

EVALUATION OF SHRUB REMOVAL EFFECTS ON UNDERSTORY RICHNESS AND DIVERSITY IN A
NATIVE GRASSLAND

BY

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THESIS

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Abstract

Tallgrass prairie is a highly endangered ecosystem in North America, and woody plant encroachment is one of the leading stressors facing prairie remnants. Insights into factors that predict vulnerability and resistance to invasion and information concerning the most effective treatment combinations are needed to preserve and restore remaining remnants. The study site, located in Lake County, Illinois, is an approximately 65 ha matrix of native tallgrass prairie and old field habitats that underwent treatment for wide-spread and intensive shrub encroachment in 2010. The study questions were: (1) How does shrub removal affect plant communities, both in terms of the vegetation parameters and the community trajectories, (2) Is there a legacy effect of buckthorn (*Rhamnus cathartica*) on plant community recovery, and (3) Does the intensity or composition of shrub re-invasion vary across soil moisture gradients? Data were collected on both ground layer and overstory composition and structure across 44 sampling plots in three community types (high-quality reference prairie, disturbed prairie referred to as transect prairie and old field) and span a total of 6 years, with a baseline sample before treatment and 4-5 years of post-treatment data, depending on the plot. In 2013, 5 plots were also added in a patch of shrub-encroached prairie adjacent to the site to serve as an approximation of untreated control for future monitoring. Restoration progress was evaluated using metrics of diversity and habitat quality, and restoration goals included convergence between the lower-quality habitat types (old field and transect prairie) and the reference prairie over time.

Overall, the response following treatment was somewhat ambiguous. Profile analysis revealed significantly non-parallel trajectories by community type, and significant overall

change regardless of community type, but definitive evidence of restoration progress, particularly among the transect prairie and old field community types, has not yet appeared. Reference prairie has remained fairly stable and high-quality, possibly due to the fact that it received the least intensive treatment. Transect prairie and old field community types, on the other hand, showed undesirable responses in several variables immediately following treatment (e.g., increases in non-native species richness and density and decreases in mean C and FQI) followed by moderating trends over the course of the study that, by 2014, returned to levels similar to baseline measurements. These trajectories combined with amalgamative grouping of the 2014 data indicate that old field and transect prairie may be converging with one another rather than reference prairie. The early fluctuations in trajectories and the apparent convergence of old field and transect prairie likely result from disturbance due to management activities as well as seeding activities. Generally desirable trends following initial decreases (notably FQI, percent bare ground, percent cover native species richness and native species density) imply that plots have recovered from initial stressors due to management action, but it will likely take several more years of subsequent monitoring to determine whether the old field and transect prairie communities continue to recover.

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1. Introduction

1.1 Study System

Once the most expansive ecosystem in North America, tallgrass prairie has undergone what may be the fastest and most thorough decline of any ecosystem. This is particularly true in Illinois, where most of the prairie area has been converted to agricultural uses. Only 0.013% of the estimated original area of prairie remains in a relatively undegraded condition (Taft et al. 2009). The wide-scale habitat loss and degradation has left remaining patches that tend to be small and isolated fragments, rendering them vulnerable to invasion by ruderal native and non-native species. Vigilant management action is required to protect and sustain remnants.

Woody plant encroachment has been observed in grasslands and savannahs worldwide as one of the most urgent grassland stressors (Archer et al. 1995; Briggs et al. 2005; Price & Morgan 2008) and is a chronic problem in Illinois prairie remnants. Several causes for the increasing rates of invasion by woody species have been suggested, including increased grazing intensity (Brown & Archer 1999; Van Auken 2000), alterations in burning regime (Bragg & Hulbert 1976; Lett & Knapp 2005), and altered climatic conditions (Archer et al. 1995). Once the woody plant community begins to establish, it is capable of altering understory conditions through shading (Köchy & Wilson 2000; Lett & Knapp 2003; Brantley & Young 2007), changes in soil nutrient dynamics and soil moisture (Köchy & Wilson 2000) and increasing the thickness of the litter layer (Lett & Knapp 2003; Price & Morgan 2008). The resulting alterations in soil conditions can favor woody plant encroachment, creating a positive feedback that accelerates the rate of invasion (Schlesinger et al. 1990). Increasing woody plant dominance and resulting shifts in the microclimate can suppress understory vegetation (Köchy & Wilson 2000),

decreasing understory species richness and net primary productivity (Lett & Knapp 2005; Price & Morgan 2008; Mason et al. 2009).

Removal of the woody plant canopy has been shown to increase native species richness and productivity in some cases (Lett & Knapp 2003). However, once established, removal of thickets can be difficult and time consuming. Though burning can be an effective preventative measure (Bragg & Hulbert 1976; Briggs et al. 2005), burning established thickets can be ineffective and even accelerate the rate of invasion (Heisler et al. 2004; Briggs et al. 2005). More intensive management, such as mechanical removal, herbicide application and frequent burning is required, and even when intensive management is applied, success may still be limited (Briggs et al. 2005; Lett & Knapp 2005; Bowles & Jones 2013).

The ineffectiveness of traditional management methods may indicate that prairies heavily encroached by woody plants may constitute an alternate stable state. Alternate stable states can be initiated when novel combinations of disturbances or high intensities of disturbance, such as intensive woody plant encroachment, cause an ecosystem to cross a threshold into a persistent disturbed state (Suding et al. 2004). Once the threshold is crossed, the alternate stable state is maintained by new conditions or processes such as resource limitations or positive feedbacks. Because the state is self-stabilizing, removal of the original stressor is often not sufficient for restoration and additional, often intensive, management is required for restoration success (Hobbs & Norton 1996; Suding et al. 2004; Firn et al. 2010). If woody plant encroachment is a self-stabilizing state, restoration of heavily woody plant encroached prairies may be so demanding of time and resources that it is infeasible in some

cases. Further detailed study is needed to recognize factors that predict vulnerability and resistance to invasion and to identify whether restoration can be achieved following removal of woody plants in heavily encroached grassland. With information on the recovery potential of even heavily encroached grassland, managers could prioritize activities to apply treatment where it will be most effective. An opportunity to evaluate the restoration potential of heavily woody plant encroached grassland habitats exists at the North Chicago Wetland Mitigation Site in Lake County, Illinois where a long-term study has been in progress since 2009.

1.2 Study Site and Previous Work

1.2.1 Site Description

The study was conducted at the North Chicago Wetland Mitigation site in Lake County, Illinois (42.30104N, 87.88278W). The study site is a mitigation bank owned by the Illinois Tollway and Illinois Department of Transportation, and is embedded in an urban matrix, with a state highway (Illinois 137) along the northern border (Figure 1) and housing developments and industrial parks on all other sides. The site extends 1,582 m from north to south and 424 m from east to west and totals approximately 65 ha in size. Habitats present include prairie, old field, and wetlands, with patches of high-quality prairie at the south end of the site (Figure 2).

The site was selected as a good candidate for restoration after an initial survey in the 1990s (Taft 1996). The survey found high densities of woody plants, but also identified several patches of high-quality wetland and prairie (Figure 2). The original survey identified 324 species of vascular plants, including three state threatened plant species (*Elymus trachycaulus*,

Oenothera perennis, and *Veronica scutellata*), persisting primarily in local openings in the shrub canopy (Taft 1996). Later surveys estimated the total shrub-sapling density at about 20,000 stems per hectare prior to restoration (Taft et al. 2010). Though trees and saplings were present in the canopy, the woody plant encroachment was dominated by shrub species, and will be referred to as 'shrub encroachment' in the following sections.

1.2.2 Site History

According to the General Land Office (GLO) Public Land Survey notes from 1837-1840, the area was originally composed mainly of prairie with patches of wet prairie, marsh and savanna. Aerial photography from 1967 shows the northern half of the site was used for cultivation with some areas in pasture. Pasturing likely extended through most of the southern half of the site (Taft 1996; Taft 2006). Cultivation ceased in 1970, allowing first prairie species and then woody plants to spread throughout the area.

1.2.3 Climate

The climate in Lake County is continental, with warm summers and cold winters. Precipitation and temperature data from a station at the Chicago Waukegan Regional Airport (9 miles north of the study site) shows an average yearly precipitation of 86.1 cm for the last 14 years, with the greatest amount of precipitation in June (average 10.5 cm) and the least in January (average 2.9 cm). Mean annual temperature is 48 °F, with the highest mean in July (71.5 °F) and the coolest mean in January (23.1 °F) (Midwest Regional Climate Center 2014).

1.2.4 Previous Work

Management and data collection at the North Chicago Wetland Mitigation Site had been progressing for several years before the advent of this study in 2013. The baseline data

were collected during the summer of 2009, and performance standards were established at the beginning of the study in the original contract. Performance standards relevant to this project included the following:

- Dominant species at the site should not include non-native *Rhamnus* spp. at the end of the five-year monitoring period. If still present at the end of the study, relative cover of *Rhamnus* spp. should trend downwards
- Planted prairie species (grasses and forbs) within the designated upland buffers should exceed an overall percent cover of 75% by the end of the five-year monitoring period
- Floristic quality should trend upward over the course of the five-year monitoring period

Shrub removal treatment commenced during the dormant season 2010 and continued through the summer. Restoration efforts included mechanical removal of shrubs and trees (most notably *Rhamnus cathartica**, *Cornus racemosa*, *Viburnum lentago*, and various *Crataegus* species [non-native species are denoted with an *]), localized seeding, erosion prevention, mowing, and limited applications of fire (Taft et al. 2013). Yearly surveys have occurred each summer from 2009 through 2014 and have included quadrat sampling of ground-layer vegetation, canopy cover measurements and stem counts of shrubs by species. Plots were initially divided into terrestrial and wetland classifications. The wetlands were monitored by a separate research group and were not included in this study. More detail on the treatment methods and sampling protocol can be found in the Methods (Section 2).

Community types were distinguished from baseline species abundance data recorded from permanent sample plots using hierarchical cluster analysis (Taft et al. 2010). Two main cluster groups were identified including prairie (n = 15) and old field (n = 29). Further comparisons of vegetation parameters revealed two distinct groupings within the prairie class. Analysis of vegetation parameters showed that the prairie plots located along stratified

transects were significantly lower-quality than the prairie at the southern end of the site. Furthermore, analysis of vegetation parameters also revealed that the high-quality prairie qualified as grade B prairie based on criteria used by the Illinois Natural Areas Inventory (White 1978) and use of Floristic Quality Assessment (Taft et al. 1997). Due to these distinctions, the prairie class was divided into two groups. The high-quality prairie was designated as the restoration target for the site, and referred to as reference prairie. The lower-quality prairie on transects was referred to as transect prairie, due to the location. These categories differed in measures of species richness, diversity, and habitat quality and have been used to track changes in vegetation parameters and assess restoration success over the course of the study.

1.3 Study Questions and Predictions

1.3.1 Treatment Effects on Community Types

The main objective of this study was to evaluate the effects of shrub removal on the trajectory of plant community parameters (e.g., structure, composition, and diversity), assess the degree of ecological recovery in the three community types from 2009 to 2014, and examine whether any community types have fallen into alternate stable states. Information on how the different community types respond to treatment could help managers assess restoration potential and apply treatments where they will be most effective in future.

Question 1- How does shrub removal affect the plant community, both in terms of the vegetation parameters and the community trajectories? Does the transect prairie show signs of convergence with the reference prairie?

Prediction- If competition for light is a major factor in understory suppression, shrub removal should reduce direct competition for light and cause changes in vegetation parameters of the treatment plots relating to structure, composition, and diversity. Furthermore, plots containing more prairie plants (greater native species richness and density) in the baseline data should meet restoration goals more rapidly than plots that experienced greater understory suppression due to shrub encroachment. This would be reflected by the different community types producing distinct recovery trajectories. I predict that transect prairie plots will display stronger signs of convergence with reference prairie than the old field plots.

1.3.2 Testing for Buckthorn Legacy Effect

The high abundance of buckthorn in the baseline data could have a significant effect on recovery trajectories. Buckthorn (*Rhamnus cathartica**) is highly invasive in the Midwest (Kurylo & Endress 2012), and has a variety of adaptations that allow it to achieve a competitive advantage over native species. These adaptations include prolific reproduction, tolerance of a wide range of habitat types, and the ability to produce dense shade and alter soil conditions (Heneghan et al. 2006; Knight et al. 2007; Klionsky et al. 2011; Kurylo & Endress 2012). It has been suggested that some of the resulting changes in soil conditions or processes may have a lingering effect that can suppress other species even after the buckthorn has been removed, though the mechanism remains unclear (Heneghan et al. 2006; Klionsky et al. 2011). In order to explore this phenomenon, a secondary goal of the study was to determine if baseline buckthorn abundance was a good predictor of recovery potential. If baseline buckthorn abundance is a factor in recovery potential of buckthorn-encroached sites, managers could use buckthorn abundance data to identify areas where treatment would be most effective.

Question 2- Is there a legacy effect of buckthorn on plant community recovery?

Prediction- I predict that plots that had the greatest abundance (measured using stem counts) of buckthorn in the baseline data will show delayed or incomplete recovery relative to plots with lower baseline buckthorn abundance.

1.3.3 Relationship between Soil Moisture and Shrub Regrowth

Observations in the baseline data indicated less shrub encroachment occurred in the wetland compared to the upland plots (Taft et al. 2010), and previous studies have suggested that shrub germination can be suppressed if soil remains saturated for an extended period of time (Archer et al. 1995; Knight et al. 2007; Kurylo & Endress 2012). Baseline surveys did not include measurements of soil moisture, making pre- and post-treatment comparisons infeasible. However, the site does provide a variety of terrestrial habitat types that may represent a variety of different moisture conditions. Soil moisture characteristics were measured using soil magnetic susceptibility as a proxy (Grimley et al. 2004; Grimley et al. 2008), described in the methods section, and compared to shrub data to evaluate differences in shrub regeneration following treatment. If soil moisture is associated with different rates of shrub regeneration, managers could use soil moisture to identify areas that might need more vigilant management to prevent shrub reestablishment.

Question 3- Does the intensity or composition of shrub re-invasion vary across soil moisture gradients?

