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# Using Plant Functional Traits to Estimate Prairie Restoration Species Composition

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By

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Abstract:

Prairie restoration is costly and complex with many methods and types. The use of technology to enhance, economize and simplify prairie restorations is highly desirable, as is the ability to gauge restoration success. The program Maxent allows for an interpretation of data that may facilitate the prediction of plant species composition from species functional traits in different ages of prairie restorations. The inexpensive and diverse nature of Maxent makes it advantageous to restoration managers allowing them to manage expenditures in the field. Maxent determines if specific species trait values and abundance concur with the aggregate trait values of a site. The aggregate trait values of a site are assumed to be the result of natural selection and are used to predict the species composition based on functional trait values of the different species. The objective of this this study was to apply this technique to plant functional traits in Midwest prairie restorations. The technique was applied to data from 11 sites in 8 restoration locations in Illinois. Restorations ranged from 3 to 45 years of age and two remnant site >100 years of age. Six functional traits were measured for 31 dominant perennial plant species. Plant functional traits can be used to estimate prairie restoration species composition by predicting the relative percent cover based on the age of a site Although Maxent's performance in predicting plant species composition varied among sites, its performance in predicting relative percent cover of species present at sites was good ($R^2 = 0.62$, $P < 0.001$). In restorations younger than 30 years the most abundant species were *Solidago altissma, Poa pratensis, Solidago rigida*, and *Andropogon gerardii.* Older sites

were much more varied in their species composition with no species being dominant in the older sites. Maxent correctly predicted at least 50% of the dominant species in 7 out of 11 of the sites. The sites with most accurate predictions of species composition were from 13 to 45 years in age, with > 50% of the dominant species correctly predicted.

## Chapter 1: Literature Review

Prairies have been studied extensively since the dust bowl of the 1930's. The dust bowl led to a greater interest in prairie restoration as part of a push to stabilize prairie and agricultural areas (Kindscher and Tieszen 1998). Before European settlement greater than 68 x $10^6$ ha of tall grass prairie existed in the Great Plains of North America (Sampson and Knopf 1994). Agriculture and urbanization led to an estimated 82-99% loss and destruction of tall grass prairies (Sampson and Knopf 1994). Of the remaining prairie most is very fragmented and is being threatened with development and woody vegetation moving into the area (McLachlan and Knispel 2005). The conversion of grassland to agriculture, urban development and industry has not only reduced the overall biomass of native vegetation, it also has altered abiotic conditions such as soil nitrogen and phosphorus concentrations, pH and water movement and availability (Dobson et al. 1997, Eom et al. 1999, Parton et al. 1995, Knapp et al. 1993). In some of these altered ecosystems, artificial restoration has been used to restore biological diversity and abiotic conditions (Choi and Pavlovic 1998). By scientifically studying the restoration of prairie we gain better understanding of succession, competition, plant population dynamics, ecological processes and prairie ecosystem management (Kindscher and Tieszen 1998).

Plant Species Functional Traits

The use of functional traits to predict community composition (Lavorel and Garnier 2002) has been promoted as the “Holy Grail” in plant community ecology, and may prove useful in understanding and managing prairie restorations. In recent years the use of quantitative traits of plant species has been promoted instead of taxonomic groups for determination of effects of community composition on ecosystem processes (Lavorel and Garnier 2002). The traits of the dominant species in an ecosystem have the most effect on the processes of an ecosystem, and species traits have more effect on the ecosystem than on the number of species present (Garnier et al. 2004). Plants have to balance the energy used in reproduction, storage and plant growth (Leishman 2001). Each plant allocates its energy differently. The “Biomass Ratio Hypothesis” states that species traits influence ecosystem function in proportion to the relative biomass contribution of the species to the community (Grime 1998). This “scaling up” from species traits to ecosystem function has been proposed as a strategy to track modifications in ecosystems from human activity (Garnier et al. 2007, Quested et al. 2007).

This study focuses on traits important to the fitness of a plant species. Seed mass, seed structure, seed maturation date, specific leaf area, leaf mass and maximum plant height are some of the traits that differential allocation of energy determines (Cornelissen et al. 2003).Seed mass, shape and number have been shown to directly affect fitness. Seed shape is most likely a product of natural selection to disperse seeds, as seen by a large array of plants developing similar strategies for seed dispersal (Matlack 1987). Plants producing the most seeds yield the greatest number of potential offspring, while plants with larger seeds are more likely to survive environmental hazards but with fewer potential offspring (Leishman 2001). Small seeds, while more susceptible to environmental hazards, can compete with larger seeds due to their large numbers, while larger seeds compete by being much more hardy (Leishman 2001). Rabinowitz and Rapp (1981) found that seeds of sparsely spaced plants tended to travel farther than those of the more common or numerous species. Rabinowitz and Rapp (1981) also found that larger parent plants generated larger seeds.

Leaf characteristics and anatomy can affect processes within individual plants, as well as ecological and evolutionary processes (Pyankov et al. 1999). Specific leaf area (SLA) has been found to affect multiple aspects of plant function including: gas exchange, relative growth rate and palatability (Shipley 1995). SLA correlates positively with growth rate and total mass of a plant. The more resources available in an environment the higher the SLA tends to be (Cornelissen et al. 2003).

