchier* cf. *arborea* in the old field plots. Some species were important regardless of the habitat. For example, the most important species of the biennial forb functional group were *Melilotus alba**, *Erigeron annuus,* and *Daucus carota** in both the old field and prairie. *Spartina pectinata*, *Andropogon gerardii*, and *Schizachyrium scoparium* were the most important C4 grasses in the old field plots while *Schizachyrium scoparium*, *Andropogon* *gerardii*, and *Sorghastrum nutans* were important in the prairie plots. Additionally, *Vitis riparia* was the most important vine in both community types. The only other vine that occurred in the prairie was *Parthenocissus quinquefolia*. The latter vine species was more common in the old field plots compared to the prairie plots.

<u>Stressor(s)</u>

Stressor is the driving force behind disassembly within a contingent community (Zaveleta et al. 2009). When a stressor interacts with a vulnerable species, the result is the non-random decline and loss of species. The environment surrounding the study area may provide several stressors common to many prairie communities. Several large-scale housing developments and industrial centers have recently (in the past 30years) been built surrounding the site. Changes in runoff patterns to and from the site could alter the water table, changing the resource availability of the surrounding environment, but this remains untested. Agricultural fields and a state road to the north provide additional stressors, such as runoff/sedimentation and edge effects (Koper et al. 2010). The most noticeable and documented change, however, is the recent colonization of the site by two invasive shrub species: the native *Cornus racemosa*, and non-native *Rhamnus cathartica*. Comparisons to previous studies at the site (Plocher et al. 1996) indicate a three fold increase in shrub density per hectare over a 14-year period (Taft et al. 2010). Aerial photos from the 1980's and land survey records from the 1840's (Moran 1976) show little to no shrub presence. This indicates that shrubs, particularly *R. cathartica*, are a possible stressor at the site. Briggs et al. (2002) showed that *Juniperus virginiana* expansions into Midwest grasslands drastically reduced diversity and shifted dominance from C4 grasses to C3 plants. Many Prairie plants are inhibited by the shade from litter (Goldberg and Wemer 1983), and their seedling survivorship often correlate strongly with available light (Jurik and Pleasants 1990). The primary cause of increased shrub density at this site likely is fire absence. Fire suppression in grasslands can lead to a closed canopy forest in as little as 35 years (Hoch and Briggs 1999) Additionally, secondary compounds in the tissues of *R. cathartica* may play a role in its spread across the site (see complete review in Knight et al. 2007). Emodin, a secondary compound produced in the roots, leaves, bark, and fruit of *R. cathartica*, may deter insects and other herbivores from eating leaves, bark, and fruit, protect plants from pathogens at high light levels, have allelopathic effects on nearby plants, affect soil microorganisms, and affect fruit consumption by birds (Izhaki 2002).

<u>Disassembly Patterns</u>

A non-random decline and loss of species was observed in the tallgrass prairie community. Ground layer cover consistently decreased across the site for several functional groups, with increasing shrub canopy cover. Ground layer shrub cover (shrubs < 1m in height) had no relationship to the amount of canopy cover, and was fairly consistent throughout the study. Seedlings of *Rhamnus cathartica* were observed in nearly every plot, in addition to several other species of shrub. The consistently high density of shrub seedlings and saplings in the ground layer (< 1m) suggests that shrubs will continue to be a dominant member of the plant community. Shrub canopy cover was greatest in plots with low stem density while stem density tended to be greatest in plots with low percent canopy cover. These latter areas represent recently invaded open prairie, as there were often dwarfed prairie plants present in these quadrats. There was an initial increase in species richness with intermediate levels of canopy cover. As the community switches from open prairie to shrubland, some species adapted to both habitats will commingle until one community out competes the other. *R. cathartica* occasionally formed nearly monotypic stands with dwarfed prairie plants in the ground layer. The ground layer was mostly bare in this old field community, with < 5 species per quadrat and < 1% cover.

Community and ecosystem level effects

Many functional groups were lost at the highest levels of canopy cover. This loss of functional diversity may have profound affects on ecosystem functioning and structure. The drastic reduction in perennial nitrogen fixers, C4 grasses, and annual forbs could lead to a loss of these unique functional roles in the local community. Analysis of the seed bank indicated that many of the unique prairie specialist species were not found (Chapter 3). Other species of plants and animals may depend on those groups in the local environment and their absence could lead to a cascading affect up the trophic levels.

The drastic reduction in ground layer cover may have significant effects on the overall productivity of the landscape, and its ability to support diverse flora and fauna. Lett et al (2004) found that annual net primary productivity (ANPP) in shrub dominated ecosystems was three times higher than that found in adjacent grasslands. Additionally, shrubs were found to displace native grasses (Heisler et al 2004) by reducing their ANPP. However, traditional measures of productivity determine very little about diversity patterns, and if the interest is in biodiversity, ANPP may be insensitive to changes that lead to dramatic losses.

Restoration

Early in 2010, large scale restoration began on the site. Assuming that the increased shrub density was responsible for the loss of species, managers at the site removed a significant proportion of all woody species occurring at the site (Taft and Kron 2011). Initial removal was associated with slight declines in species richness and cover, but the results were not significant. Shrub removal may eventually lead to new problems. Many new niches will now be open, allowing quickly colonizing ruderal and invasive species to dominate the site for the near future, until a burning regime can be established. Prescribed fire was identified as an additional management tool, but was not implemented immediately. Insufficient fuel loads under dense shrub cover may have been partially to blame. For example, leaf litter from *R. cathartica* breaks down quickly because of its high nitrogen content (Heneghan et al. 2002). In addition, other litter types break down faster when combined with *R. cathartica* litter (Heneghan et al. 2002).

In order for this study to be informative for restoration, we need to look at the patterns of disassembly and attempt to reverse species loss. Barren areas left after shrub removal can be reseeded proportional to the functional group IV in the remnant plots, when corrected for individual species' germination rates and any prairie species found to be present in the seed bank. Seed bank analysis from the previous chapter can help to guide the content of the seed mixes, replacing dominant species that are now absent from both the vegetation and the soil germinable seed bank. Eventually, established seedlings and maturing plants will provide the fuel necessary for prescribed burns that have the potential to deter future shrub invasion at the site.

4.5 References

Archer, S., D. Schimel, and E.H. Holland. 1995. Mechanisms of shrubland expansion: land use, Climate or CO_2. *Climatic Change* 29: 91-99.

Archer, S., T.W. Boutton, and K.A. Hibbard. 2001. Trees in grasslands: Biogeochemical consequences of woody plant expansion. *Global Biogeochemical Cycles in the Climate System*: 115-137.

Bragg, T.B. and L .C. Hulbert. 1976. Woody plant invasion of unburned Kansas bluestem prairie. *Journal of Range Management* 29: 19-23.

Briggs, J.M., G.A. Hoch, and L.C Johnson. 2002. Assessing the rate, mechanisms, and consequences of the conversion of tallgrass prairie to *Juniperus virginiana* forest. *Ecosystems* 5: 578-586.

Briggs, J.M, A.K. Knapp, J.M. Blair, J.L. Heisler, G.A. Hoch, M.L. Lett, and J.K. McCarron. 2005. An ecosystem in transition: Causes and consequences of the conversion of mesic grassland to shrubland. *Bioscience* 55(3): 243-254.

Brown, J.R. and S. Archer. 1999. Shrub invasion of grassland: recruitment is continuous and not regulated by herbaceous biomass or density. *Ecology* 80: 2385-2396.

Clarke, K.R. 1993. Non-parametric multivariate analysis of changes in community structure. *Australian Journal of Ecology* 18: 117-143.

Duncan, R.P. and R.J. Young. 2000. Determinants of plant extinction and rarity 145 years after European settlement of Auckland, New Zealand. *Ecology* 1: 3048–3061.

Goldberg, D.E. and P.A. Wemer. 1983. The effects of size opening in vegetation and litter cover on seedling establishment of goldenrods (*Solidago* spp.). *Oecologia* 60: 149-155.

Gibson, D.J., and L.C. Hulbert. 1987. Effects of fire, topography and year-to-year climatic variation on species composition in tallgrass prairie. *Vegetatio* 72(3): 175-185.

Heneghan, L., C. Clay, and C. Brundage. 2002. Rapid decomposition of Buckthorn litter may change soil nutrient levels. *Ecological Restoration* 22: 108-111.

Hiesler, J.L., J.M. Briggs, A.K. Knapp, J.M. Blair, and A. Seery. 2004. Direct and indirect effects of fire on shrub density and aboveground productivity in a mesic grassland. *Ecology* 85(8): 2245-2257.

Hooper, D.U. and P.M. Vitousek. 1997. The effects of plant composition and diversity on ecosystem processes. *Science* 277: 1302-1305

Hoch, G.A, and J.M. Briggs. 1999. Expansion of eastern red cedar (*Juniperus virginiana*) in the northern Flint Hills, Kansas. In J.T Springer (ed.). *Proceedings 16th North American Prairie Conference*. University of Nebraska, Kearney.

Izhaki, I. 2002. Emodin-a secondary metabolite with multiple ecological functions in higher plants. *New Phytologist* 155: 205-217.

Jurik, T.W. and J.M. Pleasants. 1990. The effects of light and plant size on fate of seedlings of the prairie compass plant (*Silphium laciniatum* L.). *Functional Ecology* 4: 661-665.

Kindscher, K. and P.V. Wells. 1995. Prairie plant guilds: A multivariate analysis of prairie species based on ecological and morphological traits. *Vegetatio* 117: 29-50.

Knight, C.L., J.M. Briggs, and M.D. Nellis. 1994. Expansion of gallery forest on Konza Prairie Research Natural Area, Kansas, USA. *Landscape Ecology* 9:117-125.

Knight, K.S., J.S Kurylo, A.G. Endress, J.R. Stewart, and P.B. Reich. 2007. Ecology and ecosystem impacts of common buckthorn (*Rhamnus cathartica*): a review. *Biological Invasions* 9: 925-937.

Koper, N., K.E. Mozel, and D.C. Henderson. 2010. Recent declines in northern tallgrass prairies and effects of patch structure on community persistence. *Biological Conservation* 143(1): 220-229.

Kruskal, J. B. 1964a. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. *Psychometrika* 29: 1-27.

Kruskal, J. B. 1964b. Nonmetric multidimensional scaling: a numerical method. *Pychometrika* 29: 115-129.

Leach, M.K. and J.T. Givnish. 1996. Ecological determinants of species loss in remnant prairies. *Science* 273: 1555–1558.

Lett, M.S. and A.K. Knapp. 2005. Woody plant encroachment and removal in mesic grassland: Production and composition responses of herbaceous vegetation. *American Midland Naturalist* 153(2): 217-231.

Lett, M.S., A.K. Knapp, J.M. Briggs, and J.M. Blair. 2004. Influence of shrub encroachment on plant productivity and carbon and nitrogen pools in a mesic grassland. *Canadian Journal of Botany* 82: 1363-1370.

Mason, T.J., K. French, and M.W. Lonsdale. 2009. Do graminoid and woody invaders have different effects on native functional groups? *Journal of Applied Ecology* 46: 426-433.

Mather, P.M. 1976. *Computational methods of multivariate analysis in physical geography*. J. Wiley and Sons, London. 532 pp.

McLaren J.R, and R. Turkington. 2010. Ecosystem properties determined by plant functional group identity. *Journal of Ecology* 98: 459-469.

McCune, B. & J. Grace. 2002. *Analysis of ecological communities*. MjM Software Design, Gleneden Beach, OR, US.

McCune, B. and M.J. Mefford. 1999. PC-ORD. *Multivariate analysis of ecological data.* Version 4.34. MjM Software, Gleneden Beach, OR, US.

McPherson, G.R. 1997. *Ecology and management of North American savannas*. University of Arizona Press, Tucson.

Plocher, A., P. Tessene, and J. Olson. 1996. Wetland mitigation site assessment of the US 41/IL 137 Illinois Department of Transportation project area. Technical report submitted to the Illinois Department of Transportation, Bureau of Design and Environment, Springfield.

Price, J.N. and J.W. Morgan. 2008. Woody plant encroachment reduces species richness of herb-rich woodlands in southern Australia. *Austral Ecology* 33: 278-289.