Prediction- I predict that soil moisture will be negatively correlated with the degree of post-treatment shrub regeneration.

2. Methods

2.1 Site Management Prior to 2013

Management was provided by McGinty Brothers Inc. Shrub removals occurred throughout the site in 2010. Stumps were treated with an herbicide (Roundup Pro or an equivalent) after they were cut to prevent resprouting. Treatment varied slightly by habitat type in order to minimize disturbance in the high-quality reference prairie. In old field and transect prairie communities, a compact track loader was used to remove cut shrubs, while shrubs were removed from reference prairie by hand. Brush was piled in concentrated areas around the site and burned. To encourage the growth of native species, the site was seeded with native seed mixes during the dormant season. Subsequently, transect prairie and old field portions of the site were covered with several inches of straw and seeded with a cover crop (*Lolium multiflorum**) to prevent erosion following shrub removal. The old field and transect prairie portions of the site were mowed once yearly during the growing season from 2010-2012 in an attempt to provide light to seedlings and suppressed prairie plants. Managed burns were conducted in the non-wetland areas of the site in 2012, 2013, and 2014 during the dormant season to reduce non-native species and aid the establishment of prairie plants.

2.2 Sampling Design

2.2.1 Vegetation Sampling Design

The baseline vegetation sample data were recorded in 2009 prior to shrub removal and established the methodology of the study. Protocols have remained the same through 2014.

The study site was sampled with 10 parallel, east-west transects spaced 152 m apart and stratified from north to south across the site (Figure 2). Each transect includes five sampling plots separated by 76m, except the north-most transect which has four plots due to a fire station located at the northwest corner of the property. This distribution provided 49 sampling plots, 37 of which occur in upland habitats while the remaining 12 were classified as wetland habitat. The wetland plots were monitored by a separate research group and were not included in this study. Seven additional terrestrial plots were established in high-quality prairie in the southeastern portion of the study site, distinguished based on criteria used by the Illinois Natural Areas Inventory (White 1978) and use of Floristic Quality Assessment (Taft et al. 1997). These plots, identified as a separate prairie subgroup in cluster analysis, provide a restoration target for prairie habitat at the study site, and are referred to as reference prairie.

In addition to the established plots, five more sample units were added during the 2013 field season to provide untreated control plots for the vegetation monitoring program. Though it would have been desirable to have established the control plots during the initial survey, the need of contracting agencies to maximize total restored acreage outweighed the need for improved experimental design; consequently, the entire property was treated during the restoration program. Control plots were established just east of the property boundary (Figure 2) in 2013 to serve as an approximation of untreated baseline conditions, primarily for the benefit of long-term monitoring.

The general area containing the control plots was identified in initial surveys as consisting of high-quality prairie (Taft et al. 2010), but because it is outside the property

boundary, the area was not treated for shrub encroachment. The area was located and 12 GPS points were taken in openings with varying community composition. Five of these 12 points were selected randomly and were used to provide a basis of comparison to the treated sites. With the addition of these control plots there are a total of 49 non-wetland sampling plots throughout the site (Figure 2).

Sample plots were 5 x 5m (25m²) with borders oriented along cardinal directions. In order to ensure accurate resampling, plots were marked with metal posts and geo-referenced with GPS (Ashtech MobilMapper 100) to the southwest corner of each plot. Composition and stem counts for all woody stems greater than one meter tall with a diameter at breast height (DBH) less than 10cm were recorded within each plot. Canopy cover was estimated with the use of digital photography. Photographs of the canopy were taken from the center of the plot using a hemi-view lens. In order to minimize interference from ground-layer vegetation, the camera was elevated on a tripod 45 cm above the ground. The images were then imported to HemiView Canopy Analysis Software, ver. 2.1 to calculate leaf area index and percent visible sky. Percent canopy cover was calculated as 100 - % visible sky. Trees (woody stems ≥ 10 cm dbh) were sampled within a 200 m² plot anchored at the same corner as the 25m² plot (Taft et al. 2010).

Ground layer vegetation was sampled with three 1 x 1m (1m²) quadrats nested within each shrub plot, placed at the southwest corner, northeast corner and center of each 25m² plot. Data recorded for each quadrat consisted of species presence and estimated percent cover for each species measured with a modified Daubenmire cover-class scale (0-1 %, 1-5%, 5-

25%, 25-50%, 50-75%, 75-95%, 95-100%) and included woody species <1m tall. These measurements were employed to calculate parameters used to characterize vegetation structure and habitat quality, including native and non-native species richness, Shannon-Weiner Index of Diversity, Simpson's Index of Dominance, percent vegetative cover, percent bare ground, and measurements for Floristic Quality Assessment (FQA) including Mean Coefficient of Conservatism and Floristic Quality Index (Taft et al. 1997; Taft et al. 2010). More detail on the calculation of these parameters can be found in Section 2.3.1. Vegetation sampling occurred yearly from 2009 to 2014 with data recorded from mid-June to mid-July, with control plots sampled in late July.

2.2.2 Soil Moisture Sampling and Analysis

Soil moisture for each plot was approximated using Soil Magnetic Susceptibility (SMS). SMS generally measures the concentration ferrimagnetic soil minerals such as magnetite and maghemite through the application of a magnetic field and the measured response (Grimley & Vepraskas 2000; Grimley et al. 2004). As soil moisture increases, anaerobic and reducing conditions are created. This causes iron reduction and enhanced dissolution of ferrimagnetic minerals, likely facilitated with iron reducing bacteria, thereby lowering the concentration of strongly magnetic minerals. When measured across a site, SMS can be used as a proxy or an approximation of long-term soil moisture, assuming other factors such as parent material and disturbance remain constant (Grimley & Vepraskas 2000; Grimley et al. 2004). Previous studies have successfully used SMS as a way to quantify the hydric tolerances of tree species (Grimley et al. 2008).

In order to measure the relationship between SMS and patterns of shrub abundance, soil samples were taken adjacent to each 1m² quadrat during the 2014 field season. Soil samples were air dried for a minimum of 7 days, ground with a mortar and pestle and sifted with a <2mm sieve. The mass of each sample was measured and recorded in grams, and SMS was measured in small plastic cubes with a Barington MS2 magnetic susceptibility meter with a MS2B attachment. Two SMS measurements were taken for each sample, and the results were averaged. Mass-based magnetic susceptibility was calculated using the formula $\left(\frac{\text{Average MS} \times 10}{\text{Mass}}\right)$ and reported in units of 10⁻⁸ m³/kg. Plot values for SMS were calculated by averaging the values for the 3 quadrats.

2.3 Data Analysis

2.3.1 Data Preparation

Vegetation parameters selected for this study were calculated both at the quadrat scale for ground layer vegetation and at the plot scale for woody overstory. Quadrat-level data are presented as averages from all three quadrats in a plot or, in the case of species richness, as the total for all three quadrats. Vegetation parameters are defined as follows (Whittaker 1975; Taft et al. 2010):

Ground Layer Vegetation Diversity Measures

- **Native Species Density:** Mean number of native species/quadrat (1 m²)
- **Non-Native Species Density:** Mean number of non-native species/quadrat (1 m²)
- **Native Species Richness:** Total number of native species/plot (sum of three quadrats)

- **Non-native Species Richness:** Total number of non-native species/plot (sum of three quadrats)
- **Shannon-Wiener Index of Diversity (H')**: $-\sum [p_i \ln(p_i)]$, where p_i is the relative abundance of each native species (based on importance values [IV200] calculated as the sum of relative cover and relative frequency)
- **Simpson's Dominance Index:** $\sum p_i^2$, where p_i is the relative importance value for each species in the sample area

Ground Layer Structure

- **Percent Cover:** Sum cover for each species in sample area
- **Percent Bare Ground:** Estimate of bare ground for each quadrat

Floristic Quality Assessment (using ground-layer vegetation data)

- **Mean Coefficient of Conservatism (Mean C):** $\sum CC/S$, where CC = Coefficient of Conservatism and S = total species richness
- **Floristic Quality Index (FQI):** Mean C($\sqrt{N}$) where N = native species richness

Shrub-Sapling Layer

- **Shrub Density:** Total stem number per plot (sum of all species)
- **Shrub Canopy Cover:** 100 - % visible sky, as determined from analysis of digital canopy photos with Hemi-View Canopy Analysis Software (ver. 2.1).
- **Leaf Area Index (LAI):** The amount of leaf surface area per unit ground area as determined from analysis of digital canopy photos with Hemi-View Canopy Analysis Software (ver. 2.1).

Data were initially entered into Microsoft Excel (Microsoft Excel 2010) for preliminary calculations of vegetation parameters and to create matrices for statistical software. PCORD (ver. 5) was used to obtain the Shannon-Weiner Index of Diversity and Simpson's Dominance Index, and Minitab 17 was used for normality tests and data transformation. SPSS (IBM SPSS Statistics 22) was used for statistical analysis including regression analysis, mean comparisons of vegetation parameters among habitat types (reference prairie, transect prairie and old field), and repeated measures analysis of variance (RM-ANOVA). Several transformations were attempted for data failing normality tests, including square root, natural log, log 10 and the BoxCox transformation to obtain residual distributions without strong kurtosis or skew. Data

transformations were not always successful, however, and in some instances untransformed data were analyzed using non-parametric tests (e.g. Wilcoxon Signed-Ranks test, Kruskal-Wallis test and Friedman's test). These instances are noted in the tables.

Previous analysis of the baseline data showed that Leaf Area Index (LAI) and percent canopy cover explained more variance in the understory parameters than stem density, with LAI explaining slightly more variance than percent canopy cover (Taft & Kron 2014). In order to remain consistent, LAI was used as the primary measure of shrub encroachment.

2.3.2 Question 1: Plot Response and Changes in Vegetation Parameters

Comparisons of various parameters of the 2014 sampling data to the baseline (2009) data were made using paired t-tests. Non-normal data that could not be successfully transformed were analyzed using the related-samples Wilcoxon Signed Ranks test. The null expectation for both sets of tests was no change in vegetation parameters over time.

Mean comparisons of 2014 sample data among the three habitat types (reference prairie, transect prairie and old field) and the control plots were made with one-way ANOVA. Planned pairwise comparisons among habitat types were made with Tukey's highly significant difference test when data met assumptions of equal variance, which was assessed using Levine's test. Data that failed Levine's test were analyzed using Dunnett's T3 test.

Change in individual vegetation parameters from 2009 to 2014 for each community type was assessed using one-way repeated measures analysis of variance (one-way RM-ANOVA). RM-ANOVA has two basic assumptions. The first requires homogeneity of variance, meaning that the covariance of the vegetation parameters (the dependent variables) should be equal.

The second is sphaericality of the data, meaning that within-subject variances, in this case years, should be equal to one another. Homogeneity of variance was tested with Box's Test of Equality of Covariance Matrices. Data that failed Box's test were analyzed using Pillai's Trace, a multivariate statistic that is robust to most violations of homogeneity of variance. Data that failed Mauchly's test of sphaericality were analyzed using Greenhouse-Geisser adjustment to the degrees of freedom. Non-normal data were analyzed using the Friedman's test, a non-parametric test used to detect differences among groups over time.

The trajectory of the response curves between vegetation types over time was examined with profile analysis (VonEnde 1993), a procedure suited to analyzing repeated measures utilizing both univariate (ANOVA) and multivariate (MANOVA) tests. The primary objective of profile analysis is a test of the parallelism hypothesis, and in this study, the null expectation is no difference in slope (i.e., a parallel response) over time for vegetation types. The test of parallelism can be followed by a test of the within-subject factor (time [i.e., year]) in a test of the flatness hypothesis, combining the between-subjects factor, with the null expectation of no change over time. These are priority tests of convergence because trajectories must demonstrate significant change over time and be non-parallel for plots to converge.

In addition to testing data on vegetation parameters, data on composition were used to reexamine the community classifications of each plot. Plot community types originally were determined via cluster analysis, using the Sørensen similarity distance measure and flexible Beta linkage method where $\beta = -0.25$ (Taft et al. 2010). Plot community classifications were

reevaluated using the same method with 2014 data in order to assess whether any plots had shifted to a new or different community type. The null expectation was that there would be no re-alignment of plots according to community type. The 2009 data also were re-analyzed via cluster analysis along with the 2014 control plot data to determine whether the control plots were a suitable approximation of untreated baseline reference prairie.

2.3.3 Question 2: Is there a Legacy Effect of Buckthorn on Ground Layer Recovery?

In order to examine the possibility of buckthorn legacy effect, the interactions between baseline buckthorn abundance and subsequent changes in vegetation parameters (native and nonnative species richness and density, mean C, FQI, percent cover, percent bare ground, dominance and diversity) were examined with regression analysis using the difference between 2014 and baseline (2009) values against baseline buckthorn stem count. It is expected that plots with high baseline abundances of buckthorn will show smaller changes over time compared to plots with low baseline abundances of buckthorn. The null expectation is no association between baseline buckthorn stem counts and change in variables over time. Recovery was also compared to overall stem density regardless of species in order to test for confounding factors. In order to determine whether linear or quadratic regressions were appropriate, both techniques were applied. Interactions that showed an increase in R^2 with a quadratic function were subject to hierarchical multiple regression analysis to assess whether the quadratic model explained a significant amount of additional variance, in which case the quadratic function was used.

2.3.4 Question 3: Is the Degree of Shrub Regrowth Related to SMS?

In order to explore the relationship between patterns in shrub regrowth and SMS, data were examined using regression analysis to identify significant trends between 2014 SMS values and measures of shrub regrowth. Measurements of shrub regrowth included total shrub stem count, counts separated by individual shrub species for species that had more than a single occurrence in 2014, and measurements of Leaf Area Index (LAI). The null expectation was no relationship between SMS and measures of shrub regrowth. Mean SMS also was compared to quadrat mean Coefficient of Wetness (CW) in order to detect expected coincidence between the two measurements. Coefficient of Wetness is a measure of how likely it is for a given species of plant to be found growing in wet soils (Reed 1988).

3. Results

3.1 2014 Vegetation Survey Results

3.1.1 Summary Vegetation Description

A total of 231 species were identified during the 2014 sampling season in quadrat samples. This included 185 native species and 46 non-native species. Average species density per 1m² quadrat was 23.4, average percent bare ground was 10.7 and average percent cover was 173.9. Overall, dominant species of ground layer vegetation included *Rhamnus cathartica**, *Andropogon gerardii*, *Sorghastrum nutans*, *Fragaria virginiana*, *Solidago canadensis*, *Ratibida pinnata* and *Poa pratensis**. Combined, these species account for about 25% of the importance value of all species present at the site.

Dominant species varied by habitat type, but several species were dominant in both habitats. Top ten dominant species in the old field plots included *Solidago canadensis*, *Fragaria virginiana*, *Sorghastrum nutans*, *Ratibida pinnata*, *Cirsium arvense**, *Rhamnus cathartica**, *Andropogon gerardii*, *Dactylis glomerata**, *Helianthus grosseserratus* and *Poa compressa**. Top ten dominant species in the prairie (combining the reference prairie and the transect prairie) included *Sorghastrum nutans*, *Andropogon gerardii*, *Rhamnus cathartica**, *Schizachyrium scoparium*, *Poa pratensis**, *Fragaria virginiana*, *Parthenium integrifolium*, *Ratibida pinnata*, *Poa compressa**, and *Solidago juncea*.

3.1.2 Comparisons of Community Types

Significant within-subject differences were found among all 3 vegetation types and the control plots for native species density, native species richness, non-native species richness,

mean C, FQI, percent bare ground and LAI (Table 1). Measures of ground layer diversity were generally greatest in the reference prairie (native species density of 28.0, native species richness of 45.1) and lowest in transect prairie (density of 17.3, richness of 30.9) and old field (density of 15.1, richness of 27.8), with control plots ranked in between (density of 21.7, richness of 35.8). Non-native species richness was greatest in the transect prairie plots (11.1) and lowest in the reference prairie (7.6) and control plots (6.6), with the old field (9.6) falling in-between the groups. Measures of habitat quality showed slightly different patterns. Mean C was the greatest values in reference prairie (3.5), followed by the control plots (3.1), followed by transect prairie (2.1) and old field (2.0). FQI was greatest in the reference prairie (18.7) and control plots (14.3) and lower in transect prairie (8.6) and old field (7.9). There was almost no significant difference of shrub or vegetative cover between the habitat types except for LAI, which was greatest in the control plots (0.77) and lowest in the reference prairie (0.02), with old field (0.19) and transect prairie (0.08) falling in between.

3.2 Mean Comparisons of Vegetation Parameters Before and After Treatment

Significant increases were found in overall percent cover, non-native species density and non-native richness, and significant decreases were found in percent bare ground, Simpson's dominance and LAI between the 2009 baseline and 2014 (Table 2). Data divided by community types gives more insight into these changes, as community types showed unique responses in several categories: Old field showed significant increase in non-native species density, non-native species richness, and total percent cover and a decrease in percent bare ground (Table

3). Reference prairie had a significant decrease in percent cover. All community types showed a significant decrease in LAI over the course of the study. Transect prairie showed no other significant changes.

3.3 Vegetation Trends

Most parameters changed over time, and several showed distinctive trends by community type. For several parameters relating to ground layer species diversity and floristic quality, the three community types responded somewhat independently (Figure 3). Reference prairie remained relatively stable and distinct from the other community types in variables measuring diversity and quality, maintaining greater values (notably native species density and richness, diversity, mean C and FQI [Figure 3 A, C, G and H]) across the time frame of the study. In the same set of variables, transect prairie and old field communities fluctuated, with marked decreases immediately after shrub-removal treatment followed by moderating trends that reach pre-treatment levels by 2014. Non-native species density and richness showed a similar trend in the reference and transect prairie (Figure 3 B and D), increasing after treatment followed by fluctuations that reached near pre-treatment levels in 2014. Non-native species density and richness showed a rapid increase in the old field plots during the first several years of the study, followed by a mostly stable trajectory. Dominance remained low and changed little in the reference prairie, while old field and transect prairie varied widely (Figure 3 F). In old field, dominance increased initially followed by a steadily decreasing trend, while transect prairie oscillated over the course of the study but showed an overall increase by 2014. Overall,

parameters of percent cover, percent bare ground, and LAI were most dynamic (Figures 3 I, J and K). LAI showed large decreases in all community types following treatment and has remained fairly stable afterward. Old field and transect prairie showed initial increases in percent bare ground after treatment, followed by steady decreases while reference prairie remained stable. Percent bare ground showed an overall decrease in the old field, while the transect prairie recovered to pre-treatment levels by 2014. Percent cover generally decreased in reference prairie, and increased in transect prairie and old field, with community types approaching similar values over the course of the study.

When parameters were examined by community type across the 6 years of monitoring, significant differences were observed in at least one community type for every vegetation parameter tested (RM-ANOVA in Table 4). In tests of parallelism comparing trends among community types, the null hypothesis was rejected for all variables except mean C, Simpson's Dominance and Shannon-Weiner Diversity (Table 5), indicating that vegetation types had distinct trajectories in most parameters. The null flatness hypothesis was rejected for every variable except non-native species density and native species richness (Table 5), indicating that without regard to community type most variables had non-neutral trajectories over time.

3.4 Reevaluation of Community Types

Amalgamative grouping was reexamined with cluster analysis using 2014 species abundance data to determine whether original community type classifications for individual plots remained consistent, or whether plots were shifting between classifications in predictable

patterns. Cluster analysis produced two major groupings, one comprised entirely of five reference plots and the other of all remaining plots (Figure 4). The second group was divided into two major subgroups composed mainly of the transect prairie and old field plots, though one group also included two reference prairie plots. The group including two reference prairie plots also included ten plots formerly classified as old field (Table 6). The second subgroup included all eight former transect prairie plots and nineteen former old field plots. Comparisons of vegetation parameters between the two groups showed that they were similar in most measures and had lower native species richness and density, mean C, percent cover and diversity, and higher dominance, percent bare ground and LAI than the reference plots (Table 7).

In addition to reevaluating 2014 community types, 2014 species composition data from the control plots were also used to compare the control plots to the baseline data in order to evaluate the use of the control plots as an approximation of untreated baseline data. There were two notable patterns in the resulting dendrogram: all of the control plots were placed in the same group as the reference prairie, and there was some reclassification of transect prairie and old field plots into either the reference prairie group or two new subgroups (Figure 5). Further comparisons of parameters of diversity, richness and FQA via 1-way ANOVA revealed that, in these parameters, the control plots were intermediate between the reference prairie and other community types.

3.5 Effects of Buckthorn Legacy and Soil Moisture

3.5.1 Does Buckthorn Legacy Effect Play a Role in Ground Layer Recovery?

At the time of the baseline survey, shrub density averaged 58.5 stems per plot (25-m²); buckthorn was present in every plot and made up 52.8% of the stems, but there was wide variance in stem density and buckthorn abundance (Figure 6). To explore any possible legacy effect corresponding to background levels of buckthorn, baseline buckthorn abundance (stems/plot) was compared to the total degree of change among dependent variables between 2009 and 2014 (Table 3). No association was found between the baseline buckthorn abundance and response over time following shrub removal for any of the ground layer variables. The change in percent bare ground produced the highest level of explained variance ($R^2=0.077$), but the interaction was not significant (Table 8). Response over time was also compared to total baseline shrub abundance in order to test for an association between treatment intensity and recovery, with no significant results.

3.5.2 Is there a Relationship Between Soil Magnetic Susceptibility and Shrub Regrowth?

SMS values ranged from $21 \times 10^{-8} \text{m}^3/\text{kg}$ to $67 \times 10^{-8} \text{m}^3/\text{kg}$. There was some difference among habitat types, as control plots had a significantly higher average SMS ($56 \times 10^{-8} \text{m}^3/\text{kg}$), than the transect prairie ($37 \times 10^{-8} \text{m}^3/\text{kg}$) and old field ($39 \times 10^{-8} \text{m}^3/\text{kg}$), with reference prairie falling in between ($47 \times 10^{-8} \text{m}^3/\text{kg}$ [Table 1]). No association was found between SMS measurements and shrub regrowth. Stem abundance of buckthorn in 2014 was the variable most closely associated with SMS, but the association was not strong ($R^2=0.030$, $P=0.235$, see Table 9). However, the plot mean CW was weakly correlated with SMS ($R^2=0.154$, $P<0.001$; Figure 7).

4. Discussion

4.1 Evidence of Convergence

4.1.1. Post-Treatment Response

Based on the current data set, it is not possible to conclusively determine whether the transect prairie and old field communities are in the early stages of the desired convergence with reference prairie (growing more similar in measures of interest), or whether they have been suspended in an alternate stable state. Many variables showed pronounced changes immediately after shrub removal, followed by moderating trends and 2014 values that are statistically similar to pre-treatment measurements taken in 2009. Transect prairie and old field remain distinct from reference prairie in most measures of plant community quality, though transect prairie and old field have grown similar in many measures. This could indicate convergence between the old field and transect prairie, which is not a desired restoration outcome. However, there is some reason for optimism within the current dataset. The variables that did show significant change between 2009 and 2014 in multiple habitat types (LAI and percent ground cover), display trajectories where transect prairie and old field appear to converge with reference prairie. It is possible that recovery trends in variables related to species richness, diversity and habitat quality were initially delayed by disturbance due to management efforts, a prospect that is explored more fully in the following section, and that the moderating trends following the initial declines may be the beginning of recovery trajectories in those variables.

The difficulty of determining restoration success in a prairie restoration on such a relatively short timescale (5 years for most plots) has been noted in several studies of grassland

restorations. It has been suggested that typical monitoring periods may be too short-term to detect signs of recovery, and longer monitoring periods have been recommended, from greater than 5 years to greater than 10 (Brye et al. 2002; Smith et al. 2003). Results from a 21-year study of a prairie restoration noted “unsettling” disparities between the first and second decade of post-restoration data from the same site (Howe 2011), suggesting that even longer timescales might be necessary. A long-term study on calcareous grasslands suggested that recovery might take more than 60 years (Fagan et al. 2008). Compared to the length of these studies, 4-to-5 years is a fairly brief monitoring period, and may be insufficient to reveal clear evidence of restoration.

The issue of insufficient timescale is also relevant to the identification of alternate stable states. The current lack of treatment success is consistent with previous studies which have found it extremely difficult to disrupt an established shrub-dominated state (Briggs et al. 2005; Lett & Knapp 2005). Though removal efforts may yield some improvements (Lett & Knapp 2003; Lett & Knapp 2005), areas with higher densities of shrubs (such as the centers of shrub islands) can be more difficult to restore (Lett & Knapp 2005). This resistance to traditional management strategies is consistent with descriptions of alternate stable states (Hobbs & Norton 1996; Suding et al. 2004; Firn et al. 2010). Studies of similar grassland-to-shrubland transitions in the Southwest United States have already suggested arid grassland and shrubland are alternate stable states (Bestelmeyer et al. 2009; D’Odorico et al. 2012; He et al. 2015). It is entirely possible that the more heavily disturbed portions of the site have undergone a similar transition, but only continued monitoring will tell. Distinguishing between these two outcomes will be crucial to future restoration efforts. It is possible that traditional management strategies

simply are not effective past a threshold level of shrub encroachment, and new methods must be developed to trigger an effective transition back to a prairie state.

4.1.2. Potentially Negative Impacts of Management Activities

Shrub removal across the site was intensive, and it is possible that some of the methods of shrub removal and subsequent management action may have had unintended consequences. Because the study lacked experimental controls on treatments, it is only possible to speculate but plots that experienced slightly different treatments showed differences in their trajectories. Specifically, more negative effects were noted in the transect prairie and old field plots compared to the reference plots. This could be partially due to the fact that shrubs were removed by hand in the reference prairie while in the transect prairie and old field portions of the site a small treaded tractor was used to remove cut shrubs. Shrubs were then placed in piles and burned. The use of the tractor and burn piles may have caused ground layer disturbance. Disturbance and increasing gap size have been shown to cause increases in colonizing annual species (McConnaughay & Bazzaz 1987; Belsky 1992). In bare ground bordering burn piles, there was a large increase in Canada thistle (*Cirsium arvense**), a non-native perennial, which became one of the top-10 dominant species at the site by 2012 (Taft et al. 2013). Increased exposure of bare ground has also been shown to increase invasion risk of *Rhamnus cathartica** (Whitfeld et al. 2013). These groups could account for some of the initial increases in measures of non-native species and decreases in native species and quality indicators. Additionally, greater native species richness has been shown to be associated with reduced species richness and density of invaders (Dimitrakopoulos et al. 2005). Transect prairie and old field plots have had lower native species richness than reference prairie for the

duration of the study, which could have rendered them more vulnerable to disturbance effects and account for their divergent initial responses to treatment.

Following shrub removal, the transect prairie and old field plots were mowed from 2010-2012 and managed burns were conducted in 2012, 2013 and 2014. Both treatments were intended to favor native prairie plants over undesirable species, but it is possible that these treatments were ineffective. Mowing was intended to provide light to emergent prairie plants, but previous studies have found mowing to be ineffective (VanDyke et al. 2004; Simmons et al. 2007) or even counterproductive to restoration (Dornbush 2004). It has been suggested that timing is critical for mowing to be successful (Wilson & Clark 2001), and it is possible that mowing during the growing season damaged emergent prairie plants. Burning may have also been ineffective. Many studies have noted vigorous shrub resprouting following burnings of moderate intensity or low frequency (Chiang et al. 2005; Bowles et al. 2007; Scasta et al. 2014). In particular, resprouting following burns has been observed in both *Rhamnus cathartica** and *Cornus drummondii*, a congener of *Cornus racemosa* (Briggs et al. 2005; Bowles et al. 2007). Despite the applications of prescribed fire, buckthorn has remained plentiful in the understory, and it has remained one of the 10 most dominant understory species site-wide in 2014. The persistent presence of buckthorn in the understory may be a source of competition for prairie plants, and it may be slowing establishment.