Sakai, A.K., L.W. Wagner and A.L. Mehrhoff. 2002. Patterns of endangerment in the Hawaiian flora. *Systematic Biology* 51: 276–302.

Schlesinger, W.H., J.F. Reynolds, G.L. Cunningham, L.F. Huenneke, W.M. Jarrell, R.A. Virginia, and W.G. Whitford. 1990. Biological feedbacks in global desertification. *Science* 247(4946): 1043-1048

Schwartz, M.W. and D. Simberloff. 2001. Taxon size predicts rates of rarity in vascular plants. *Ecology Letters* 4: 464–469.

Sivicek, V.A. and J.B. Taft. 2011 (in press). Functional group density as an index for assessing habitat quality in tallgrass prairie. *Ecological Indicators*.

SPSS. 1998. SYSTAT for Windows, Version 9. SPSS Software Inc. Richmond, California.

Stan, A.B, L.S. Rigg and L.S. Jones. 2006. Dynamics of a managed oak woodland in northeastern Illinois. *Natural Areas Journal* 26(2), 187-197.

Taft, J.B., Z. Kron, & A. Plocher. 2010. Baseline quantitative vegetation monitoring in terrestrial and wetland communities in the North Chicago wetland mitigation site, Lake

County, Illinois. Technical report submitted to the Illinois Tollway Authority, Downers Grove.

Taft, J.B. and Z.P. Kron. 2011. Results from vegetation monitoring during 2010 in terrestrial communities at the North Chicago Wetland Mitagation Site, Lake County, Illinois. Illinois Natural History Survey technical report submitted to Illinois Tollway Authority, Downers Grove, Illinois.

Tilman, D., J. Knops, D.Wedin, P. Reich, M. Ritchie, and E. Siemann. 1997. The influence of functional diversity and composition on ecosystem processes. *Science* 277: 1300-1302.

Turner, I.M., S.K. Chua, Y.S.J. Ong, B.C. Soong, and H.T.W. Tan. 1996. A century of plant species loss from an isolated fragment of lowland tropical rain forest. *Conservation Biology* 10: 1229–1244.

Van Auken, O.W. 2000. Shrub invasions of North American semiarid grasslands. *Annual Review of Ecology & Systematics 31, 197.*

Walker, B. 1995. Conserving biological diversity through ecosystem resilience. *Conservation Biology* 9: 747–752.

Walker, K.J. and D.C. Preston. 2006. Ecological predictors of extinction risk in the flora of lowland England, UK. *Biodiversity Conservation* 15: 1913–1942.

White, J and M.H. Madany 1978. Classification of natural communities in Illinois. 305-405 (Appendix 30) In J. White, *Illinois Natural Areas Inventory Technical Report Volume 1: Survey methods and results*. Illinois Natural Areas Inventory, Department of Landscape Architecture, University of Illinois at Urbana-Champaign.

Williams, N.S.G., W.J. Morgan, J.M. Mcdonnell and M.A. McCarthy. 2005. Plant traits and local extinctions in natural grasslands along an urban-rural gradient. *Journal of Ecology* 93: 1203–1213.

Wilson, S.D. and H.R. Kleb. 1996. The influence of prairie and forest vegetation on soil moisture and available nitrogen. *American Midland Naturalist* 136: 222-231.

Zavelata, E., J. Pasari, J. Moore, D. Hernandez, K.B. Suttle, and C.C. Wilmers. 2009. Ecosystem Response to Community Disassembly. The Year in Ecology and Conservation Biology, 2009: *Annals of the New York Academy of Sciences* 1162: 311-333.

4.6 Figures

Figure 12. Correlations between percent visible sky and a) species richness, b) dominance, c) Shannon-Weiner Diversity, and d) Evenness. All correlations are significant (P < .05) except for evenness (P > .05). Ellipses are 95% confidence intervals on the centroid of sample means.

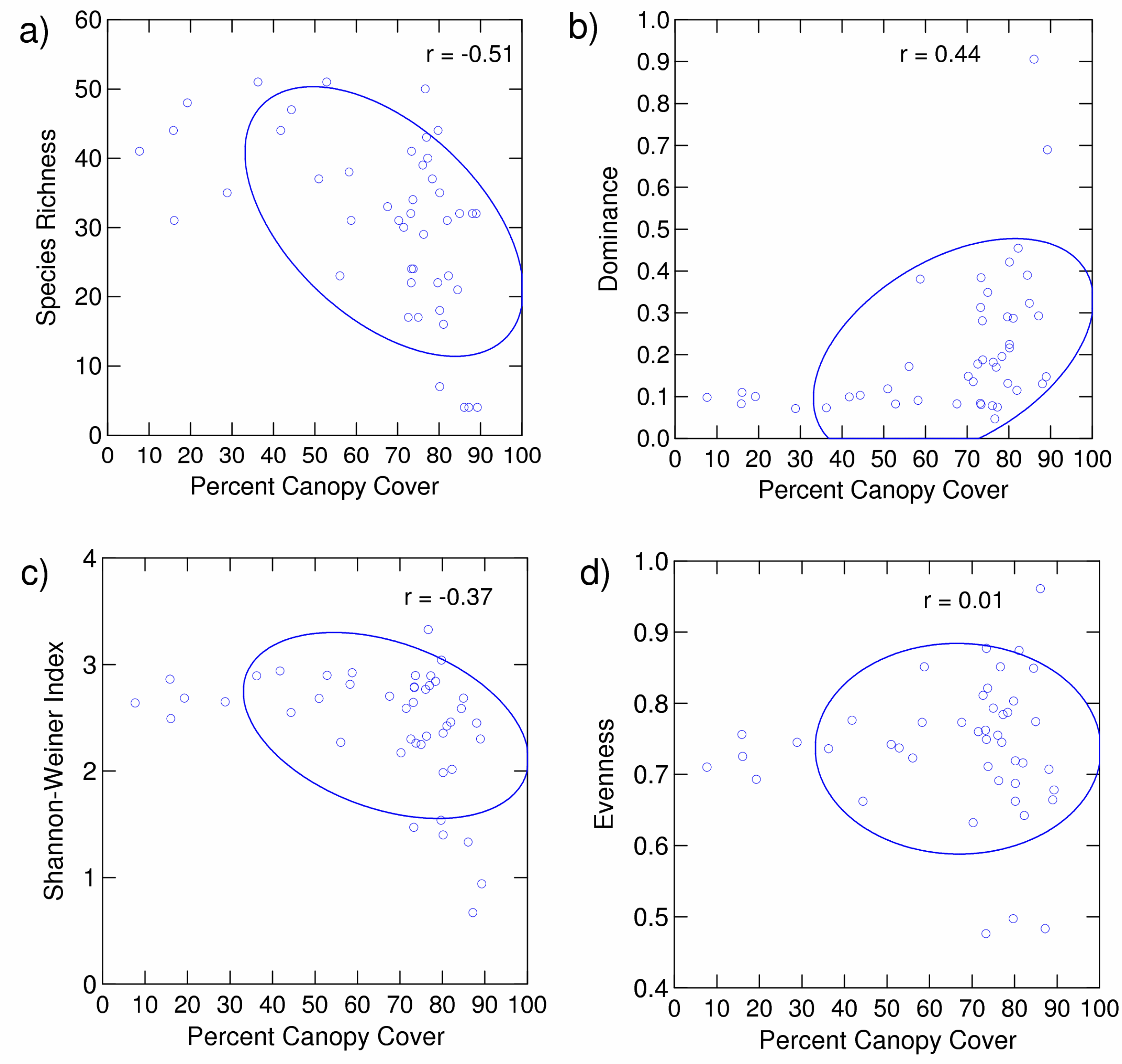


Figure 13. The relationship between percent ground layer cover and percent shrub canopy cover. Large values of ground layer cover are due to the overlapping nature of the vegetation on a quadrat level basis. Shrub cover derived from HemiView digital canopy analyzer software and calculated as 100-% visible sky.

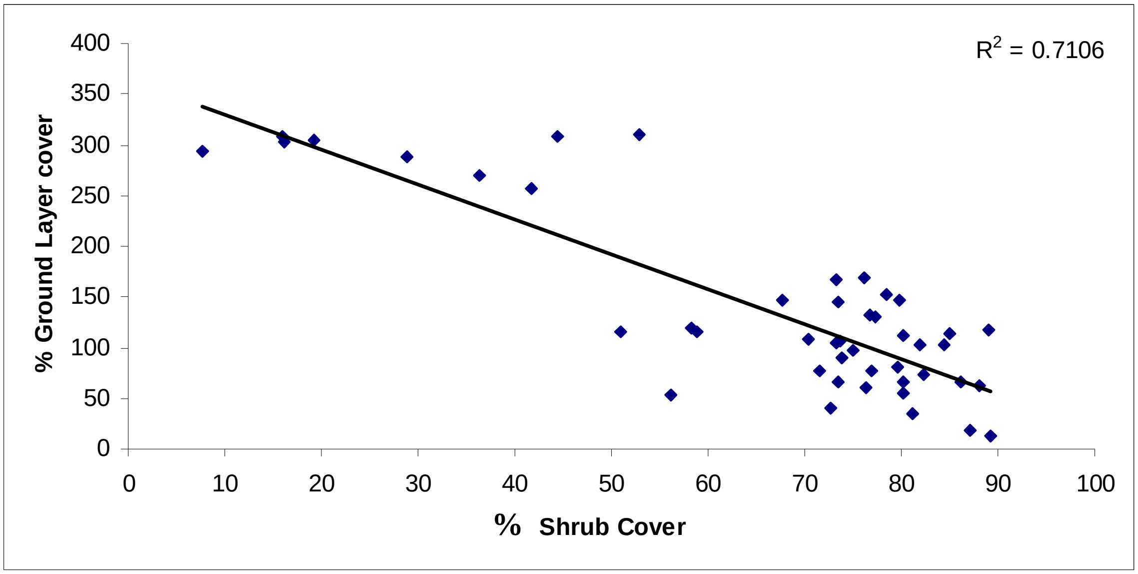


Figure 14. Results from an ANOVA of the total ground layer cover per plot within each shrub canopy cover class. Large values of cover are due to the overlapping nature of the vegetation on a quadrat level basis. Results are significant (P < 0.0001), and indicate a reduction in the mean ground layer cover in the higher canopy cover classes. Shrub canopy cover classes are 1 (0-25% shrub canopy cover), 2 (25-50% shrub canopy cover), 3 (50-75% shrub canopy cover), and 4 (75-100% shrub canopy cover).

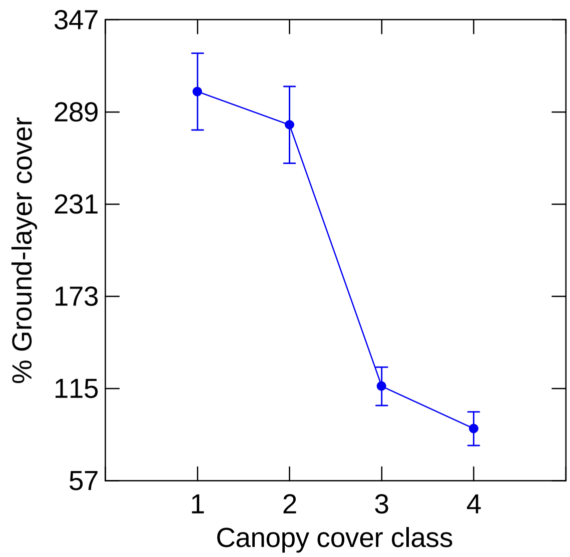


Figure 15. Results from an ANOVA of the number of functional groups within each shrub canopy cover class. Results are not significant (P = 0.089). After an initial increase in the number of functional groups, there is a reduction in the mean number of functional groups per increasing shrub canopy cover class. Shrub canopy cover classes are 1 (0-25% shrub canopy cover), 2 (25-50% shrub canopy cover), 3 (50-75% shrub canopy cover), and 4 (75-100% shrub canopy cover).