Several factors may have also reduced the effectiveness of seeding. Studies on seed viability and reproduction in prairies have noted that recruitment of new individuals from seed is often rare in prairie species, leaving many species reliant on vegetative propagation (Abrams

1988; Benson & Hartnett 2006; McNicoll & Augspurger 2010). This can make gap colonization problematic, as plants that colonize using clonal growth grow from the edge of the gap inwards as plants establish and put out runners (Lett & Knapp 2005). These limitations may have been compounded by the use of straw mulch and the cover crop *Lolium multiflorum** as erosion prevention strategies. Straw may have shaded and suppressed new seedlings or established plants. *Lolium multiflorum** turned out to be an aggressive colonizer and may have suppressed seedling growth and establishment through competition for light and other resources. It is possible that the erosion prevention strategies, along with the other management procedures mentioned in this section, may have delayed recovery trends and contributed to the convergence of old field and transect prairie vegetation types.

4.1.3. Drought Effects

During 2012 the state of Illinois experienced a severe drought that stretched across the entire state by July (IDNR & IEPA 2013). Precipitation data from the Chicago Waukegan Regional Airport shows a yearly average of 86.13 cm of precipitation from 2000 to 2014 (calculated using WBAN data obtained through Midwest Regional Climate Center). The same station reported a yearly total of 68.61 cm of precipitation in 2012, 17.52 cm below the average (Midwest Regional Climate Center 2014). The reference prairie shows decreases in percent cover and native species density and richness in 2012. Though transect prairie and old field show an increase in native species richness and a very slight increase in native species density, increases in overall percent cover were relatively small when the aggressive colonizer *Lolium multiflorum** was not included (increases from 2011 to 2012 of 20% to a total 130% in the transect prairie and 17% to a total of 128% in the old field compared with a net decrease in the

reference prairie). The water shortage appeared to be a stress factor in the reference prairie during 2012 sampling, and it is possible that the recovery trajectories of the old field and transect prairie were muted or delayed due to the drought.

4.2 Evidence of Buckthorn Legacy Effect

There was no pattern detected between baseline buckthorn stem density and understory recovery. Understory recovery was also compared to total baseline shrub density, in an attempt to test for an association between treatment intensity and recovery, with no significant results. Previous studies have linked the presence of buckthorn to long-term understory suppression through altered soil conditions or processes, though the mechanism remains unclear (Heneghan et al. 2006; Klionsky et al. 2011). Because the mechanism for buckthorn legacy effect is uncertain, it is possible that stem density was not the correct variable to quantify different intensities of legacy effect. It has been shown recently that intensive shrub invasion in hill prairies is associated with altered soil fungal community composition, creating soil fungal communities more similar to forest areas than prairies (Yannarell et al. 2014). In future, measurements of soil bacterial and fungal community composition may give more insight into the mechanisms and impacts of buckthorn legacy. It is also possible that buckthorn was too pervasive to uncover any relationship with ground layer parameters. Buckthorn comprised 52.8% of the stems in the baseline data, and the delayed or suspended recovery could be evidence of generalized suppression due to high densities of buckthorn across the site.

Including uninvaded reference units in future studies might help isolate the role of buckthorn legacy effect in plant community assemblages.

4.3 Relationship Between Soil Magnetic Susceptibility and Shrub Regrowth

The absence of a relationship between SMS and the pattern of shrub regrowth may be due in part to the burn piles used to dispose of cut shrubs. Exposure to high temperatures has been shown to be associated with formation of minerals linked with greater SMS values (Jordanova et al. 2001; Linford & Platzman 2004; Clement et al. 2011), and it is possible that some soil samples were taken in locations that previously held burn piles. Several samples showed abnormally high SMS values, and it is possible that the burn piles were a confounding factor. It is also possible that the sampling plots did not represent a wide enough range of moisture conditions to influence the regrowth patterns of buckthorn and other shrubs, as only the plots classified as terrestrial were included in this study. Including wetland plots with more extreme soil moisture values might reveal a stronger correlation.

Though there was no relationship between SMS and shrub regrowth, there was a weak relationship between plot SMS and plot coefficient of wetness. The results show that plots with lower CW values (plots with plants deemed more likely to be found in wet areas) tended to have lower SMS values, which are associated with higher soil moisture.

4.4 Control Plots

Comparisons to the baseline data have shown that the control plots serve as a reasonable proxy for untreated reference prairie. It is hoped that multiple years of monitoring in the control plots will provide insights into how the untreated prairie changes over time, and that comparisons between the trends in treated and untreated plots will help researchers better identify and understand the effects of treatment.

4.5 Conclusions

Overall, the results of this study are somewhat ambiguous, though buckthorn legacy effect and soil moisture were conclusively found to have no significant influence on plot recovery. The reference prairie has remained fairly stable and high-quality, despite the fact that it received the least intensive treatment. This supports previous research which has observed the stability of small, diverse prairie remnants in the region (Simberloff & Gotelli 1984). Phylogenetic diversity, a measurement of evolutionary relatedness, also may have played a role in the reference prairie's stability, as it has been associated with lower abundances of buckthorn (Whitfeld et al. 2013). In the future, including measures of phylogenetic diversity and comparing to measures of buckthorn and general shrub invasion intensity may help to further explain invasion and recovery dynamics.

Outcomes following shrub removal in the prairie and old field communities are still unclear. Both community types seem to have recovered from initial stressors due to management action, but it will likely take subsequent monitoring to determine whether

trajectories for parameters of conservation interest continue to improve or stabilize at pre-treatment levels. This is in agreement with several studies which have suggested that longer timescales are necessary to assess restoration success in prairies (Brye et al. 2002; Smith et al. 2003; McLachlan & Knispel 2005; Fagan et al. 2008; Howe 2011). However, there is reason for optimism in the currently available dataset; several measures have shown generally favorable trends following shrub removal in the most recent samples (notably FQI, percent bare ground, percent cover native species richness and native species density) and may continue to do so. Continued monitoring may show this to be the beginning of a recovery trajectory. The North Chicago Wetland Mitigation Project is scheduled to continue vegetation monitoring through the summer of 2015. However, several more years of monitoring may be necessary to definitively conclude whether the transect prairie and old field are in the process of recovery or have crossed into an alternate stable state. In future, because recovery timescales in prairies are so long, it may be a more effective use of time and resources to resample at slightly longer intervals (3 or 4 years) after initial stages of monitoring as opposed to yearly.

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6. Tables and Figures

Table 1. Results from one way analysis of variance comparing vegetation parameters (dependent variables) by vegetation types (within subjects differences) in 2014 data from the North Chicago Wetland Mitigation Site in Lake County, IL. Post-hoc analysis examines individual paired comparisons to identify where differences by habitat type (independent variable) occur. Tukey's highly significant difference test was applied to datasets with equal variance, which was examined using Levine's test. Dunnett's T3 test applied to groups that failed Levine's test. Different letters indicate significant pairwise comparisons. Significant values ($P < 0.05$) shown in **bold**. * indicates data transformed for normality (Means and Standard error are for the original data, starred F and P values are for transformed data).

2014 Sample Data	Reference Prairie (n=7)	Transect Prairie (n=8)	Old Field (n=29)	Control Plots (n=5)	1-Way ANOVA			Levine's Test	Reference Prairie	Transect Prairie	Old Field	Control Plots
Parameters	Mean SE	Mean SE	Mean SE	Mean SE	df 1, df 2	F Stat	P	P	Post-Hoc Test Results			
Native Spp. Density/Quadrat	28.0 ± 1.7	17.3 ± 1.8	15.1 ± 1.2	21.7 ± 2.3	3, 45	9.62	< 0.001	0.469	a	b	b	a, b
Non-Native Spp. Density/Quadrat	5.3 ± 0.5	7.0 ± 0.5	5.6 ± 0.3	5.1 ± 0.7	3, 45	2.17	0.105	0.810	-	-	-	-
Native Richness/Plot	45.1 ± 2.3	30.9 ± 2.4	27.8 ± 1.9	35.8 ± 2.8	3, 45	7.32	< 0.001	0.052	a	b	b	a, b
Non-Native Richness/Plot	7.6 ± 0.6	11.1 ± 0.8	9.6 ± 0.5	6.6 ± 0.5	3, 45	4.97	0.005	0.197	a	b	a, b	a
Simpson's Dominance *	0.1 ± <0.1	0.2 ± <0.1	0.1 ± <0.1	0.1 ± <0.1	3, 45	* 1.45	* 0.240	* 0.728	-	-	-	-
Shannon-Wiener Diversity *	2.8 ± 0.1	2.4 ± 0.1	2.5 ± 0.1	2.7 ± 0.2	3, 45	* 2.07	* 0.117	* 0.211	-	-	-	-
Mean C/Quadrat	3.5 ± 0.1	2.1 ± 0.1	2.0 ± 0.1	3.1 ± 0.3	3, 45	19.9	< 0.001	0.027	a	b, c	b	a, c
FQI/Quadrat	18.7 ± 1.1	8.6 ± 0.7	7.9 ± 0.7	14.3 ± 1.7	3, 45	23.6	< 0.001	0.287	a	b	b	a
Percent Cover	208.1 ± 21.0	173.6 ± 13.3	169.6 ± 7.3	196.6 ± 7.9	3, 45	2.1	0.113	0.254	-	-	-	-
Percent Bare Ground *	4.8 ± 1.4	14.3 ± 3.7	11.9 ± 1.4	7.7 ± 1.2	3, 45	* 2.81	* 0.005	* 0.417	a	a	a	a
Leaf Area Index (LAI) *	0.02 ± <0.1	0.08 ± <0.1	0.19 ± 0.1	0.77 ± 0.3	3, 45	* 4.50	* 0.008	* 0.044	a	a, b	a, b	b
Soil Magnetic Susceptibility (SMS)	47 ± 4.0	37 ± 2.7	39 ± 2.3	56 ± 3.8	3, 45	4.12	0.012	0.247	a, b	a	a	b

Table 2. Results from paired t-tests for comparison of overall means between 2009 and 2014 at the North Chicago Wetland Mitigation Site in Lake County, IL. Significant differences ($P < 0.05$) are shown in **bold**. * indicates non-normal data analyzed using the Wilcoxon paired-samples test.

	2009	2014			
PARAMETERS	Mean SE	Mean SE	t stat	df	P
Native Species Density	17.3 ± 1.2	17.5 ± 1.1	-0.29	43	0.776
Non-Native Species Density	4.8 ± 0.3	5.8 ± 0.3	-3.65	43	0.001
Native Species Richness	29.4 ± 1.8	31.1 ± 1.7	-1.36	43	0.180
Non-Native Species Richness	6.9 ± 0.5	9.6 ± 0.4	-5.68	43	<0.001
Simpson's Index of Dominance	0.2 ± 0.1	0.1 ± 0.1	-3.78	43	<0.001
Shannon-Wiener Diversity	2.4 ± 0.1	2.5 ± 0.1	-0.5	43	0.617
Mean C	2.3 ± 0.1	2.2 ± 0.1	1.82	43	0.075
FQI	10.0 ± 0.7	9.7 ± 0.8	0.64	43	0.527
Percent Ground Cover *	131.3 ± 12.8	176.4 ± 6.5	* 3.30	-	* 0.001
Percent Bare Ground	25.9 ± 2.9	11.2 ± 1.2	5.28	43	<0.001
Leaf Area Index (LAI)	1.24 ± 0.1	0.15 ± 0.1	16	43	<0.001

Table 3. Results from paired t-tests for comparison of means between 2009 and 2014 by vegetation type at the North Chicago Wetland Mitigation Site in Lake County, IL. Significant differences ($P < 0.05$) are shown in **bold**. * indicates non-normal data analyzed using the Wilcoxon paired-samples test.

PARAMETERS	2009	2014			
Native Species Density	Mean SE	Mean SE	t stat	df	P
Reference Prairie (n=7)	29.0 ± 0.6	28.0 ± 1.7	0.66	6	0.537
Transect Prairie (n=8)	20.2 ± 1.1	17.3 ± 1.8	1.41	7	0.201
Old Field (n=29)	13.7 ± 1.3	15.1 ± 1.2	-1.33	28	0.197
Non-Native Species Density					
Reference Prairie (n=7)	5.7 ± 0.7	5.3 ± 0.5	0.76	6	0.474
Transect Prairie (n=8)	6.9 ± 0.8	7.0 ± 0.5	-0.18	7	0.863
Old Field (n=29)	3.9 ± 0.3	5.6 ± 0.3	-4.98	28	<0.001
Native Species Richness					
Reference Prairie (n=7)	44.4 ± 1.4	45.1 ± 2.3	-0.30	6	0.777
Transect Prairie (n=8)	33.3 ± 1.5	30.9 ± 2.4	0.88	7	0.409
Old Field (n=29)	24.7 ± 2.1	27.8 ± 1.9	-1.90	28	0.068
Non-Native Species Richness					
Reference Prairie (n=7)	7.0 ± 1.2	7.6 ± 0.6	-0.73	6	0.493
Transect Prairie (n=8)	10.9 ± 0.9	11.1 ± 0.8	-0.31	7	0.763
Old Field (n=29)	5.7 ± 0.6	9.6 ± 0.5	-7.07	28	<0.001
Simpson's Index of Dominance					
Reference Prairie (n=7)	0.1 ± <0.1	0.1 ± <0.1	-0.75	6	0.481
Transect Prairie (n=8)	0.1 ± <0.1	0.2 ± <0.1	0.80	7	0.451
Old Field (n=29)	0.3 ± <0.1	0.1 ± <0.1	-5.36	28	<0.001
Shannon-Wiener Diversity					
Reference Prairie (n=7)	2.8 ± 0.1	2.8 ± 0.1	-0.33	6	0.750
Transect Prairie (n=8)	2.6 ± 0.1	2.4 ± 0.1	1.21	7	0.264
Old Field (n=29)	2.3 ± 0.1	2.5 ± 0.1	-0.87	28	0.392
Mean C					
Reference Prairie (n=7)	3.5 ± 0.2	3.5 ± 0.1	-0.29	6	0.780
Transect Prairie (n=8)	2.2 ± 0.1	2.1 ± 0.1	1.17	7	0.280
Old Field (n=29)	2.1 ± 0.1	2.0 ± 0.1	1.73	28	0.094
FQI					
Reference Prairie (n=7)	18.8 ± 0.7	18.7 ± 1.1	0.13	6	0.901
Transect Prairie (n=8)	9.9 ± 0.5	8.6 ± 0.7	1.37	7	0.214
Old Field (n=29)	7.9 ± 0.7	7.9 ± 0.7	-0.06	28	0.952
Percent Ground Cover *					
Reference Prairie (n=7)	292.7 ± 8.0	208.1 ± 21.0	* -2.20	* N/A	* 0.028
Transect Prairie (n=8)	155.0 ± 20.9	173.6 ± 13.3	* 0.84	* N/A	* 0.401
Old Field (n=29)	85.8 ± 6.9	169.6 ± 7.3	* 4.64	* N/A	* <0.001
Percent Bare Ground					
Reference Prairie (n=7)	5.3 ± 1.2	4.8 ± 1.4	0.70	6	0.513
Transect Prairie (n=8)	13.4 ± 3.6	14.3 ± 3.7	-0.16	7	0.879
Old Field (n=29)	34.3 ± 3.3	11.9 ± 1.4	7.03	28	<0.001
Leaf Area Index (LAI)					
Reference Prairie (n=7)	0.31 ± 0.1	0.02 ± >0.1	14.62	6	<0.001
Transect Prairie (n=8)	1.24 ± 0.2	0.08 ± >0.1	9.36	7	<0.001
Old Field (n=29)	1.46 ± 0.1	0.19 ± 0.1	11.35	28	<0.001

Table 4. Repeated Measures Analysis of Variance (RM-ANOVA) comparisons of means from 2009-2014 sample data (sample size = 3 quadrats [each 1-m²]/ plots, N listed by class) for vegetation parameters at the North Chicago Wetland Mitigation Site in Lake County, IL. Significant differences ($P < 0.05$) are shown in **bold**. T indicates data transformed for normality (Means and Standard error are for the original data, starred F and P values are for transformed data). Non-normal data was analyzed using the Friedman test.

PARAMETERS	2009	2010	2011	2012	2013	2014		
Native Species Density	Mean SE	Mean SE	Mean SE	Mean SE	Mean SE	Mean SE	F (df)	P
Reference Prairie (n=7) *	29.0 ± 0.6	28.0 ± 0.9	30.9 ± 1.4	25.8 ± 0.7	24.5 ± 1.5	28.0 ± 1.7	4.55 ₍₅₎	0.003
Transect Prairie (n=8) **	20.2 ± 1.1	19.5 ± 0.9	12.1 ± 2.5	13.5 ± 1.5	16.8 ± 1.7	17.3 ± 1.8	7.55 _(1.595)	0.011
Old Field (n=29) **	13.7 ± 1.3	13.6 ± 1.3	12.8 ± 1.3	13.9 ± 1.4	13.3 ± 1.2	15.1 ± 1.2	1.21 _(2.174)	0.309
Non-Native Species Density								
Reference Prairie (n=7) *	5.7 ± 0.7	5.4 ± 0.6	6.1 ± 0.9	4.5 ± 0.4	5.0 ± 0.6	5.3 ± 0.5	3.59 ₍₅₎	0.012
Transect Prairie (n=8) *	6.9 ± 0.8	8.2 ± 0.4	7.3 ± 1.1	6.0 ± 0.5	7.1 ± 0.5	7.0 ± 0.5	2.28 ₍₅₎	0.068
Old Field (n=29) **	3.9 ± 0.3	4.7 ± 0.4	5.6 ± 0.3	5.4 ± 0.3	5.8 ± 0.3	5.6 ± 0.3	6.84 _(3.171)	<0.001
Native Species Richness								
Reference Prairie (n=7) *	44.4 ± 1.4	44.6 ± 1.8	48.3 ± 1.5	41.7 ± 1.4	40.7 ± 2.6	45.1 ± 2.3	2.49 ₍₅₎	0.053
Transect Prairie (n=8) **	33.3 ± 1.5	28.6 ± 1.5	20.9 ± 3.5	26.1 ± 2.6	30.5 ± 2.4	30.9 ± 2.4	5.86 _(1.395)	0.029
Old Field (n=29) **	24.7 ± 2.1	22.6 ± 1.9	21.0 ± 2.2	26.2 ± 2.4	25.0 ± 2.0	27.8 ± 1.9	4.70 _(2.664)	0.006
Non-Native Species Richness								
Reference Prairie (n=7) *	7.0 ± 1.2	7.6 ± 1.0	8.4 ± 1.2	6.6 ± 0.5	7.0 ± 0.8	7.6 ± 0.6	2.44 ₍₅₎	0.057
Transect Prairie (n=8) *	10.9 ± 0.9	12.0 ± 0.4	12.1 ± 1.6	9.6 ± 1.0	11.1 ± 0.9	11.1 ± 0.8	1.51 ₍₅₎	0.212
Old Field (n=29) **	5.7 ± 0.6	7.2 ± 0.6	10.2 ± 0.5	9.2 ± 0.6	9.5 ± 0.5	9.6 ± 0.5	15.65 _(3.065)	<0.001
Simpson's Index of Dominance								
Reference Prairie (n=7) T **	0.1 ± <0.1	0.1 ± <0.1	0.1 ± <0.1	0.1 ± <0.1	0.1 ± <0.1	0.1 ± <0.1	* 76.41 _(1.093)	* <0.001
Transect Prairie (n=8) T **	0.1 ± <0.1	0.1 ± <0.1	0.3 ± 0.1	0.2 ± <0.1	0.1 ± <0.1	0.2 ± <0.1	* 45.35 _(1.133)	* <0.001
Old Field (n=29) T **	0.3 ± <0.1	0.2 ± <0.1	0.3 ± <0.1	0.2 ± <0.1	0.1 ± <0.1	0.1 ± <0.1	* 105.47 _(1.195)	* <0.001
Shannon-Wiener Diversity								
Reference Prairie (n=7) T **	2.8 ± 0.1	2.7 ± 0.1	2.8 ± 0.1	2.7 ± 0.1	2.8 ± 0.1	2.8 ± 0.1	* 36.88 _(2.060)	* <0.001
Transect Prairie (n=8) T *	2.6 ± 0.1	2.7 ± 0.1	2.0 ± 0.2	2.3 ± 0.1	2.7 ± 0.1	2.4 ± 0.1	* 29.04 ₍₅₎	* <0.001

Table 4 Continued

PARAMETERS	2009	2010	2011	2012	2013	2014		
Shannon-Wiener Diversity	Mean SE	Mean SE	Mean SE	Mean SE	Mean SE	Mean SE	F (df)	P
Old Field (n=29) T **	2.3 ± 0.1	2.3 ± 0.1	2.4 ± 0.1	2.1 ± 0.1	2.4 ± 0.1	2.5 ± 0.1	* 27.06 _(2,117)	* <0.001
Mean C								
Reference Prairie (n=7) *	3.5 ± 0.1	3.5 ± 0.1	3.4 ± 0.1	3.5 ± 0.2	3.5 ± 0.1	3.5 ± 0.1	0.59 ₍₅₎	0.704
Transect Prairie (n=8) **	2.2 ± 0.1	2.0 ± 0.1	1.4 ± 0.2	1.9 ± 0.2	2.0 ± 0.1	2.1 ± 0.1	6.21 _(1,635)	0.018
Old Field (n=29) **	2.1 ± 0.1	2.0 ± 0.1	1.7 ± 0.1	1.8 ± 0.1	1.9 ± 0.1	2.0 ± 0.1	7.05 _(3,121)	<0.001
FQI								
Reference Prairie (n=7) *	18.8 ± 0.7	18.6 ± 0.3	18.8 ± 0.7	17.8 ± 1.0	17.2 ± 1.0	18.7 ± 1.1	1.41 ₍₅₎	0.249
Transect Prairie (n=8) **	9.9 ± 0.5	8.9 ± 0.6	5.2 ± 1.1	7.1 ± 0.9	8.3 ± 0.8	8.6 ± 0.7	8.44 _(1,442)	0.010
Old Field (n=29) **	7.9 ± 0.7	7.5 ± 0.6	6.2 ± 0.6	7.1 ± 0.7	7.1 ± 0.6	7.9 ± 0.7	4.46 _(2,529)	0.009
Percent Cover								
Reference Prairie (n=7) *	292.7 ± 8.0	236.2 ± 17.1	252.2 ± 17.3	170.5 ± 11.4	203.6 ± 7.7	208.1 ± 21.0	12.96 ₍₅₎	<0.001
Transect Prairie (n=8) *	155.0 ± 20.9	126.5 ± 18.2	95.3 ± 11.0	129.7 ± 7.8	128.1 ± 13.9	173.6 ± 13.3	5.06 ₍₅₎	0.001
Old Field (n=29) **	85.8 ± 6.9	68.2 ± 7.7	110.2 ± 7.3	150.4 ± 8.7	140.5 ± 6.3	169.6 ± 7.3	40.46 _(3,644)	<0.001
Percent Bare Ground								
Reference Prairie (n=7) T*	5.3 ± 1.2	5.0 ± 2.4	3.2 ± 0.7	6.5 ± 2.1	3.0 ± 0.8	4.8 ± 1.4	* 1.93 ₍₅₎	* 0.118
Transect Prairie (n=8) T*	13.4 ± 3.6	20.2 ± 6.8	30.9 ± 5.6	19.6 ± 1.6	21.1 ± 4.8	14.3 ± 3.7	* 4.19 ₍₅₎	* 0.004
Old Field (n=29) T **	34.3 ± 3.3	44.9 ± 4.3	19.5 ± 3.1	14.3 ± 3.1	14.3 ± 1.3	11.9 ± 1.4	* 42.26 _(2,991)	* <0.001
Leaf Area Index (LAI) *								
Reference Prairie (n=7) ***	0.31 ± 0.1	0.40 ± 0.1	0.18 ± 0.1	0.01 ± <0.1	0.01 ± <0.1	0.02 ± <0.1	8.20 _(1,840)	0.007
Transect Prairie (n=8) ***	1.24 ± 0.2	0.11 ± <0.1	0.21 ± 0.1	0.06 ± <0.1	0.07 ± <0.1	0.08 ± <0.1	24.23 _(1,551)	<0.001
Old Field (n=29)***	1.46 ± 0.1	0.63 ± 0.1	0.20 ± 0.1	0.18 ± 0.1	0.13 ± 0.1	0.19 ± 0.1	52.52 _(2,408)	<0.001
	Friedman Test					Key		
Leaf Area Index (LAI) *	Chi-Square _(df)	Asymptotic Significance				* = Sphaericity assumed		
Reference Prairie (n=7) ***	24.82 ₍₅₎	<0.001				** = Greenhouse-Geisser		
Transect Prairie (n=8) ***	16.47 ₍₅₎	0.006				*** = Non-normal data		
Old Field (n=29)***	72.58 ₍₅₎	<0.001				T = Data transformed for normality		

Table 5. Mixed model repeated measures analysis of variance comparing trends among vegetation parameters (dependent variables) and vegetation type (independent variable) from the 2009 to 2014 for the North Chicago Wetland Mitigation Site in Lake County, IL. Design is 3 x 6 mixed model analysis (3 vegetation types, 6 years) for each dependent variable. Significant values ($P < 0.001$ for Box's test, $P < 0.05$ for other tests) are shown in bold. Normal data that failed Box's test was subject to Pillai's trace. Non-normal data was analyzed for within subject effects using the Friedman test. No non-parametric alternative was available to assess interaction effects, therefore RM ANOVA results are listed in the table for non-normal variables. These have an increased chance of type II error.

		Box's Test of Equality of Covariance Matrices	Vegetation Type x Year		Within Subject (Year)		Friedman Test (Nonparametric Within Subject)	
PARAMETERS	Data Characteristics	<i>P</i>	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>	Chi-Square (df)	Asymptotic Significance
Native Spp. Density	**	0.23	3.88	0.003	4.01	0.015	-	-
Non-Native Spp. Density	**	0.101	3.16	0.004	2.32	0.066	-	-
Native Spp. Richness	**	0.008	3.18	0.009	2.70	0.056	-	-
Non-Native Spp. Richness	**	0.011	3.43	0.002	4.27	0.005	-	-
Simpson's Index of Dominance	** T	0.101	0.97	0.398	146.29	<0.001	-	-
Shannon-Wiener Diversity	** T	0.034	1.49	0.207	47.62	<0.001	-	-
Mean C	**	0.115	1.65	0.134	9.03	<0.001	-	-
Percent Cover	*	0.037	17.48	<0.001	7.07	<0.001	-	-
Percent Bare Ground	*** T	<0.001	5.36	<0.001	14.20	<0.001	-	-
Leaf Area Index (LAI) *	****	<0.001	3.35	0.001			103.86 (5)	>0.001
Key								
* = Sphaericality assumed								
** = Greenhouse-Geisser								
*** = Pillai's trace								
**** = Non-normal, uncorrected with transformation. Friedman's test and Pillai's trace applied								
(T) = Data transformed for normality								

Table 6. Summary of plant community type classifications by plot from original cluster analysis in 2009 compared to plot classifications in 2014 for the North Chicago Wetland Mitigation Site in Lake County, IL.