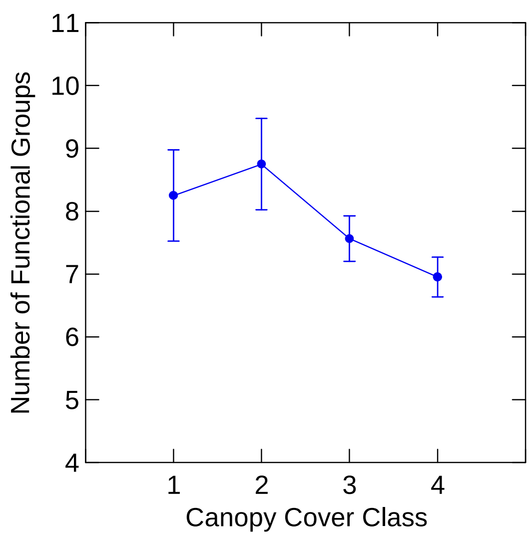


Figure 16. Average cover of each functional group per canopy cover class. . Large values of cover are due to the overlapping nature of the vegetation on a quadrat level basis. Error bars represent standard error. Letters indicate statistical differences among shrub canopy cover classes based on separate ANOVA tests for each functional group (corrected for multiple comparisons, alpha = $P < 0.0042$). Cover decreases with increasing shrub canopy cover classes in annual forbs, perennial forbs, perennial legumes, C3 grasses, C4 grasses, and sedges. Legend refers to percent canopy cover (100 - % visible sky).

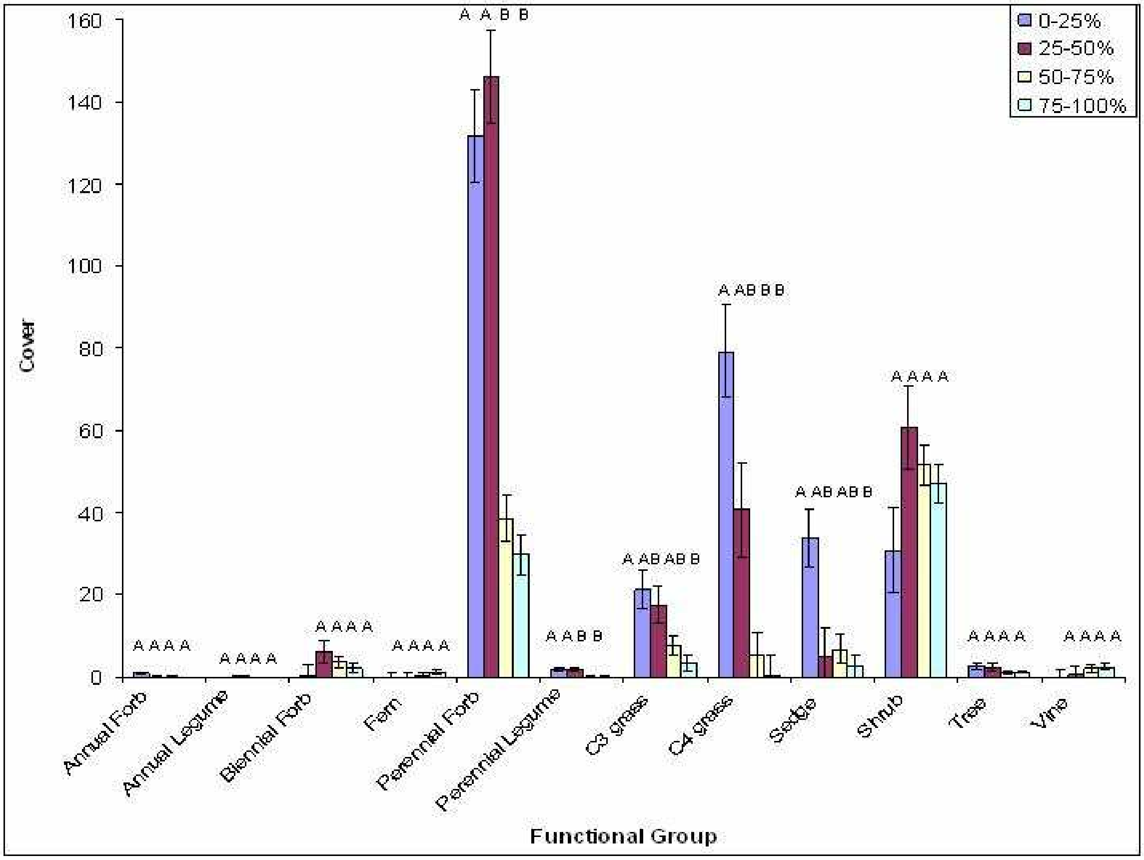


Figure 17. Average richness of each functional group per canopy cover class. Error bars represent standard error. Letters indicate statistical differences among shrub canopy cover classes based on separate ANOVA tests for each functional group (corrected for multiple comparisons, alpha = $P < 0.0042$). Perennial forbs, perennial legumes, and C4 grasses show an overall significant decrease in richness with high shrub canopy cover classes. Vines show the opposite pattern and increase with increasing shrub canopy cover. Legend refers to percent canopy cover (100 - % visible sky).

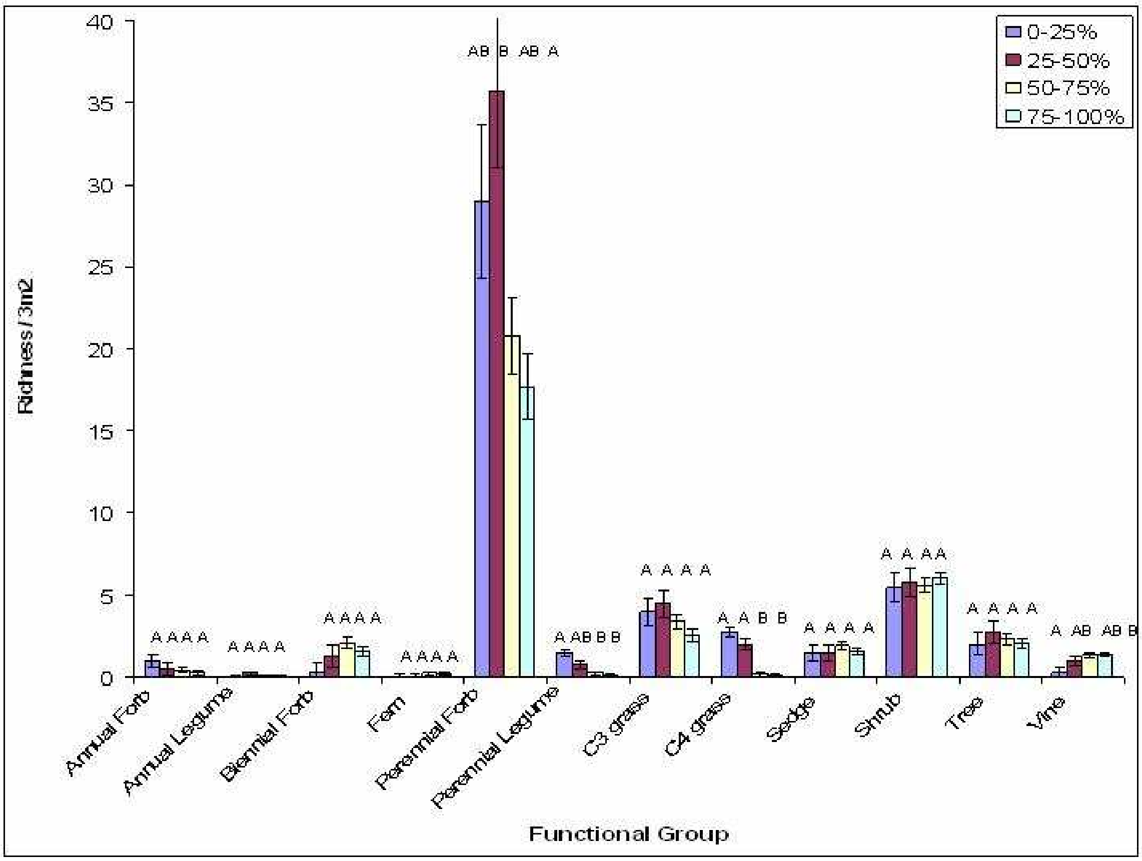


Figure 18. The IV for each functional group is shown relative to the IV it contributes to each canopy cover class. The x-axis is then sorted by rank descending order. For example, C4 grasses contribute the most of their total IV within the first class. In fact, they have the highest relative IV in the first canopy cover class of any functional group. Conversely, C4 grasses contribute least to the IV of the 4th canopy cover class, relative to the other classes it contributes to. This method gives weight to rare species. IV calculated as relative cover + relative frequency. The Legend represents shrub canopy cover classes 1 (0-25% shrub canopy cover), 2 (25-50% shrub canopy cover), 3 (50-75% shrub canopy cover), and 4 (75-100% shrub canopy cover).

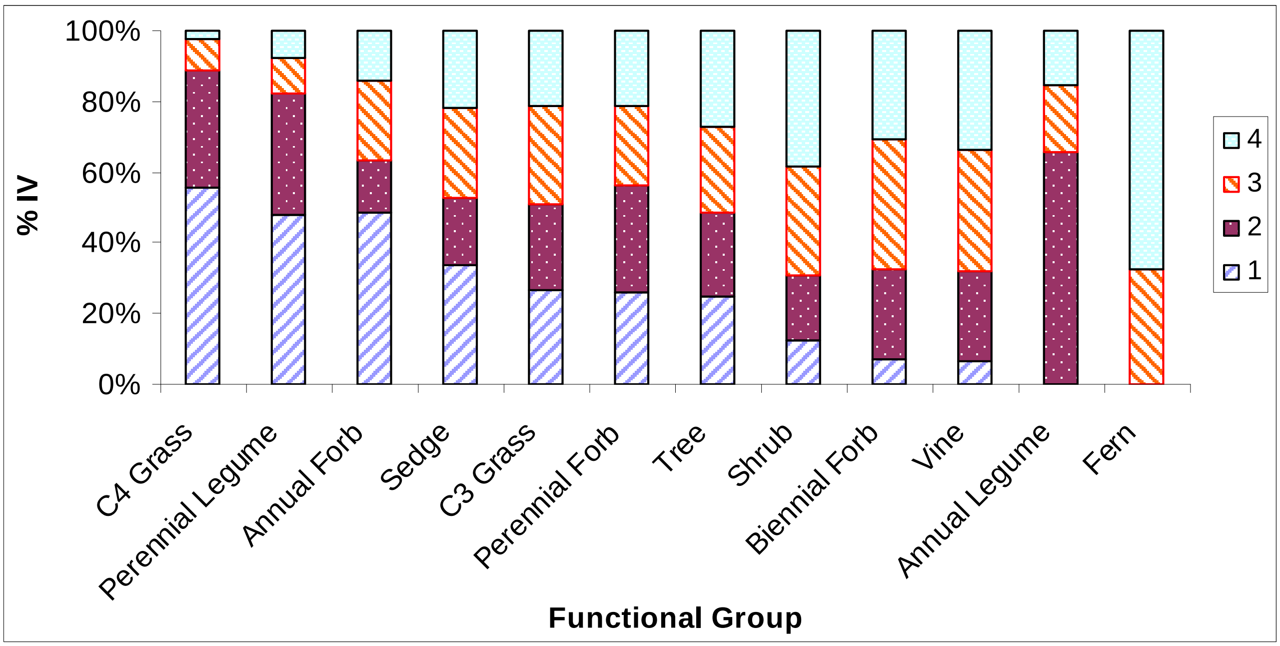


Figure 19. NMS ordination of functional group cover data with correlation to environmental variables. Final Kruskal stress was 8.871 for the 2-dimensional solution. Final instability was <0.0001 based on 40 iterations. The solution was rotated so that the first axis explained a majority of the variance (83%). Two environmental variables (Non-Native Richness and Shrub Density) were not pictured because they did not meet the correlation cutoff (r > 0.10, see Table 19). Red vectors portray the correlation of an environmental variable with the richness data. The relative length of the vector indicates how much variance is explained in the correlation between the vector and the plot data. The legend describes which canopy cover class the plots belong to (1 = 0% – 25% shrub canopy cover, 2 = 25% to 50% shrub canopy cover, 3 = 50% to 75% shrub canopy cover, and 4 = 75% to 100 % canopy cover). Plots 5E and 8E were excluded from the graphical representation as a result of outlier analysis.