Plot #	Code 09	Code 2014
PR 1	Reference Prairie	Reference Prairie
PR 2	Reference Prairie	Reference Prairie
PR 3	Reference Prairie	Reference Prairie
PR 4	Reference Prairie	Reference Prairie
PR 5	Reference Prairie	Reference Prairie
PR 6	Reference Prairie	New Group 1
PR 7	Reference Prairie	New Group 1
1A	Old Field	New Group 1
1D	Old Field	New Group 2
1E	Old Field	New Group 2
2A	Old Field	New Group 1
2B	Old Field	New Group 2
2C	Old Field	New Group 2
2D	Old Field	New Group 1
2E	Old Field	New Group 2
3A	Old Field	New Group 1
3B	Old Field	New Group 2
3C	Old Field	New Group 1
3D	Old Field	New Group 2
4A	Old Field	New Group 2
4B	Old Field	New Group 2
4C	Old Field	New Group 2
5A	Old Field	New Group 2
5B	Old Field	New Group 2
5D	Old Field	New Group 2
5E	Old Field	New Group 1
6D	Transect Prairie	New Group 2
6E	Transect Prairie	New Group 2
7A	Transect Prairie	New Group 2
7B	Transect Prairie	New Group 2
7C	Old Field	New Group 2
7D	Transect Prairie	New Group 2
7E	Old Field	New Group 2
8B	Old Field	New Group 1
8C	Old Field	New Group 1
8E	Old Field	New Group 1
9A	Old Field	New Group 2
9B	Old Field	New Group 2
9C	Transect Prairie	New Group 2
9D	Transect Prairie	New Group 2
9E	Old Field	New Group 1
10A	Old Field	New Group 2
10C	Old Field	New Group 2
10D	Transect Prairie	New Group 2

Table 7. Summary of mean values for various vegetation parameters of groupings created by the 2014 cluster analysis of the North Chicago Wetland Mitigation Site in Lake County, IL.

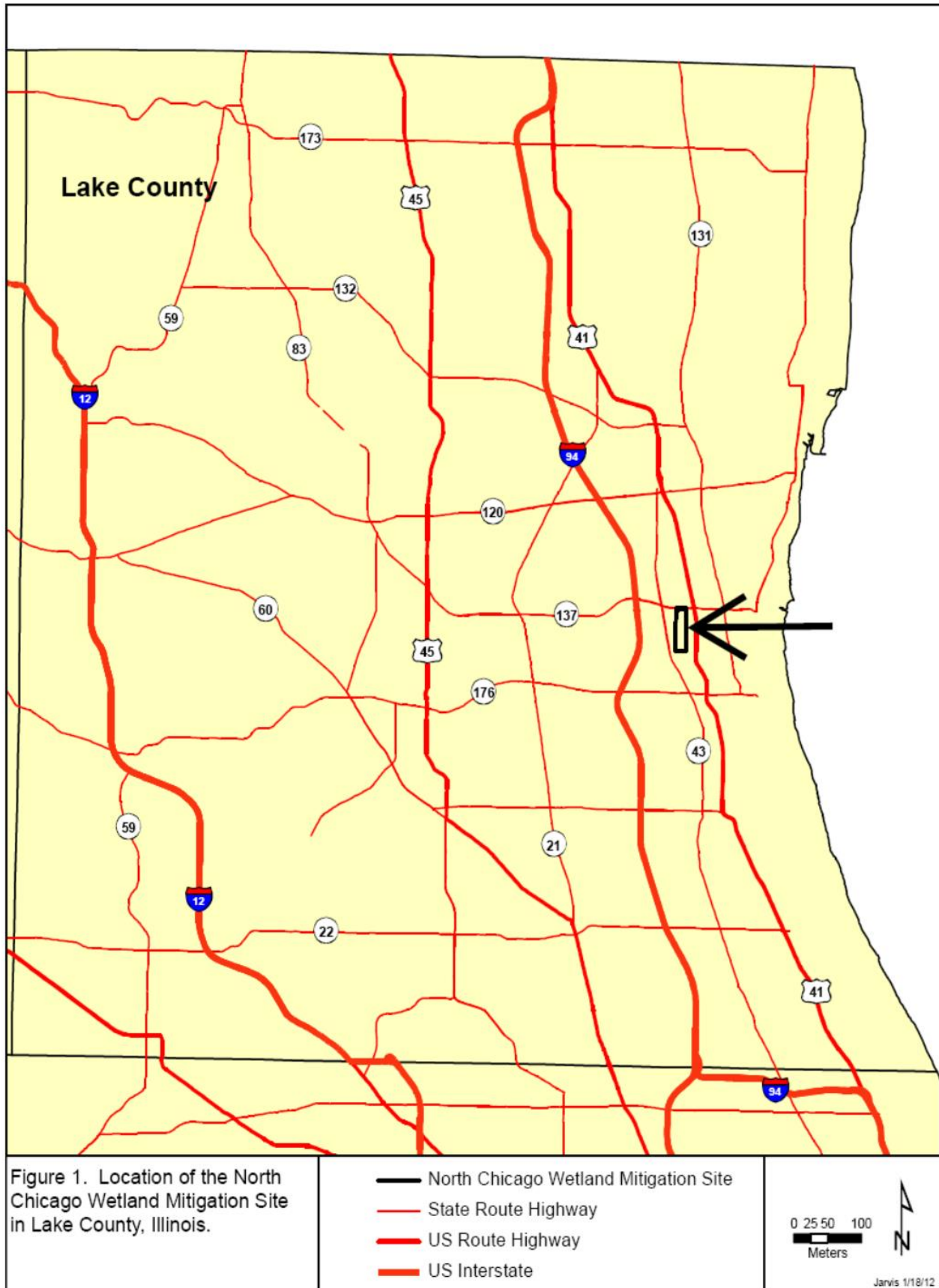
	Reference Prairie		New Group 1		New Group 2	
	Mean	SE	Mean	SE	Mean	SE
Native Spp. Density	29.5 ± 1.3		16.5 ± 0.2		15.8 ± 1.2	
Non-Native Spp. Density	5.9 ± 0.5		5.6 ± 0.5		5.9 ± 0.3	
Native Spp. Richness	47.6 ± 1.5		29.0 ± 2.9		29.0 ± 1.9	
Non-Native Spp. Richness	8.2 ± 0.6		9.5 ± 0.7		9.9 ± 0.6	
Simpson's Index of Dominance	0.1 ± 0.0		0.1 ± 0.0		0.1 ± 0.0	
Shannon-Wiener Diversity	2.9 ± 0.1		2.3 ± 0.1		2.5 ± 0.1	
Mean C	3.7 ± 0.1		2.0 ± 0.2		2.0 ± 0.1	
Percent Cover	218.7 ± 28.8		176.3 ± 9.9		168.7 ± 7.6	
Percent Bare Ground	5.1 ± 1.8		9.0 ± 2.2		13.3 ± 1.6	
Leaf Area Index	0.02 ± 0.0		0.20 ± 0.1		0.15 ± 0.0	

Table 8. Summary of R^2 results from linear regressions of baseline buckthorn stem counts vs change in vegetation parameters from 2009 to 2014 for the North Chicago Wetland Mitigation Site in Lake County, IL. Significant values ($P < 0.05$) shown in **bold**.

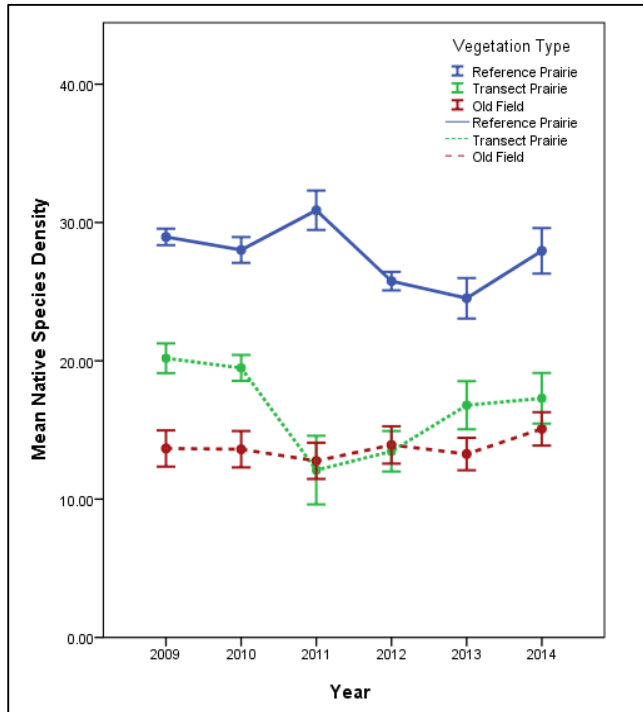
Dependent Variable	R^2 Value	Significance
Change in Native Species Density	0.006	0.620
Change in Non-Native Species Density	0.003	0.745
Change in Native Species Richness	0.004	0.669
Change in Non-Native Species Richness	0.050	0.148
Change in C Dom	0.008	0.571
Change in Hn	0.002	0.794
Change in Mean C	0.074	0.078
Change in FQI	0.064	0.102
Change in Percent Cover	0.036	0.226
Change in Percent Bare Ground	0.077	0.072

Table 9. Summary of R^2 results from linear regressions of average plot Soil Magnetic Susceptibility vs various metrics of shrub regrowth following treatment for the North Chicago Wetland Mitigation Site in Lake County, IL. Significant values ($P < 0.05$) shown in **bold**.

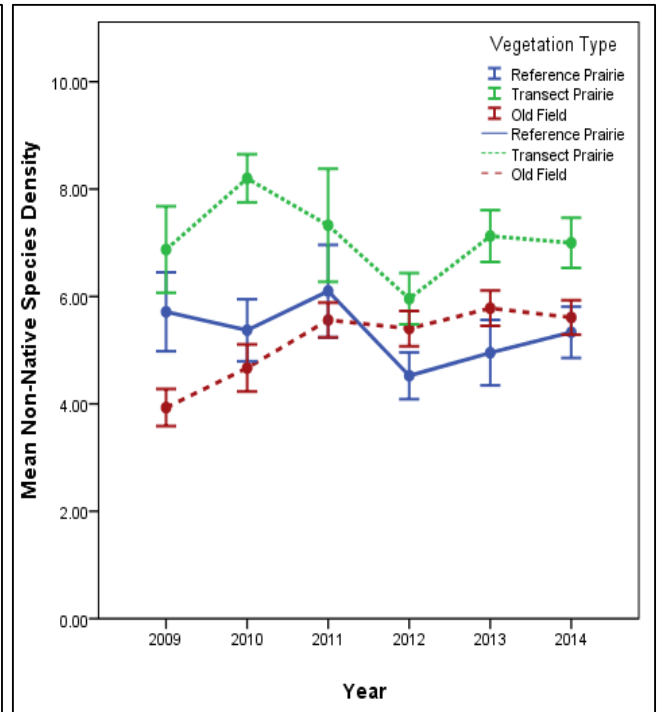
Dependent Variable	R^2 Value	Significance
Total Shrub Stem Count	0.003	0.745
Cornus racemosa Stem Count	0.002	0.782
Lonicera x Bella Stem Count	0.000	0.910
Rhamnus cathartica Stem Count	0.030	0.235
Viburnum lentago Stem Count	0.001	0.819
Leaf Area Index (LAI)	0.001	0.859



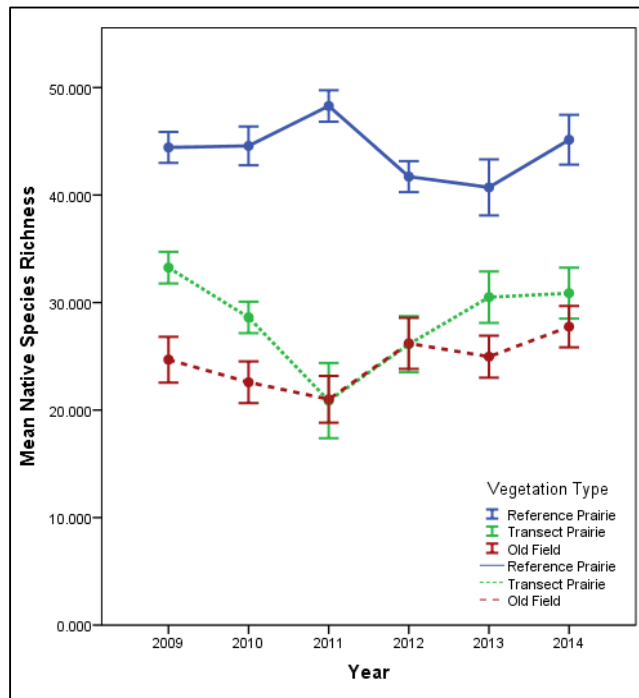




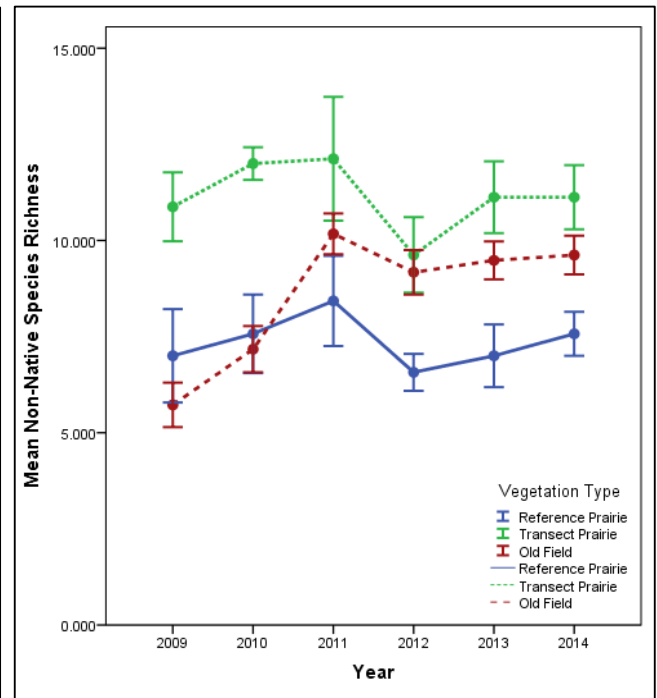
A. Mean native species density over time