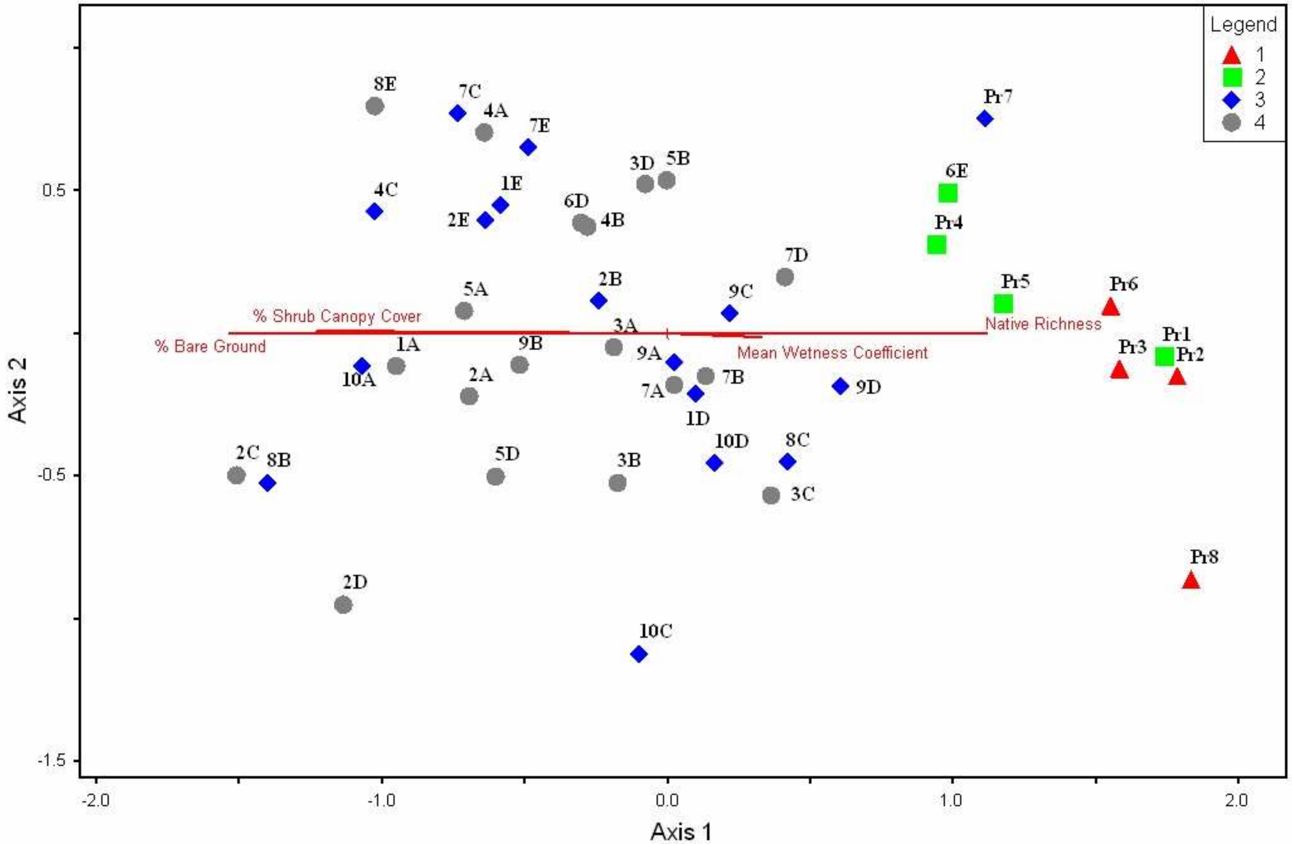


Figure 20. NMS ordination of functional group richness with correlation to environmental variables. Final stress was 12.246 for the 2-dimensional solution. Final instability was 0.0123 based on 400 iterations. The solution was rotated so that the first axis explained a majority of the variance (90%). Two environmental variables (Mean Wetness Coefficient and Shrub Density) were not pictured because they did not meet the correlation cutoff (r > 0.20, see Table 20). Red vectors portray the correlation of an environmental variable with the richness data. The relative length of the vector indicates how much variance is explained in the correlation between the vector and the plot data. The legend describes which canopy cover class the plots belong to (1 = 0% – 25% shrub canopy cover, 2 = 25% to 50% shrub canopy cover, 3 = 50% to 75% shrub canopy cover, and 4 = 75% to 100 % canopy cover). Plots 1A, 5E, 8E, and 9E were excluded as a result of outlier analysis performed in PCORD.

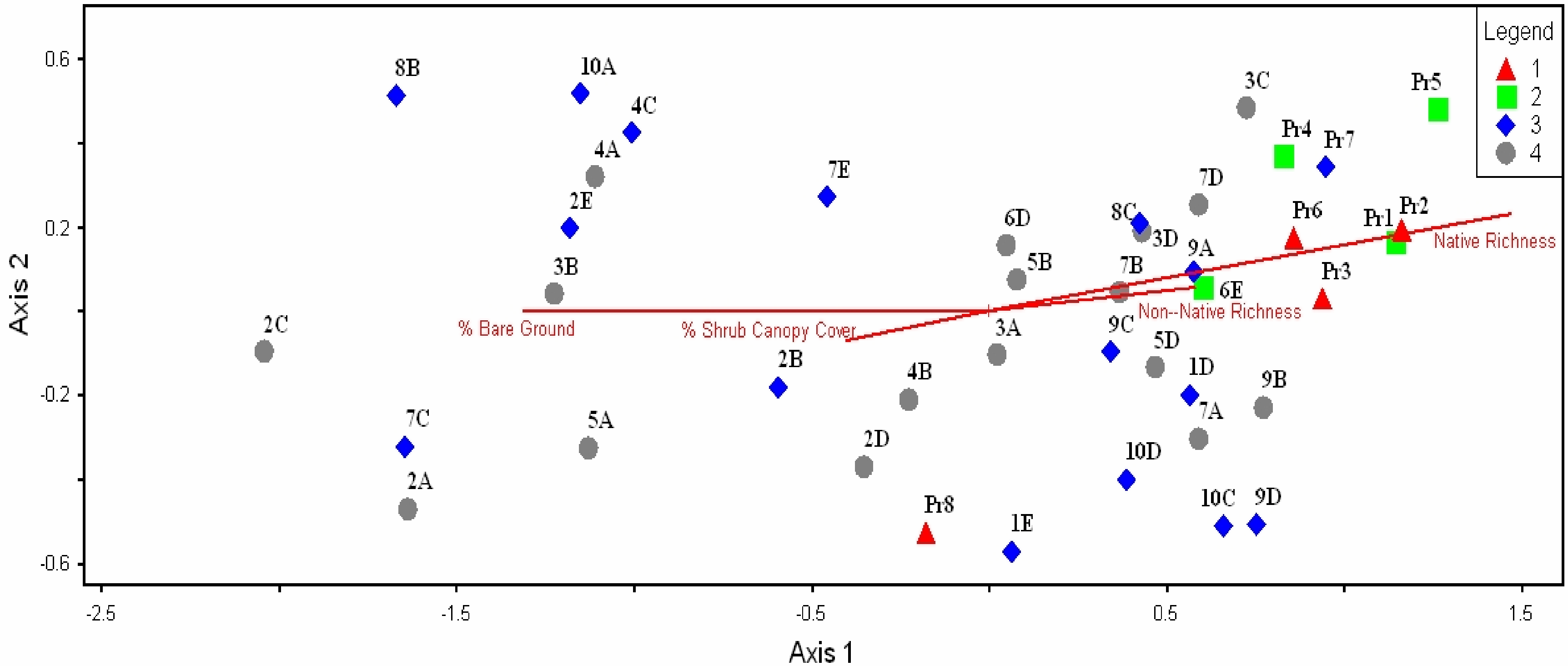


Table 8. Regression statistics for linear regression of individual functional group cover vs percent canopy cover. Significance was corrected for multiple comparisons with the Bonferroni correction ($P < 0.0042$). All significant relationships had a negative relationship with the independent variable.

Regression Statistics	**Multiple R**	**Adjusted R Square**	**Standard Error**	***F***	***Significance F***
Perennial Forb	0.82	0.66	26.9	88.30	**<0.0001**
C4 Grass	0.698	0.48	23.44	40.91	**<0.0001**
Perennial Legume	0.66	0.43	0.73	33.64	**<0.0001**
C3 Grass	0.58	0.32	8.69	22.02	**<0.0001**
Sedge	0.48	0.21	14.10	13.00	**0.0008**
Annual Forb	0.46	0.20	0.35	11.73	**0.0014**
Tree	0.28	0.05	1.57	3.55	0.0700
Annual Legume	0.24	0.04	0.15	2.71	0.1070
Vine	0.19	0.01	3.5	1.55	0.2200
Fern	0.12	-0.01	2.25	0.67	0.4200
Biennial Forb	0.07	-0.02	5.35	0.20	0.6570
Shrub	0.05	-0.02	21.22	0.10	0.7490

Table 9. Regression statistics for linear regression of individual functional group richness vs percent canopy cover. Significance was corrected for multiple comparisons with the Bonferroni correction ($P < 0.0042$). All significant dependant variables had a negative relationship with the independent variable, except for vine richness which had a positive relationship with the independent variable.

Regression statistics	**Multiple R**	**Adjusted R Square**	**Standard Error**	***Significance F***
C4 Grass	0.77	0.59	0.69	**<0.0001**
Perennial Legume	0.65	0.41	0.47	**<0.0001**
Perennial Forb	0.52	0.26	9.12	**0.0002**
Vine	0.50	0.24	0.56	**0.0004**
C3 Grass	0.34	0.09	1.68	0.0231
Annual Forb	0.24	0.03	0.71	0.1151
Biennial Forb	0.20	0.02	1.33	0.1840
Annual Legume	0.09	0	0.25	0.5506
Fern	0.13	0	0.41	0.3897
Sedge	0.04	0	1.01	0.8138
Shrub	0.04	0	1.71	0.8020
Tree	0.15	0	1.31	0.3260

Table 10. Between groups F-matrix results from discriminant analysis using functional group cover data. Values are proportional to distance measures between group means. Large numbers between groups indicate that two groups are dissimilar to one another. Based on functional group cover data, canopy cover classes three and four are the most similar to one another, whereas canopy cover classes one and four are the most different. See Table 5 for the variables included in the forward stepping model. Wilks' lambda of 0.009, F = 23.936, $P < 0.0001$.

Complete discriminant analysis df = 12 29

Canopy Cover classes	1	2	3	4
1	0			
2	6.156	0		
3	14.337	8.326	0	
4	16.462	9.165	0.561	0

Forward Stepping Discriminant Analysis df = 7 35

Canopy Cover classes	1	2	3	4
1	0			
2	10.362	0		
3	25.955	20.31	0	
4	30.893	22.801	0.88	0

Table 11. Between groups F-matrix results from discriminant analysis using functional group richness data. Values are proportional to distance measures between group means. Large numbers between groups indicate that two groups are dissimilar to one another. Based on functional group richness data, canopy cover classes three and four are the most similar to one another, whereas canopy cover classes one and four are the most different. See Table 6 for the variables included in the forward stepping model. Wilks' lambda of 0.086, F = 18.406, $P < 0.0001$.

Complete discriminant analysis -- df = 12 30

Canopy Cover Classes	1	2	3	4
1	0			
2	1.284	0		
3	6.074	4.006	0	
4	6.365	4.278	0.471	0

Forward Stepping Discriminant Analysis df = 3 39

Canopy Cover Classes	1	2	3	4
1	0			
2	2.451	0		
3	22.218	11.856	0	
4	25.872	14.143	0.221	0

Table 12. Results from Discriminant Analysis examining affiliation of functional group cover with each shrub canopy class using complete and forward selection analysis. Variables are in rank descending order of F-to-remove values. The F-to-remove value indicates relative importance of variables included within the model. For example, perennial forb cover is clearly more important to discriminating among shrub canopy cover classes than other variables. Conversely, vine cover is the least important variable contributing to the separation of the classes. Forward stepping analysis indicates which variables were not important to the model, and excludes them from the analysis. Variables included within the model have a F-to-remove > 2.22. It then recalculates the F-to-remove values of all variables included in the model.

Complete

Variable	F-to-remove	Tolerance
Perennial Forb	15.19	0.46
Perennial Legume	4.77	0.16
Sedge	4.22	0.36
Annual Forb	2.79	0.52
Biennial Forb	2.62	0.59
Annual Legume	2.19	0.19
Fern	2.00	0.73
Shrub	1.37	0.84
C4 Grass	0.52	0.46
Tree	0.28	0.74
C3 Grass	0.22	0.38
Vine	0.13	0.93

Forward

Variable	F-to-remove	Tolerance	Variable	F-to-enter	Tolerance
Perennial Forb	29.92	0.61	Shrub	0.82	0.91
Sedge	11.75	0.53	C4 Grass	0.44	0.48
Perennial Legume	9.24	0.25	C3 Grass	0.18	0.39
Annual Forb	5.17	0.54	Tree	0.18	0.78
Annual Legume	4.78	0.29	Vine	0.11	0.94
Biennial Forb	2.79	0.69			
Fern	2.26	0.87			

Table 13. Results from Discriminant Analysis examining affiliation of functional group richness with each shrub canopy class using complete and forward selection. Variables are in rank descending order of F-to-remove values. The F-to-remove value indicates relative importance of variables included within the model. For example, C4 grass richness contributes the most to the separation of shrub canopy cover classes in both the backward and forward stepping models. Conversely, C3 grass richness is the least important variable that discriminates among shrub canopy cover classes. Forward stepping analysis indicates which variables are most important to the model, and excludes them from the analysis. Variables included in the model have a F-to-remove > 2.22. It then recalculates the F-to-remove values of all variables included in the model.

Complete

Variable	F-to-remove	Tolerance
C4 Grass	2.08	0.52
Perennial Forb	1.72	0.20
Perennial Legume	1.71	0.66
Biennial Forb	1.7	0.30
Annual Legume	1.66	0.67
Annual Forb	1.34	0.59
Sedge	1.25	0.50
Shrub	0.98	0.44
Tree	0.71	0.55
Vine	0.71	0.75
Fern	0.38	0.75
C3 Grass	0.25	0.43

Forward

Variable	F-to-remove	Tolerance	Variable	F-to-enter	Tolerance
C4 Grass	16.57	0.87	Biennial Forb	1.77	0.76
Perennial Forb	2.47	0.99	Perennial Legume	1.48	0.76
Annual Legume	2.22	0.88	Vine	0.99	0.95
			C3 Grass	0.95	0.91
			Fern	0.58	0.96
			Annual Forb	0.56	0.83
			Tree	0.53	0.97
			Sedge	0.43	0.96
			Shrub	0.26	0.99

Table 14. Importance Values for functional groups by canopy cover classes presented as a percent of the total importance value per shrub canopy cover class. The most important functional group is **bolded** and the least important is *italicized*. Notice the shift in importance from perennial forbs to shrubs in the higher classes of shrub canopy cover. Shrub canopy cover classes are 1 (0-25% shrub canopy cover), 2 (25-50% shrub canopy cover), 3 (50-75% shrub canopy cover), and 4 (75-100% shrub canopy cover). Functional groups are organized by rank descending order of % IV in the 1st shrub canopy cover class

	% IV 1	% IV 2	% IV 3	% IV 4
Perennial Forb	**27.87**	**31.73**	23.69	22.61
C4 Grass	19.18	11.52	3.04	0.83
Sedge	11.65	6.57	8.63	7.66
Shrub	11.13	16.51	**27.72**	**34.28**
C3 Grass	9.57	8.81	9.98	7.68
Tree	6.47	6.13	6.22	7.14
Perennial Legume	6.36	4.60	1.28	1.06
Annual Forb	4.68	1.44	2.13	1.39
Biennial Forb	1.56	5.37	7.74	6.55
Vine	1.52	5.84	7.86	7.73
Annual Legume	*0.00*	1.47	*0.42*	*0.35*
Fern	*0.00*	*0.00*	1.31	2.72
	100	100	100	100

Table 15. Pearson (r) correlation with NMS ordination axes for functional group cover data. Correlations were calculated following the rotation of the first axis so that it explains the variables explain the most variance on axis 1. For example, axis one is mostly a gradient of % bare ground and native richness. Both functional groups and Environmental variables were sorted in rank descending order of the Pearson correlation (r). See Figure 19 for the graphical representation of the ordination.

Axis:	**1**	**2**
Functional Groups	r	r
Perenial Forb	0.95	-0.09
C4 Grass	0.70	0.05
C3 Grass	0.63	-0.17
Perennial Legume	0.55	0.12
Sedge	0.51	-0.12
Annual Forb	0.41	-0.11
Tree	0.25	0.11
Vine	-0.25	-0.08
Biennial Forb	0.20	0.16
Annual Legume	0.19	0.07
Shrub	-0.06	0.92
Fern	0.02	0.15
Environmental Variables		
% Bare Ground	-0.88	0.01
% Shrub Canopy Cover	-0.79	0.06
Native Richness	0.75	0.02
Mean Wetness Coefficient	0.40	-0.08
Non-Native Richness	0.29	0.05
Shrub Density	-0.15	-0.08

Table 16. Pearson (r) correlation with ordination axes for functional group richness data. Correlations were calculated following the rotation of the first axis so that it explains the most variance on axis 1. For example, axis one is mostly a gradient of Native Richness and % bare ground. Both functional groups and Environmental variables were sorted in rank descending order of the Pearson correlation (r). See Figure 20 for the graphical representation of the ordination.

Axis:	**1**	**2**
Functional Groups	r	r
Perennial Forb	0.97	0.14
C3 Grass	0.64	-0.02
Perennial Legume	0.54	-0.03
C4 Grass	0.48	0.31
Annual Forb	0.47	-0.32
Biennial Forb	0.35	-0.21
Vine	-0.35	-0.04
Tree	0.23	0.57
Annual Legume	0.20	-0.07
Fern	-0.14	0.23
Shrub	0.05	0.52
Sedge	-0.05	0.22
Environmental Variables		
Native Richness	0.86	0.30
% Bare Ground	-0.80	0.04
Non-Native Richness	0.54	0.14
% Shrub Canopy Cover	-0.46	-0.15
Mean Wetness Coefficient	0.39	-0.14
Shrub Density	0.13	-0.19

Chapter 5

Conclusion

5.1 Summary and Conclusions

The initial portion of the study highlights the differences in the upland communities of the North Chicago Wetland Mitigation Site and provides a framework for a five year monitoring program following habitat management. The upland areas of the site include both prairie and old field communities that are differentiated by species composition identified from cluster analysis. Prairie and old field communities differed significantly in native species density, native species richness, ground layer cover, percent bare ground, Mean C, FQI, and percent shrub canopy cover. 48 species were significant indicators of the prairie community while six species were significant indicators of the old field community, indicating that the old field community is a nested subset within the prairie community. *Rhamnus cathartica*, *Cornus racemosa*, *Lonicera* X *bella*, *Viburnum lentago*, and *Rhamnus frangula* were the most important species in the shrub plots (25 m^2) regardless of community type and together accounted for 87.82% and 82.22% of the importance value in prairie and old field communities, respectively.

Analysis of the seed bank suggests that many areas of the site are seed limited, as few species were found in the seed bank and there was very little similarity between the species found in the seed bank and the standing vegetation. Possible causes of seed bank failure could be attributed to the past history of cultivation at the site and the recent history of shrub encroachment. Results of this study and analysis of aerial photography suggest the most likely source of the species occurring on previously cultivated land is the largely uncultivated prairie remnants scattered throughout the site. However, little evidence was found suggesting that remnants are responsible for colonizing the disturbed areas at the site. Nevertheless, in light of the results of the soil seed bank refugia analysis, it remains the most plausible explanation of the current vegetation patterns across the site.

Shrub encroachment into grassland communities is a significant issue that most prairie managers face today. A common cause of shrub encroachment is the lack of disturbance in these fire-adapted ecosystems. Lack of management often results in changes in diversity and dominance of characteristic prairie species and increases in shrub abundance and dominance. The purpose of the final portion of the study was to determine whether nonrandom ordered patterns of plant functional group losses could be detected with increasing woody invasion in native grassland habitats.

Percent cover of the ground layer and the total number of functional groups were inversely correlated with shrub canopy cover. To determine whether all functional groups responded consistently to changes in shrub canopy cover, functional group responses to increasing canopy cover were analyzed separately. Cover and richness of C4 grass, perennial legume, and perennial forb functional groups follow ordered decline with increasing shrub canopy cover and differences among canopy cover classes were significant. Cover of perennial sedge, C3 grass, and annual forb functional groups were most affiliated with particular canopy cover classes, declining with increasing shrub canopy cover. In addition, vine richness was the only variable directly related to increasing shrub canopy cover. Functional groups most commonly dominant in prairie communities are associated with low canopy cover plots compared with closed canopy plots.

5.2 Significance

Results suggest that at least some of the North Chicago Wetland Mitigation site should be supplemented with native grassland seed because seed limitation may be a limiting factor in local patterns of species richness and composition. Though most plots along transects were probably cultivated at one time (Chapter 1), there were significant differences among the plots after they were grouped into prairie and old field plots based on species composition and a comparison to local remnants at the site. Since prairie plots were more similar to the reference prairie remnant plots (Chapter 2), they should be excluded from supplemental seeding because they are already similar to prairie remnants in terms of species richness and composition. The old field plots and surrounding areas under dense shrub canopy cover should be the target of seed augmentation, with the goal of increasing local species richness comparable to the plots classified collectively as prairie (Chapter 2).

A three fold increase in shrub density over the past 15 years suggests that recent shrub encroachment is a management concern for the site. Results from this study highlight ordered patterns of losses in the cover and richness of plant species and functional groups that can be used as a guideline to evaluate sites undergoing shrub encroachment. These results have important management implications for restoration and management of grassland ecosystems, and should be used to guide restoration activities at the North Chicago Wetland Mitigation site.

In the spring of 2010, management and restoration began at the North Chicago Wetland Mitigation site. The initial stages of management involved the removal of shrubs and trees, seeding with native herbaceous species, and mulching with straw to reduce erosion. Invasive and adventive shrub and trees species were targeted for removal while non-invasive native species were removed sparingly. The entire site was seeded with a general mix of native grassland species. Future management will include the reintroduction of fire to the site.

Appendix

A listing of the species identified in the 2009 sampling of the 65ha of old field prairie mosaic at North Chicago Excess Parcel in North Chicago, IL. Common names, scientific name and acronyms for each species are listed if known. Importance values (% IV) are listed by both community types identified from cluster analysis (see Chapter 2). CC refers to the Coefficient of Conservation, and is used to calculate Mean C and FQI (Chapter 2). WC is the wetness coefficient, and was used to calculate the mean wetness coefficient (Chapter 2). Each species is also assigned to a functional group based partially on physiognomy (see Chapter 4). An asterisk denotes a non-native species.