B. Mean non-native species density over time

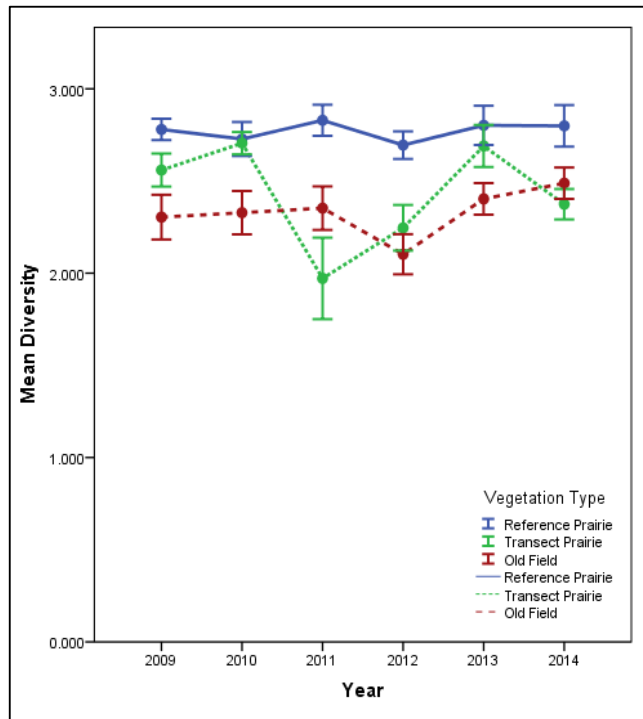


C. Mean native species richness over time

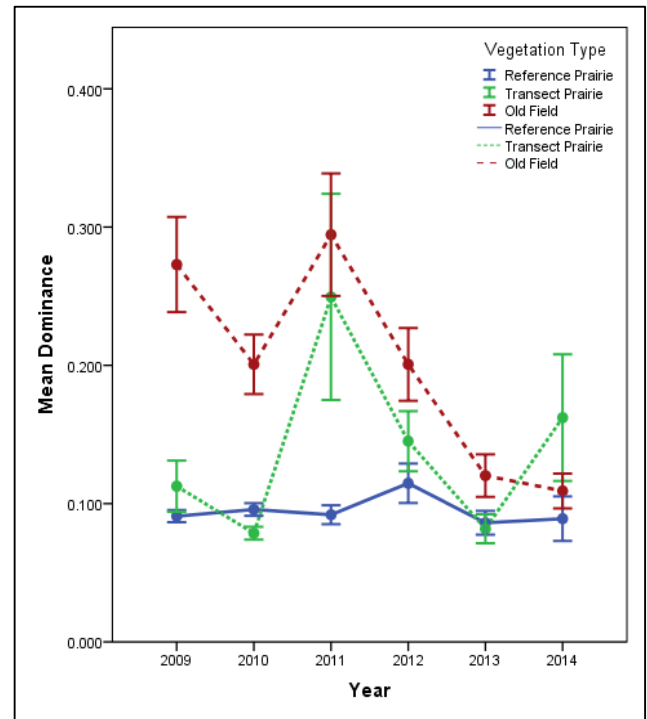


D. Mean non-native species richness over time

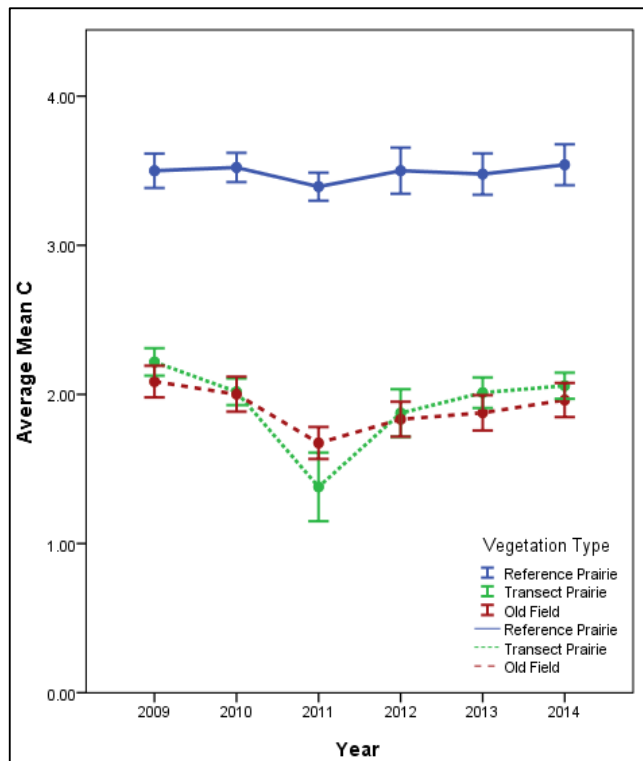
Figure 3. Trends for vegetation types from 2009 to 2014 for ground layer quality parameters at the North Chicago Wetland Mitigation Site in Lake County, IL. Trajectories were tested for within subject differences over time (flatness hypothesis) and between subject x within subject interaction (parallelism hypothesis) via profile analysis (see Table 6).



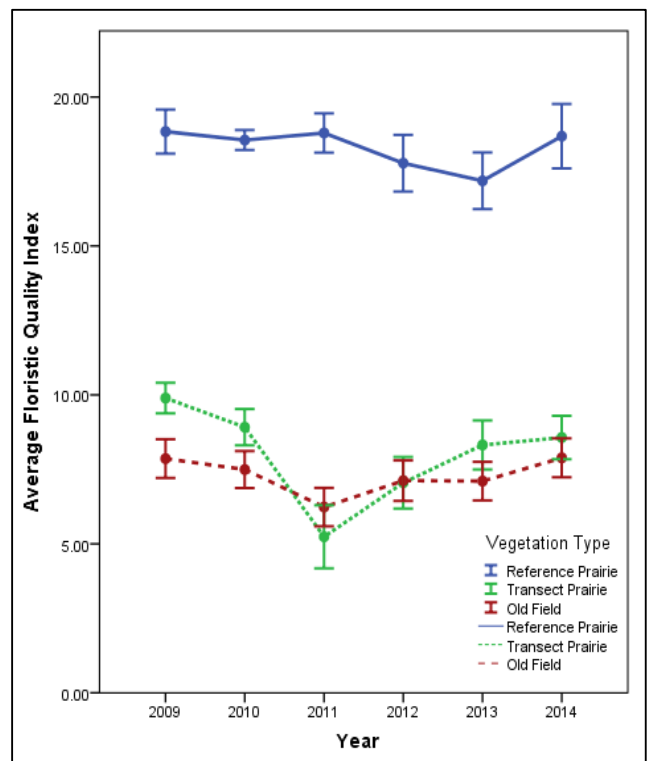
E. Mean diversity over time



F. Mean dominance over time

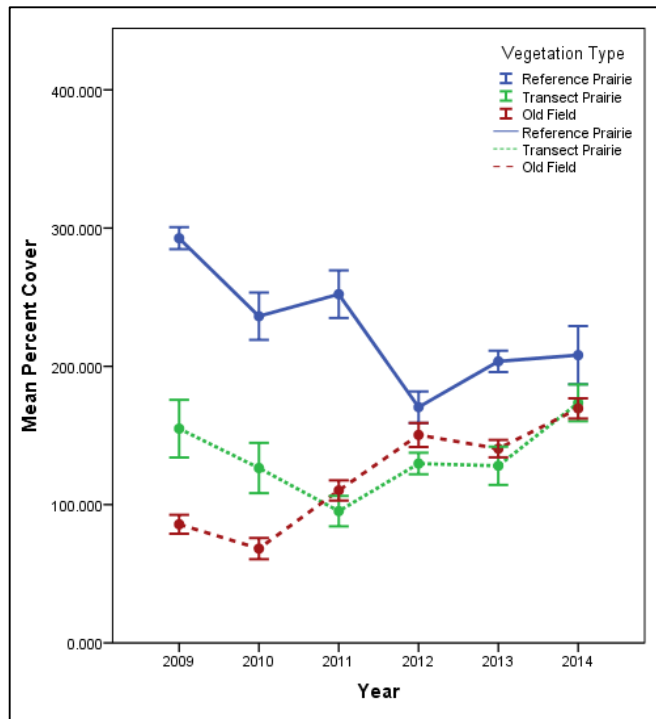


G. Average mean C over time

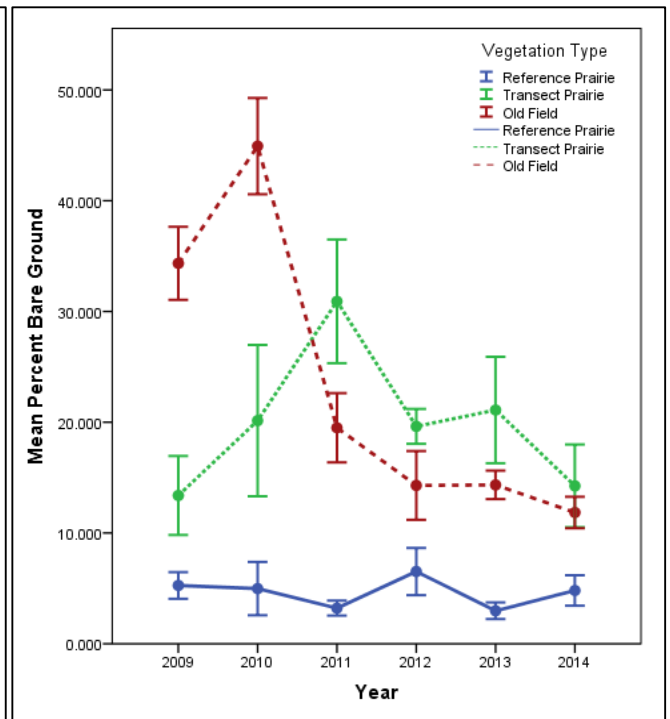


H. Average floristic quality index over time

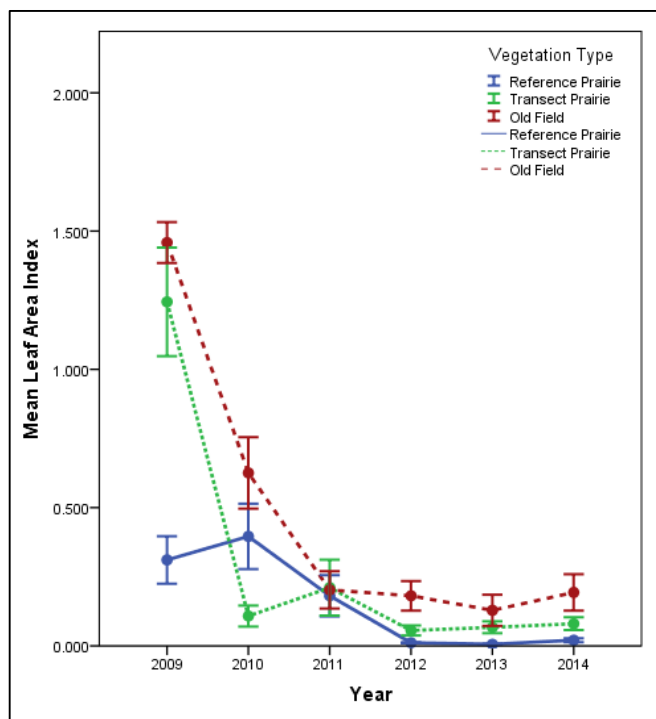
Figure 3 (continued).



I. Mean percent cover over time



J. Mean percent bare ground over time



K. Mean leaf area index over time

Figure 3 (continued).

Figure 4. Dendrogram of the results of cluster analysis of 2014 plant species data from the North Chicago Wetland Mitigation Site in Lake County, IL.