		Old Field			Prairie							
ACRONYM	**Species**	**Freq**	**Cover**	**%IV**	**Freq**	**cover**	**% IV**	**CC**	**WC**	**WET-NESS**	**PHYSIOG-NOMY**	**COMMON NAME**
ACENEG	*Acer negundo*	0.35	0.04	0.19	0.07	0.00	0.04	1	-2	FACW-	Tree	BOXELDER
ACESAI	*Acer saccharinum*	0.18	0.02	0.10	0.28	0.02	0.15	1	-3	FACW	Tree	SILVER MAPLE
ACHMIL	*Achillea millefolium**	0.47	0.08	0.28	1.60	0.70	1.15	0	3	FACU	P-Forb	COMMON MILFOIL
AGRGRY	*Agrimonia gryposepala*	0.18	0.11	0.14	0.21	0.08	0.15	3	2	FACU+	P-Forb	TALL AGRIMONY
AGRTRT	*Agropyron trachycaulum*	0.00	0.00	0.00	0.07	0.03	0.05	8	0	FAC	C3 Grass	BEARDED WHEAT GRASS
AGRTRT	*Agrostis alba **	1.06	0.42	0.74	1.60	1.98	1.79	8	0	FAC	C3 Grass	BEARDED WHEAT GRASS
AGRALP	*Agrostis alba palustris*	0.00	0.00	0.00	0.21	1.49	0.85	8	-3	FACW	C3 Grass	CREEPING BENT GRASS
ALLPET	*Alliaria petiolata**	0.12	0.04	0.08	0.00	0.00	0.00	0	0	FAC	B-Forb	GARLIC MUSTARD
ALLCAC	*Allium canadense*	2.00	6.33	4.17	0.07	0.00	0.04	2	3	FACU	P-Forb	WILD GARLIC
ALLCER	*Allium cernuum*	0.00	0.00	0.00	1.32	1.35	1.34	7	5	UPL	P-Forb	NODDING WILD ONION
AMBART	*Ambrosia artemisiifolia*	0.12	0.01	0.06	0.07	0.00	0.04	0	3	FACU	A-Forb	COMMON RAGWEED
AMESAN	*Amelanchier arborea*	0.41	0.04	0.23	0.28	0.02	0.15	7	3	FACU	Tree	JUNEBERRY
ANDGER	*Andropogon gerardii*	0.06	0.04	0.05	0.90	4.97	2.94	5	1	FAC-	C4 Grass	BIG BLUESTEM
ANECYL	*Anemone cylindrica*	0.29	0.09	0.19	0.00	0.00	0.00	8	5	UPL	P-Forb	CANDLE ANEMONE
ANEVIR	*Anemone virginiana*	2.35	1.17	1.76	1.95	0.41	1.18	4	5	UPL	P-Forb	TALL ANEMONE
ANTNEG	*Antennaria neglecta*	0.47	0.08	0.28	1.39	1.88	1.64	4	5	UPL	P-Forb	CAT'S FOOT
APOAND	*Apocynum androsaemifolium*	0.06	0.04	0.05	0.00	0.00	0.00	6	5	UPL	P-Forb	SPREADING DOGBANE
APOSIB	*Apocynum sibiricum*	0.00	0.00	0.00	0.07	0.00	0.04	2	-1	FAC+	P-Forb	INDIAN HEMP
AQUCAN	*Aquilegia canadensis*	0.00	0.00	0.00	0.07	0.03	0.05	5	1	FAC-	P-Forb	COLUMBINE
ARITRI	*Arisaema triphyllum*	0.06	0.18	0.12	0.00	0.00	0.00	4	-2	FACW-	P-Forb	INDIAN TURNIP
ASCINC	*Asclepias incarnata*	0.00	0.00	0.00	0.07	0.03	0.05	4	-5	OBL	P-Forb	SWAMP MILKWEED
ASCPUR	*Asclepias purpurascens*	0.06	0.04	0.05	0.00	0.00	0.00	7	3	FACU	P-Forb	PURPLE MILKWEED
ASCTUB	*Asclepias tuberosa var interior*	0.00	0.00	0.00	0.21	0.04	0.12	5	5	UPL	P-Forb	BUTTERFLYWEED
ASTDRU	*Aster drummondii*	3.29	2.34	2.82	1.39	0.93	1.16	3	3	FACU	P-Forb	DRUMMOND'S ASTER
ASTERI	*Aster ericoides*	0.71	0.17	0.44	2.09	0.94	1.51	4	4	FACU-	P-Forb	HEATH ASTER
ASTLAT	*Aster lateriflorus*	2.06	1.71	1.88	0.70	0.32	0.51	2	-2	FACW-	P-Forb	SIDE-FLOWERING ASTER

		Old Field			Prairie							
ACRONYM	Species	Freq	Cover	%IV	Freq	cover	% IV	CC	WC	WET-NESS	PHYSIOG-NOMY	COMMON NAME
ASTNOV	*Aster novae-angliae*	0.18	0.08	0.13	0.35	0.14	0.24	4	-3	FACW	P-Forb	NEW ENGLAND ASTER
ASTPIL	*Aster pilosus*	0.18	0.02	0.10	0.49	0.08	0.28	0	4	FACU-	P-Forb	HAIRY ASTER
ASTPRA	*Aster praealtus*	0.41	0.20	0.30	0.49	0.53	0.51	4	-5	OBL	P-Forb	WILLOW ASTER
ASTSAG	*Aster sagittifolius*	0.12	0.04	0.08	0.00	0.00	0.00	4	5	UPL	P-Forb	ARROW-LEAVED ASTER
ASTSIM	*Aster simplex*	1.06	0.23	0.65	0.56	0.11	0.33	3	-5	OBL	P-Forb	PANICLED ASTER
BARVUL	*Barbarea vulgaris*	0.06	0.01	0.03	0.00	0.00	0.00	0	0	FAC	B-Forb	WINTER CRESS
BIDFRO	*Bidens frondosa*	0.00	0.00	0.00	0.07	0.00	0.04	1	-3	FACW	A-Forb	COMMON BEGGAR'S TICKS
BOTDID	*Botrychium dissectum*	0.06	0.01	0.03	0.00	0.00	0.00	6	0	FAC	Fern	BRONZE FERN
BROKAL	*Bromus kalmii*	0.00	0.00	0.00	0.28	0.09	0.18	10	0	FAC	C3 Grass	PRAIRIE BROME
CACPLA	*Cacalia tuberosa*	0.00	0.00	0.00	0.28	0.22	0.25	10	0	FAC	P-Forb	PRAIRIE INDIAN PLANTAIN
CALCAN	*Calamagrostis canadensis*	0.06	0.01	0.03	0.00	0.00	0.00	3	-5	OBL	C3 Grass	BLUE JOINT GRASS
-	*Carex (section ovales)*	0.06	0.04	0.05	0.00	0.00	0.00	-	-	-	P-Sedge	-
CXBLAN	*Carex blanda*	0.35	0.34	0.35	0.28	0.09	0.18	2	0	FAC	P-Sedge	COMMON WOOD SEDGE
CXBUXB	*Carex buxbaumii*	0.00	0.00	0.00	0.14	1.17	0.65	9	-5	OBL	P-Sedge	DARK-SCALED SEDGE
CXCRIS	*Carex cristatella*	0.12	0.22	0.17	0.00	0.00	0.00	3	-4	FACW+	P-Sedge	CRESTED OVAL SEDGE
CXGRAH	*Carex granularis*	2.00	0.73	1.37	1.46	0.94	1.20	2	-4	FACW+	P-Sedge	PALE SEDGE
CXHIRS	*Carex hirsutella*	0.18	0.05	0.11	0.35	0.46	0.41	5	4	FACU-	P-Sedge	HAIRY GREEN SEDGE
CXLANU	*Carex pellita*	0.35	0.16	0.26	0.76	3.04	1.90	4	-5	OBL	P-Sedge	WOOLY SEDGE
-	*Carex sp. (vegetative)*	0.06	0.04	0.05	0.07	0.00	0.04	-	-	-	P-Sedge	-
-	*Carex sp. (vegetative)*	0.00	0.00	0.00	0.07	0.00	0.04	-	-	-	P-Sedge	-
CXSTRC	*Carex stricta*	0.47	1.42	0.95	0.00	0.00	0.00	5	-5	OBL	P-Sedge	COMMON TUSSOCK SEDGE
CXTENE	*Carex tenera*	0.18	0.11	0.14	0.00	0.00	0.00	5	-1	FAC+	P-Sedge	NARROW-LEAVED OVAL SEDGE
CXUMBE	*Carex umbellata*	0.71	0.20	0.45	0.00	0.00	0.00	6	5	UPL	P-Sedge	EARLY OAK SEDGE
CASCOC	*Castilleja coccinea*	0.00	0.00	0.00	0.21	0.06	0.13	8	0	FAC	A-Forb	INDIAN PAINTBRUSH
CERVUL	*Cerastium vulgatum**	0.41	0.04	0.23	1.32	0.13	0.73	0	3	FACU	P-Forb	COMMON MOUSE-EAR CHICKWEED
CICMAC	*Cicuta maculata*	0.06	0.01	0.03	0.00	0.00	0.00	4	-5	OBL	B-Forb	WATER HEMLOCK
CIRLUT	*Circaea lutetiana canadensis*	0.06	0.01	0.03	0.00	0.00	0.00	2	3	FACU	P-Forb	ENCHANTER'S NIGHTSHADE
CIRARV	*Cirsium arvense**	1.12	1.33	1.22	0.00	0.00	0.00	0	3	FACU	P-Forb	FIELD THISTLE
CIRDIS	*Cirsium discolor*	0.06	0.01	0.03	0.00	0.00	0.00	3	5	UPL	B-Forb	PASTURE THISTLE
COMUMB	*Comandra umbellata*	0.00	0.00	0.00	0.49	0.26	0.37	6	3	FACU	P-Forb	BASTARD TOAD-FLAX
CORALT	*Cornus alternifolia*	0.00	0.00	0.00	0.00	0.00	0.00	7	5	UPL	Tree	ALTERNATE-LEAVED DOGWOOD
COROBL	*Cornus obliqua*	0.06	0.04	0.05	0.00	0.00	0.00	4	-5	OBL	Shrub	PALE DOGWOOD
CORRAC	*Cornus racemosa*	0.06	0.04	0.05	2.85	5.43	4.14	2	-2	FACW-	Shrub	GRAY DOGWOOD

		Old Field			Prairie							
ACRONYM	Species	Freq	Cover	%IV	Freq	cover	% IV	CC	WC	WET-NESS	PHYSIOG-NOMY	COMMON NAME
CORAME	*Corylus americana*	4.29	7.28	5.78	0.07	0.79	0.43	4	0	FAC	Shrub	AMERICAN FILBERT
CRACOA	*Crataegus coccinea (cf.)*	0.00	0.00	0.00	0.00	0.00	0.00	5	5	UPL	Tree	SCARLET HAWTHORN
CRACRU	*Crataegus crus-galli*	0.24	0.06	0.15	0.07	0.00	0.04	2	0	FAC	Tree	COCK-SPUR HAWTHORN
CRAMOL	*Crataegus mollis*	0.59	0.30	0.45	0.00	0.00	0.00	2	-2	FACW-	Tree	DOWNY HAWTHORN
CRAPRU	*Crataegus pruinosa (cf.)*	0.35	0.04	0.19	0.42	0.07	0.25	3	5	UPL	Tree	FROSTED HAWTHORN
-	*Crataegus sp (seedlings)*	0.06	0.01	0.03	0.76	0.26	0.51	-	-	-	Tree	-
DANSPI	*Danthonia spicata*	1.12	0.12	0.62	0.07	0.03	0.05	3	5	UPL	C3 Grass	POVERTY OAT GRASS
DAUCAR	*Daucus carota**	0.18	0.26	0.22	1.81	2.32	2.07	0	4	FACU-	B-Forb	QUEEN ANNE'S LACE
DIAARM	*Dianthus armeria**	1.29	0.38	0.84	0.14	0.01	0.07	0	5	UPL	A-Forb	DEPTFORD PINK
PANIMP	*Dichantelium implicatum*	0.00	0.00	0.00	0.90	0.20	0.55	2	0	FAC	C3 Grass	OLD FIELD PANIC GRASS
PANOLS	*Dichanthelium oligosanthes*	0.65	0.13	0.39	0.00	0.00	0.00	3	3	FACU	C3 Grass	SCRIBNER'S PANIC GRASS
PANVIV	*Dichanthelium villosissimum*	0.29	0.03	0.16	1.53	0.24	0.89	5	5	UPL	C3 Grass	WHITE-HAIRED PANIC GRASS
-	*Dicot seedling 1*	1.35	0.44	0.90	0.00	0.00	0.00	-	-	-	-	-
-	*Dicot seedling 2*	0.00	0.00	0.00	0.21	0.01	0.11	-	-	-	-	-
-	*Dicot seedling 3*	0.06	0.01	0.03	0.00	0.00	0.00	-	-	-	-	-
-	*Dicot seedling 4*	0.06	0.01	0.03	0.00	0.00	0.00	-	-	-	-	-
DIPLAC	*Dipsacus laciniatus*	0.06	0.04	0.05	0.00	0.00	0.00	0	5	UPL	B-Forb	CUT-LEAVED TEASEL
ELYVIR	*Elymus virginiana*	0.06	0.01	0.03	0.00	0.00	0.00	4	-2	FACW-	C3 Grass	VIRGINIA WILD RYE
EQUARV	*Equisetum arvense*	0.82	0.69	0.76	0.42	0.30	0.36	0	0	FAC	Fern	COMMON HORSETAIL
ERIANN	*Erigeron annuas*	0.88	0.25	0.56	0.63	0.06	0.35	1	1	FAC-	B-Forb	ANNUAL FLEABANE
ERIPHI	*Erigeron philadelphicus*	0.35	0.25	0.30	0.00	0.00	0.00	3	-3	FACW	P-Forb	MARSH FLEABANE
ERISTR	*Erigeron strigosus*	0.41	0.14	0.27	1.11	0.39	0.75	2	1	FAC-	P-Forb	DAISY FLEABANE
EUPALT	*Eupatorium altissimum*	0.06	0.01	0.03	0.14	0.03	0.09	2	3	FACU	P-Forb	TALL BONESET
EUPPER	*Eupatorium perfoliatum*	0.00	0.00	0.00	0.07	0.00	0.04	4	-4	FACW+	P-Forb	COMMON BONESET
EUPRUG	*Eupatorium rugosum*	0.12	0.07	0.10	0.00	0.00	0.00	2	3	FACU	P-Forb	WHITE SNAKEROOT
EUPCOR	*Euphorbia coralata*	0.00	0.00	0.00	0.21	0.08	0.15	3	5	UPL	P-Forb	FLOWERING SPURGE
EUTGRA	*Euthamia graminifolia*	0.35	0.13	0.24	0.70	0.23	0.46	3	-2	FACW-	P-Forb	GRASS-LEAVED GOLDENROD
FRAVIR	*Fragaria virginiana*	3.53	2.10	2.81	2.16	1.69	1.92	2	1	FAC-	P-Forb	WILD STRAWBERRY
FRAPES	*Fraxinus pennsylvanica subintegra*	0.24	0.09	0.16	0.35	0.09	0.22	2	-3	FACW	Tree	GREEN ASH
GALOBT	*Galium obtusum*	0.24	0.12	0.18	0.35	0.25	0.30	5	-4	FACW+	P-Forb	WILD MADDER
GALTRO	*Galium triflorum*	0.53	0.09	0.31	0.28	0.06	0.17	4	2	FACU+	P-Forb	SWEET-SCENTED BEDSTRAW
GENALB	*Gentiana alba*	0.35	0.16	0.26	0.63	0.16	0.39	9	3	FACU	P-Forb	PALE GENTIAN
GENAND	*Gentiana andrewsii*	0.00	0.00	0.00	0.28	0.06	0.17	7	-3	FACW	P-Forb	CLOSED GENTIAN

		Old Field			Prairie							
ACRONYM	**Species**	**Freq**	**Cover**	**%IV**	**Freq**	**cover**	**% IV**	**CC**	**WC**	**WET-NESS**	**PHYSIOG-NOMY**	**COMMON NAME**
GENQUI	*Gentianella quinquefolia*	0.06	0.01	0.03	0.28	0.04	0.16	7	0	FAC	A-Forb	STIFF GENTIAN
GEUALE	*Geum aleppicum*	1.06	0.23	0.65	0.63	0.06	0.35	6	-1	FAC+	P-Forb	YELLOW AVENS
GEUCAN	*Geum canadense*	0.12	0.04	0.08	0.14	0.01	0.07	2	0	FAC	P-Forb	WHITE AVENS
GLYSTR	*Glyceria striata*	0.18	0.11	0.14	0.21	0.06	0.13	4	-5	OBL	C3 Grass	FOWL MANNA GRASS
HACVIR	*Hackelia virginiana*	0.06	0.01	0.03	0.00	0.00	0.00	1	1	FAC-	P-Forb	STICKSEED
HELGRO	*Helianthus grosseserratus*	0.41	0.31	0.36	0.70	1.10	0.90	2	-2	FACW-	P-Forb	SAWTOOTH SUNFLOWER
HELRIG	*Helianthus rigidus*	0.06	0.01	0.03	1.25	1.01	1.13	6	5	UPL	P-Forb	PRAIRIE SUNFLOWER
HELSTR	*Helianthus strumosus*	0.06	0.01	0.03	0.07	0.00	0.04	3	5	UPL	P-Forb	PALE-LEAVED SUNFLOWER
HIECAN	*Hieracium caespitosum**	0.88	0.49	0.68	1.67	1.02	1.34	5	5	UPL	P-Forb	CANADA HAWKWEED
HYPPER	*Hypericum perforatum**	0.12	0.04	0.08	0.00	0.00	0.00	0	5	UPL	P-Forb	COMMON ST. JOHN'S WORT
HYPPUN	*Hypericum punctatum*	1.12	0.15	0.63	0.56	0.04	0.30	3	-1	FAC+	P-Forb	SPOTTED ST. JOHN'S WORT
HYPHIR	*Hypoxis hirsuta*	0.12	0.22	0.17	0.28	0.22	0.25	6	0	FAC	P-Forb	YELLOW STAR GRASS
JUNDUD	*Juncus dudleyi*	0.06	0.04	0.05	0.00	0.00	0.00	4	0	FAC	P-Forb	DUDLEY'S RUSH
JUNINT	*Juncus interior*	0.06	0.01	0.03	0.28	0.18	0.23	3	-1	FAC+	P-Forb	INLAND RUSH
JUNTEN	*Juncus tenuis*	0.59	0.12	0.36	0.76	0.28	0.52	0	0	FAC	P-Forb	PATH RUSH
JUNVIR	*Juniperis virginiana*	0.24	0.02	0.13	0.21	0.04	0.12	1	3	FACU	Tree	EASTERN RED CEDAR
KRIBIF	*Krigia biflora*	0.00	0.00	0.00	0.56	0.40	0.48	5	3	FACU	P-Forb	FALSE DANDELOIN
LACSER	*Lactuca serriola**	0.12	0.01	0.06	0.07	0.00	0.04	0	0	FAC	B-Forb	PRICKLY LETTUCE
-	*Lactuca sp*	0.06	0.04	0.05	0.00	0.00	0.00	-	-	-	B-Forb	-
LESCAP	*Lespedeza capitata*	1.24	0.25	0.74	0.35	0.12	0.23	4	3	FACU	P-Forb N2	ROUND-HEADED BUSH CLOVER
LEUVUL	*Leucanthemum vulgare**	0.00	0.00	0.00	1.95	0.27	1.11	0	5	UPL	P-Forb	OX-EYE DAISY
LIAASP	*Liatris aspera*	0.06	0.04	0.05	0.21	0.06	0.13	7	5	UPL	P-Forb	ROUGH BLAZING STAR
LIASPI	*Liatris cf spicata*	0.00	0.00	0.00	0.76	0.50	0.63	7	0	FAC	P-Forb	MARSH BLAZING STAR
LIAPYC	*Liatris pycnostachya*	0.12	0.04	0.08	0.07	0.03	0.05	6	1	FAC-	P-Forb	PRAIRIE BLAZINE STAR
LILMIC	*Lilium michiganense*	0.00	0.00	0.00	0.00	0.00	0.00	6	-1	FAC+	P-Forb	MICHIGAN LILY
LITCAN	*Lithospermum canescens*	1.06	0.30	0.68	0.83	0.19	0.51	6	5	UPL	P-Forb	HOARY PUCCOON
LOBSPI	*Lobelia spicata*	2.47	3.68	3.08	1.25	0.15	0.70	4	0	FAC	P-Forb	PALE SPIKED LOBELIA
LONBEL	*Lonicera X bella**	0.12	0.04	0.08	0.56	0.45	0.50	0	3	FACU	Shrub	SHOWY FLY HONEYSUCKLE
LYCAME	*Lycopus americanus*	0.12	0.01	0.06	0.00	0.00	0.00	3	-5	OBL	P-Forb	COMMON WATER HOREHOUND
LYCUNI	*Lycopus uniflorus*	0.06	0.04	0.05	0.00	0.00	0.00	7	-5	OBL	P-Forb	NOTHERN BUGLE WEED
LYTSAL	*Lythrum salicaria**	0.00	0.00	0.00	0.07	0.00	0.04	0	-5	OBL	P-Forb	PURPLE LOOSESTRIFE
MALPUM	*Malus pumila**	0.00	0.00	0.00	0.07	0.00	0.04	0	5	UPL	Tree	APPLE
MEDLUP	*Medicago lupulina**	0.29	0.03	0.16	0.21	0.04	0.12	0	1	FAC-	A-Forb N2	BLACK MEDICK
MELALB	*Melilotus alba**	1.24	0.47	0.85	0.56	0.26	0.41	0	3	FACU	B-Forb	WHITE SWEET CLOVER

		Old Field			Prairie							
ACRONYM	Species	Freq	Cover	%IV	Freq	cover	% IV	CC	WC	WET-NESS	PHYSIOG-NOMY	COMMON NAME
MONFIS	*Monarda fistulosa*	0.06	0.01	0.03	2.36	0.58	1.47	4	3	FACU	P-Forb	WILD BERGAMOT
OENBIB	*Oenothera biennis*	0.00	0.00	0.00	0.00	0.00	0.00	1	3	FACU	B-Forb	COMMON EVENING PRIMROSE
OENPER	*Oenothera perennis*	0.06	0.01	0.03	0.07	0.03	0.05	8	0	FAC	P-Forb	SMALL SUNDROPS
OSMCLI	*Osmorhiza claytonii*	1.71	0.27	0.99	0.00	0.00	0.00	3	4	FACU-	P-Forb	HAIRY SWEET CICELY
OXASTR	*Oxalis stricta*	0.35	0.13	0.24	0.49	0.03	0.26	0	3	FACU	P-Forb	TALL WOOD SORREL
OXYRIG	*Oxypolis rigidor*	0.00	0.00	0.00	0.07	0.03	0.05	7	-5	OBL	P-Forb	COWBANE
PARINT	*Parthenium integrifolium*	0.71	1.23	0.97	0.97	3.09	2.03	8	5	UPL	P-Forb	WILD QUININE
PARQUI	*Parthenocissus quinquefolia*	0.18	0.08	0.13	0.14	0.03	0.09	2	1	FAC-	W-Vine	VIRGINIA CREEPER
PENDIG	*Penstemon digitalis*	0.06	0.04	0.05	0.07	0.35	0.21	4	1	FAC-	P-Forb	FOXGLOVE BEARD TONGUE
PHAARU	*Phalaris arundinacea**	0.00	0.00	0.00	0.00	0.00	0.00	0	-4	FACW+	C3 Grass	REED CANARY GRASS
PHLPRA	*Phleum pratense**	0.18	0.05	0.11	0.07	0.00	0.04	0	3	FACU	C3 Grass	TIMOTHY
PHLGLA	*Phlox glaberrima*	0.06	0.04	0.05	0.00	0.00	0.00	6	-3	FACW	P-Forb	SMOOTH PHLOX
PHLPIP	*Phlox pilosa*	0.06	0.01	0.03	0.07	0.00	0.04	7	1	FAC-	P-Forb	SAND PRAIRIE PHLOX
PHRLEP	*Phryma leptostachya*	0.06	0.04	0.05	0.00	0.00	0.00	4	5	UPL	P-Forb	LOPSEED
PLARUG	*Plantago rugelii*	1.94	2.13	2.04	0.07	0.00	0.04	0	0	FAC	A-Forb	RED-STALKED PLANTAIN
-	*Poa bulbosa (cf.)**	1.41	1.17	1.29	0.00	0.00	0.00	-	-	-	C3 Grass	-
POACOM	*Poa compressa**	0.06	0.04	0.05	1.67	0.44	1.05	0	2	FACU+	C3 Grass	CANADIAN BLUE GRASS
POAPRA	*Poa pratensis**	0.00	0.00	0.00	1.46	2.07	1.76	0	1	FAC-	C3 Grass	KENTUCKY BLUE GRASS
-	*Poaceae sp 1*	0.24	0.06	0.15	0.00	0.00	0.00	-	-	-	-	-
POLVER	*Polygala verticillata*	0.18	0.08	0.13	0.07	0.00	0.04	5	5	UPL	A-Forb	WHORLED MILKWORT
POLCOM	*Polygonatum commutatum*	0.00	0.00	0.00	0.07	0.03	0.05	4	3	FACU	P-Forb	GREAT SOLOMON SEAL
POPTRE	*Populus tremuloides*	0.06	0.01	0.03	0.00	0.00	0.00	3	0	FAC	Tree	QUAKING ASPEN
POTARU	*Potentilla arguta*	2.29	2.14	2.22	0.14	0.01	0.07	10	4	FACU-	P-Forb	PRAIRIE CINQUEFOIL
POTREC	*Potentilla recta*	0.00	0.00	0.00	0.07	0.00	0.04	0	5	UPL	P-Forb	SULFUR CINQUEFOIL
POTSIM	*Potentilla simplex*	2.12	0.44	1.28	1.53	1.09	1.31	3	4	FACU-	P-Forb	COMMON CINQUEFOIL
PRUVUE	*Prunella vulgaris v. elongata*	0.18	0.23	0.20	1.67	0.30	0.98	1	0	FAC	P-Forb	SELF-HEAL
PRUAMA	*Prunus americana*	0.59	0.09	0.34	0.42	0.07	0.25	3	5	UPL	Tree	AMERICAN PLUM
PRUSER	*Prunus serotina*	0.12	0.07	0.10	0.28	0.04	0.16	1	3	FACU	Tree	WILD BLACK CHERRY
PRUVIR	*Prunus virginiana*	0.29	0.18	0.24	0.14	0.03	0.09	3	1	FAC-	Shrub	COMMON CHOKE CHERRY
PYCVIR	*Pycnanthemum virginianum*	0.06	0.01	0.03	0.70	0.80	0.75	5	-4	FACW+	P-Forb	COMMON MOUNTAIN MINT
QUEMAC	*Quercus macrocarpa*	0.12	0.01	0.06	0.00	0.00	0.00	5	1	FAC-	Tree	BURR OAK
QUEPAL	*Quercus palustris*	0.12	0.01	0.06	0.00	0.00	0.00	4	-3	FACW	Tree	PIN OAK
RANABO	*Ranunculus abortivus*	0.12	0.01	0.06	0.00	0.00	0.00	1	-2	FACW-	A-Forb	LITTLE-LEAF BUTTERCUP
RANREC	*Ranunculus recurvatus*	1.18	0.52	0.85	0.00	0.00	0.00	5	-3	FACW	A-Forb	HOOKED BUTTERCUP