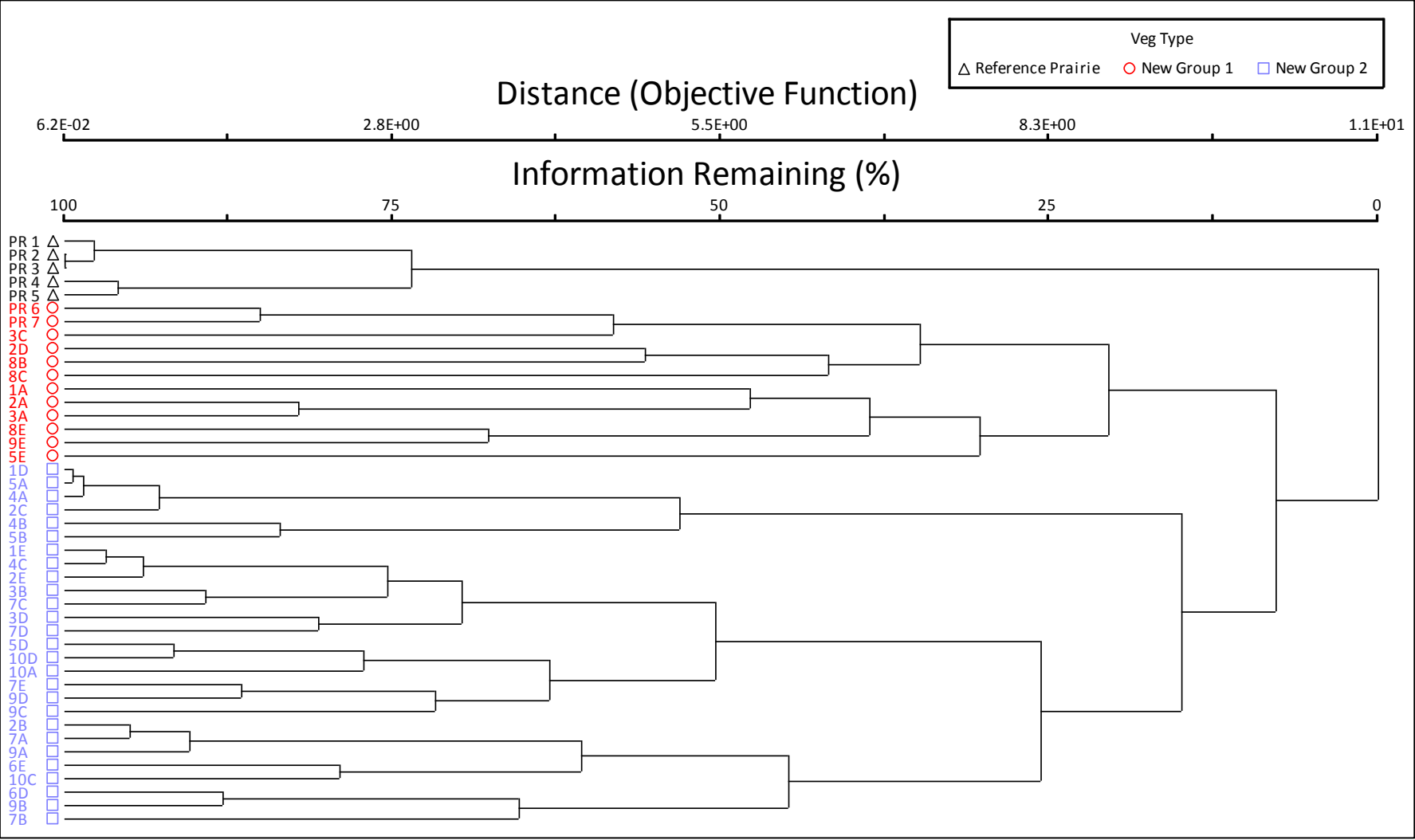
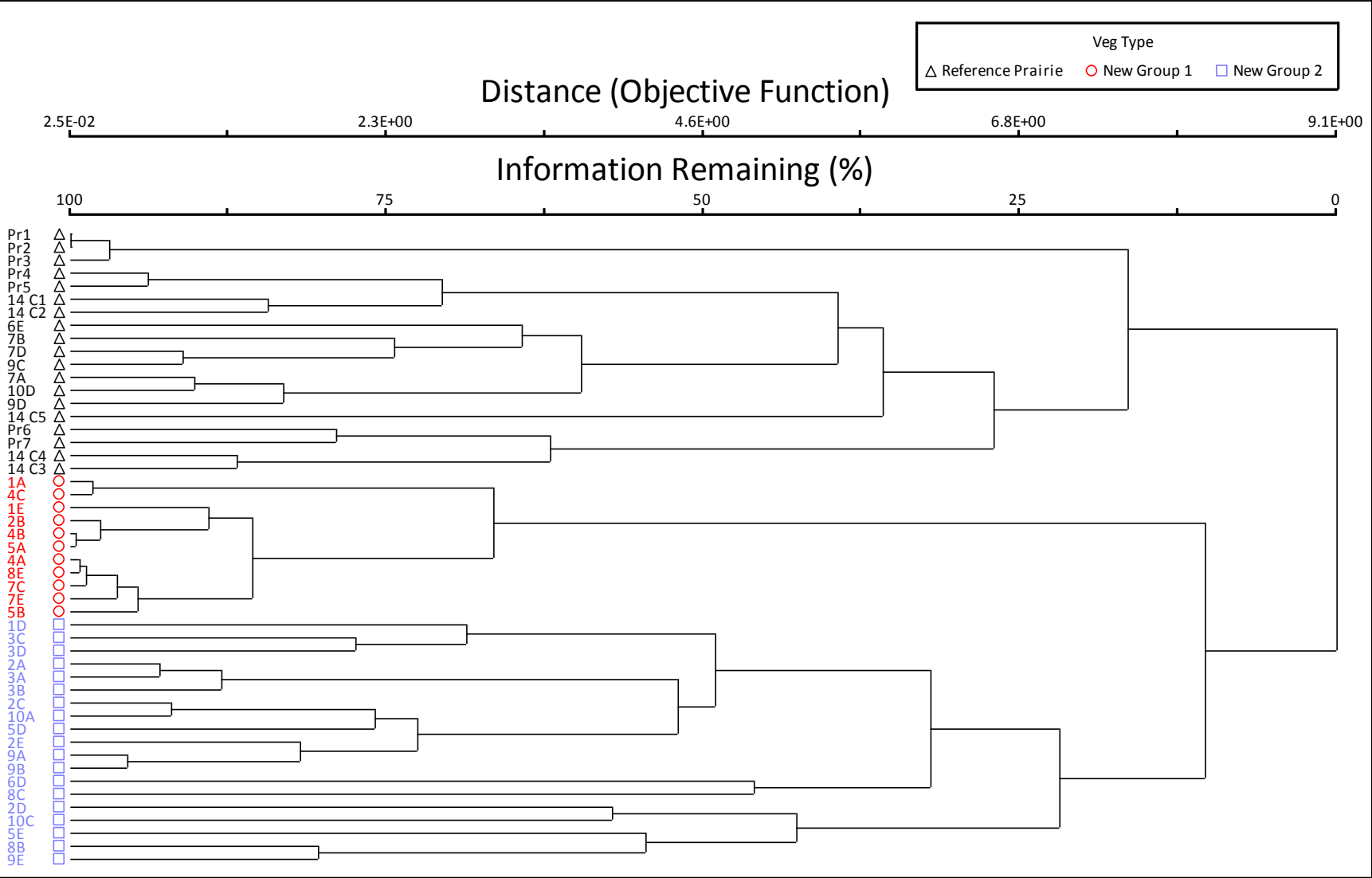


Figure 5. Dendrogram of the results of cluster analysis comparing baseline (2009) and the 2014 control plots (noted with a 14) plant species data from the North Chicago Wetland Mitigation Site in Lake County, IL.



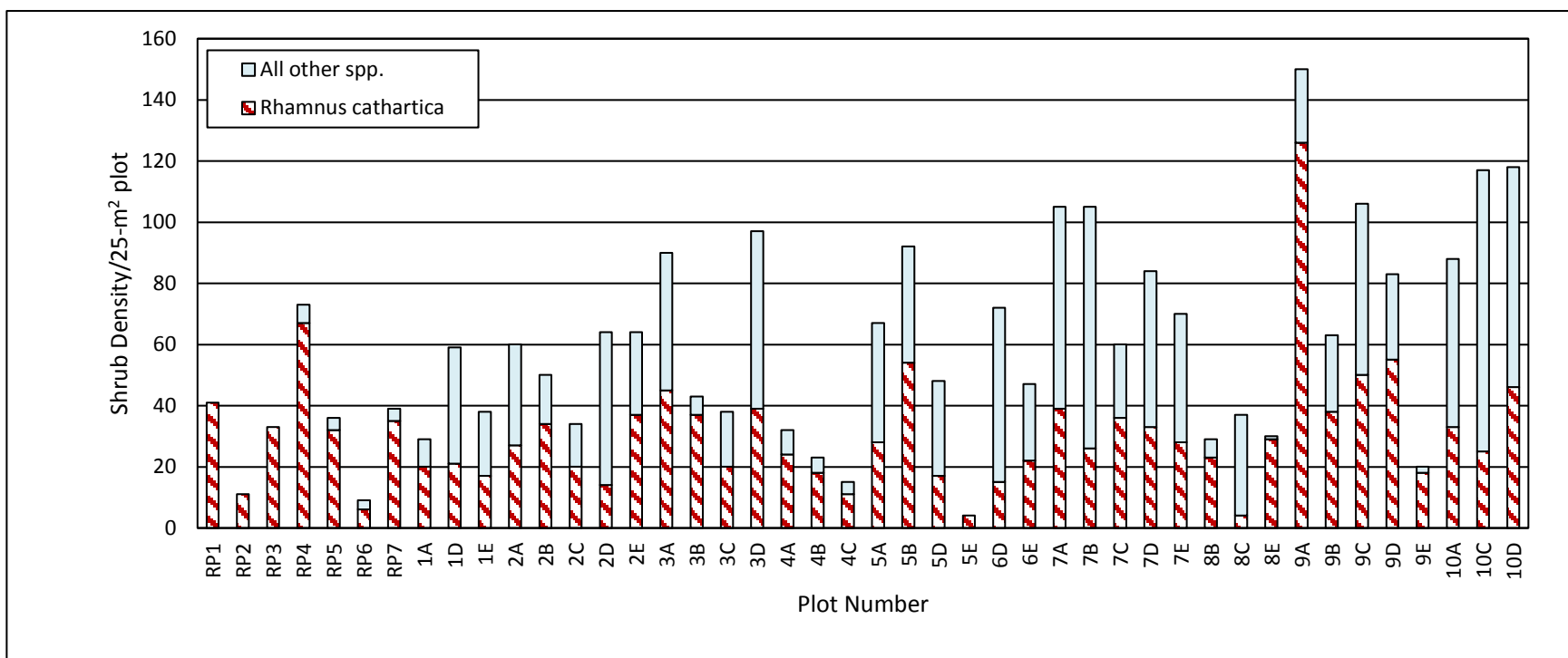


Figure 6. Baseline shrub density by plot at the North Chicago Wetland Mitigation Site in Lake County, IL, divided by *Rhamnus cathartica* and all other shrubs. Overall there was an average of 58.5 stems/plot and 52.8% were *Rhamnus cathartica*.

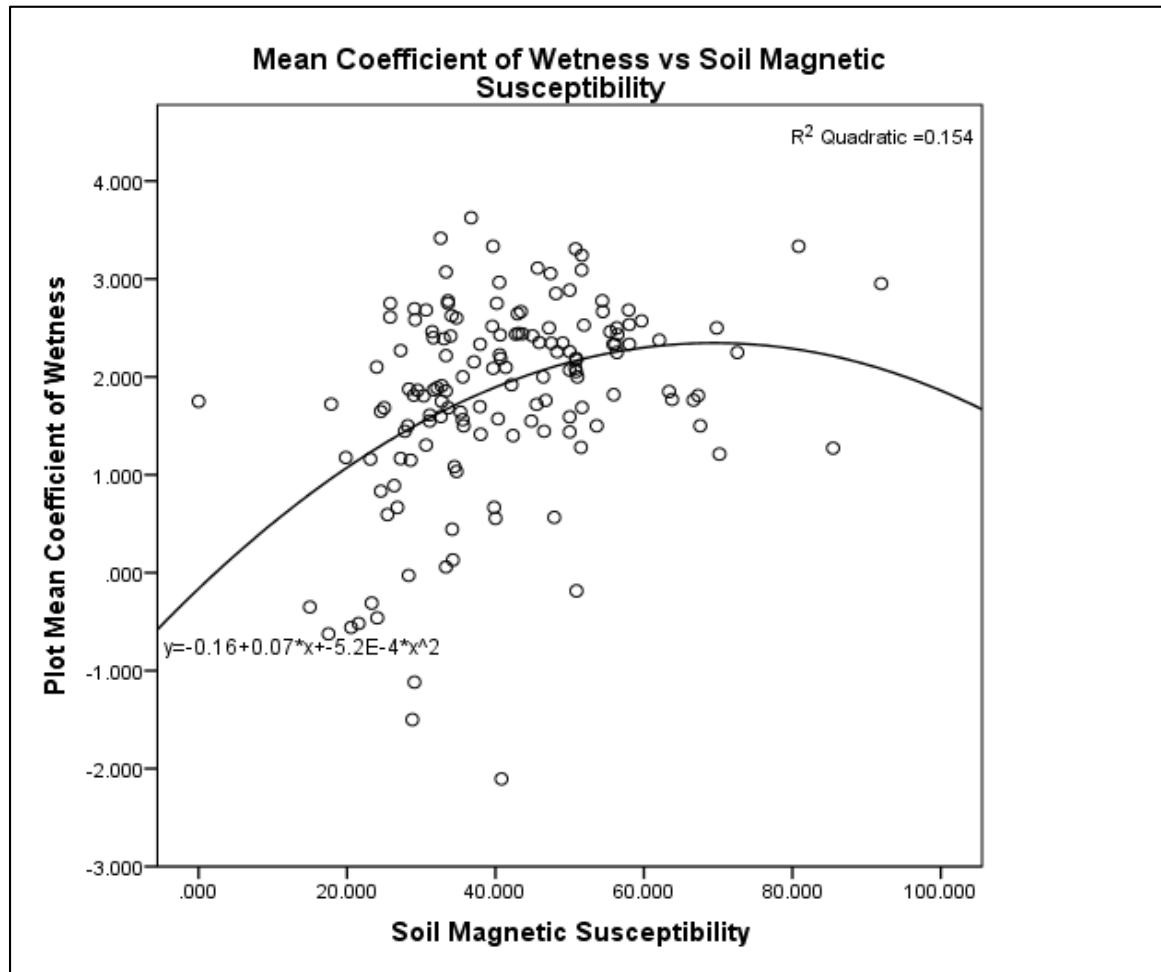


Figure 7. Trends between plot average mean coefficient of wetness and plot average soil magnetic susceptibility at the North Chicago Wetland Mitigation Site in Lake County, IL.

Appendix

Appendix 1. GPS coordinates for the southwest corner of each of the original 5 x 5 meter sampling plots at the North Chicago Wetland Mitigation Site in Lake County IL.

Plot ID	Latitude	Longitude
10a	N42.30781	W-87.88369
10c	N42.30784	W-87.88186
10d	N42.30784	W-87.88096
9e	N42.30642	W-87.88135
9d	N42.3065	W-87.88228
9c	N42.30647	W-87.88319
9b	N42.30646	W-87.88413
9a	N42.30643	W-87.88504
8b	N42.30511	W-87.88362
8c	N42.30515	W-87.88278
8e	N42.30516	W-87.88096
7d	N42.30377	W-87.88234
7c	N42.30374	W-87.88321
7e	N42.30377	W-87.88143
7b	N42.30372	W-87.88413
7a	N42.3037	W-87.88503
6d	N42.30241	W-87.88184
6e	N42.30245	W-87.88091
5e	N42.30108	W-87.88138
5d	N42.30109	W-87.88229
5b	N42.30107	W-87.88414
5a	N42.30104	W-87.88503
4a	N42.29972	W-87.88459
4b	N42.29972	W-87.8837
4c	N42.29974	W-87.88278
3d	N42.29837	W-87.88232
3c	N42.29836	W-87.88325
3b	N42.29835	W-87.88416
3a	N42.29837	W-87.88507
2a	N42.29701	W-87.88462
2b	N42.29701	W-87.88374
2c	N42.297	W-87.88275
2d	N42.29705	W-87.88185
2e	N42.29702	W-87.88095
1e	N42.2957	W-87.88142
1d	N42.29565	W-87.88233
1a	N42.29565	W-87.88508
PR1	N42.29474	W-87.88125
PR2	N42.29476	W-87.88115
PR3	N42.29479	W-87.8812
PR4	N42.29488	W-87.88129
PR5	N42.29495	W-87.8814
PR6	N42.29495	W-87.88159
PR7	N42.29459	W-87.88079
C1	N42.29711	W-87.88031
C2	N42.29671	W-87.88036
C3	N42.29653	W-87.88014
C4	N42.29673	W-87.87993
C5	N42.29691	W-87.87978