		Old Field			Prairie							
ACRONYM	**Species**	**Freq**	**Cover**	**%IV**	**Freq**	**cover**	**% IV**	**CC**	**WC**	**WET-NESS**	**PHYSIOG-NOMY**	**COMMON NAME**
RATPIN	*Ratibida pinnata*	5.29	38.27	21.78	2.36	1.46	1.91	4	5	UPL	P-Forb	YELLOW CONEFLOWER
RHACAT	*Rhamnus cathartica**	1.59	1.36	1.47	3.06	10.58	6.82	0	3	FACU	Shrub	COMMON BUCKTHORN
RHAFRA	*Rhamnus frangula**	0.06	0.01	0.03	0.97	0.29	0.63	0	-1	FAC+	Shrub	GLOSSY BUCKTHORN
ROSBLA	*Rosa blanda*	0.94	0.43	0.69	0.07	0.14	0.10	4	3	FACU	Shrub	EARLY WILD ROSE
ROSCAR	*Rosa carolina*	0.65	0.22	0.43	1.39	1.13	1.26	4	4	FACU-	Shrub	PASTURE ROSE
ROSMUL	*Rosa multiflora*	0.35	0.28	0.32	0.07	0.03	0.05	0	3	FACU	Shrub	JAPANESE ROSE
RUBFLA	*Rubus flagellaris*	0.18	0.08	0.13	0.21	0.41	0.31	2	4	FACU-	Shrub	COMMON DEWBERRY
RUBOCC	*Rubus occidentalis*	1.18	0.73	0.96	0.14	0.17	0.15	2	3	FACU	Shrub	BLACK RASPBERRY
RUBPEN	*Rubus pensilvanicus*	1.35	0.39	0.87	1.46	1.41	1.43	2	1	FAC-	Shrub	YANKEE BLACKBERRY
RUDHIR	*Rudbeckia hirta*	1.29	0.41	0.85	2.09	0.46	1.28	2	3	FACU	P-Forb	BLACK-EYED SUSAN
SANCAS	*Sanicula canadensis*	0.06	0.01	0.03	0.28	0.02	0.15	4	2	FACU+	B-Forb	CANADIAN BLACK SNAKEROOT
SCHSCO	*Schizachyrium scoparium*	0.06	0.04	0.05	1.18	5.99	3.59	5	4	FACU-	C4 Grass	LITTLE BLUESTEM
SCIPEN	*Scirpus pendulus*	0.24	0.02	0.13	0.14	0.61	0.38	3	-5	OBL	P-Sedge	RED BULRUSH
SCULEO	*Scutellaria leonardii*	0.06	0.01	0.03	0.28	0.02	0.15	5	3	FACU	P-Forb	SMALL SKULLCAP
SENPAU	*Senecio paperculus*	0.12	0.01	0.06	0.28	0.02	0.15	3	-1	FAC+	P-Forb	BALSAM RAGWORT
SILINT	*Silphium integrifolium*	0.12	0.07	0.10	0.00	0.00	0.00	5	5	UPL	P-Forb	ROSIN WEED
SILTER	*Silphium terebinthinaceum*	0.00	0.00	0.00	0.97	3.36	2.17	4	1	FAC-	P-Forb	PRAIRIE DOCK
SISALB	*Sisyrinchium albidum*	0.12	0.01	0.06	0.56	0.11	0.33	4	3	FACU	P-Forb	COMMON BLUE-EYED GRASS
SISCAM	*Sisyrinchium campestre*	0.12	0.01	0.06	0.00	0.00	0.00	6	5	UPL	P-Forb	PRAIRIE BLUE-EYED GRASS
-	*Sisyrinchium sp sterile*	0.06	0.01	0.03	0.00	0.00	0.00	-	-	-	P-Forb	-
SMIECI	*Smilax ecirrhata*	0.18	0.05	0.11	0.07	0.00	0.04	5	5	UPL	P-Forb	UPRIGHT CARRION FLOWER
SOLDUL	*Solanum dulcamara*	0.12	0.01	0.06	0.00	0.00	0.00	0	0	FAC	W-Vine	BITTERSWEET NIGHTSHADE
SOLCAN	*Solidago canadensis*	1.76	0.92	1.34	1.67	1.41	1.54	1	3	FACU	P-Forb	CANADA GOLDENROD
SOLGIG	*Solidago gigantea*	0.35	0.50	0.43	0.21	1.06	0.63	3	-3	FACW	P-Forb	LATE GOLDENROD
SOLJUN	*Solidago juncea*	1.47	2.16	1.82	2.85	8.00	5.43	4	5	UPL	P-Forb	EARLY GOLDENROD
SOLMIS	*Solidago missouriensis*	0.53	0.45	0.49	0.83	0.53	0.68	4	5	UPL	P-Forb	MISSOURI GOLDENROD
SOLNEM	*Solidago nemoralis*	0.65	0.28	0.47	1.39	0.76	1.07	3	5	UPL	P-Forb	OLD FIELD GOLDENROD
SOLRIG	*Solidago rigida*	0.24	0.27	0.25	1.11	1.25	1.18	4	4	FACU-	P-Forb	RIGID GOLDENROD
SORNUT	*Sorghastrum nutans*	0.00	0.00	0.00	0.83	3.93	2.38	4	2	FACU+	C4 Grass	INDIAN GRASS
SPAPEC	*Spartina pectinata*	0.18	0.20	0.19	0.28	0.66	0.47	4	-4	FACW+	C4 Grass	PRAIRIE CORD GRASS
SPHOBO	*Sphenopholis intermedia*	0.18	0.08	0.13	0.21	0.06	0.13	5	0	FAC	C3 Grass	PRAIRIE WEDGE GRASS
SPIALB	*Spiraea alba*	0.12	0.01	0.06	0.00	0.00	0.00	6	-4	FACW+	Shrub	MEADOWSWEET
TAROFF	*Taraxicum officinale**	2.00	0.33	1.17	1.11	0.17	0.64	0	3	FACU	P-Forb	COMMON DANDELION

		Old Field			Prairie							
ACRONYM	**Species**	**Freq**	**Cover**	**%IV**	**Freq**	**cover**	**% IV**	**CC**	**WC**	**WET-NESS**	**PHYSIOG-NOMY**	**COMMON NAME**
THADAD	*Thalictrum dasycarpum*	0.06	0.04	0.05	0.21	0.04	0.12	5	-2	FACW-	P-Forb	PURPLE MEADOW RUE
TOXRAD	*Toxicodendron radicans*	0.35	0.31	0.33	0.00	0.00	0.00	1	3	FACU	W-Vine	POISON IVY
TRAOHI	*Tradescantia ohiensis*	0.24	0.09	0.16	0.21	0.01	0.11	3	2	FACU+	P-Forb	COMMON SPIDERWORT
TRIHYB	*Trifolium hybridum**	0.00	0.00	0.00	0.07	0.03	0.05	0	1	FAC-	P-Forb N2	ALSIKE CLOVER
TRIPRA	*Trifolium pratense**	0.00	0.00	0.00	0.07	0.00	0.04	0	2	FACU+	P-Forb N2	RED CLOVER
TRIREP	*Trifolium repens**	0.18	0.02	0.10	0.14	0.14	0.14	0	2	FACU+	P-Forb N2	WHITE CLOVER
TYPANG	*Typha angustifolia**	0.06	0.04	0.05	0.00	0.00	0.00	0	-5	OBL	P-Forb	NARROW-LEAVED CATTAIL
ULMAME	*Ulmus americana*	0.06	0.01	0.03	0.28	0.15	0.22	5	-2	FACW-	Tree	AMERICAN ELM
VERVIM	*Veronicastrum virginicum*	0.12	0.01	0.06	0.00	0.00	0.00	6	0	FAC	P-Forb	CULVER'S ROOT
VIBLEN	*Viburnum lentago*	1.65	1.71	1.68	0.56	0.38	0.47	4	-1	FAC+	Shrub	NANNYBERRY
VIBOPU	*Viburnum opalus*	0.41	0.14	0.27	0.07	0.00	0.04	0	0	FAC	Shrub	EUROPEAN HIGH-BUSH CRANBERRY
VIBPRU	*Viburnum prunifolium*	0.18	0.26	0.22	0.00	0.00	0.00	4	3	FACU	Shrub	BLACK HAW
VIBREC	*Viburnum recognitum*	0.18	0.05	0.11	0.21	0.04	0.12	6	-2	FACW-	Shrub	SMOOTH ARROWWOOD
VICAME	*Vicia americana*	0.00	0.00	0.00	0.49	0.15	0.32	6	5	UPL	P-Forb	AMERICAN VETCH
VIOPEF	*Viola peditifida*	0.24	0.09	0.16	0.90	0.11	0.51	9	4	FACU-	P-Forb	PRAIRIE VIOLET
VIOPRA	*Viola pratincola*	2.29	0.70	1.50	1.60	0.34	0.97	1	0	FAC	P-Forb	COMMON BLUE VIOLET
VIOSOR	*Viola sororia*	0.35	0.10	0.23	0.00	0.00	0.00	3	1	FAC-	P-Forb	WOOLLY BLUE VIOLET
VITRIP	*Vitis riparia*	3.24	1.18	2.21	1.32	0.23	0.77	2	-2	FACW-	Vine	RIVERVBANK GRAPE
ZANAME	*Zanthoxylum americanum*	0.00	0.00	0.00	0.21	1.07	0.64	4	5	UPL	Shrub	PRICKLY ASH
ZIZAPT	*Zizia aptera*	0.71	0.23	0.47	0.76	0.56	0.66	9	3	FACU	P-Forb	HEART-LEAVED MEADOW PARSNIP
ZIZAUR	*Zizia aurea*	0.24	0.06	0.15	0.28	1.09	0.68	6	-1	FAC+	P-Forb	GOLDEN ALEXANDERS
		100	100		99	99						