Plant height is a trait that is correlated with competitive ability of plant species, largely because the tallest plants have the most access to light. Plant height also tends to correlate negatively with the degree of environmental stressors in ecosystems due to the cost of building and maintaining the stem

(Falster and Westoby 2003). Allometric relationships between plant height and other traits (e.g., biomass, root depth, root lateral growth, leaf size) have been found in studies of intraspecific competition over a broad range of species (Cornelissen et al. 2003, Falster and Westoby 2003).

Seed Maturation date was used to look at the phenology of the plants studied (McGill et al. 2006).

Using Functional Traits to Predict Species Composition

Natural area restoration, especially prairie restoration, has become a very important environmental effort being pursued both publically and privately (Schramm 1990). Restoration projects such as the Conservation Reserve Program sponsored by the United States Department of Agriculture (CRP) would benefit from a model that would allow resource managers the ability to compare the age of individual restoration sites to other similarly located and aged sites. Estimating prairie plant species and populations that should be in a restored area during an established time-frame would be of great help to restoration biologists as well as private citizens. Schramm (1990) found that the restorer should try to mimic the natural mosaic of prairie plants in a restoration project. Quantitative models formed from a trait study could be used to determine the success of a restoration project when compared to other studies of the same age and type. The ability to use plant traits to estimate plant numbers in an area is highly desirable, especially while prioritizing efforts with limited funding available (Palik et al. 2000).

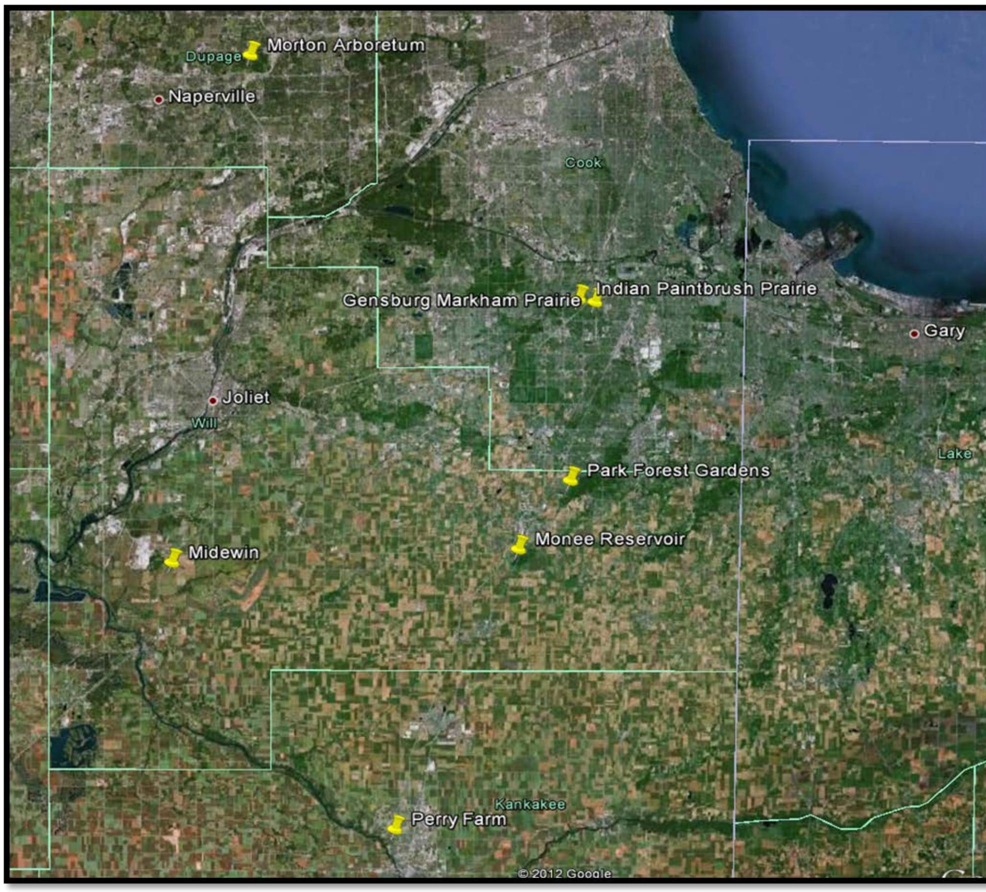
Having accurate predictive models is useful when working with environmental issues, and also when working with ecological community estimations (Keddy 1992). Monitoring natural vegetation over an extended period of time is a challenging prospect for both conservation resource managers and scientists. Community composition may be able to not only tell managers the plants in a location but the possibility of fire due to the community makeup and may allow for preventive burns, if needed, and better management of natural areas **(**Cornelissen et al. 2003).

In a recent study, a statistical mechanics model was used to predict species composition and relative abundances from functional traits of species. The study was conducted using a chronosequence of 12 former vineyards in France. The 12 sites were abandoned from 2 to 42 years before the study (Garnier et al. 2004, Shipley et al. 2006). Eight functional traits from 30 different herbaceous species were measured. The traits used were. proportion of the species that were perennial, seed number per plant, seed maturation date, specific leaf area (SLA), above ground vegetative mass, stem mass, leaf mass and maximum height of the plant (Shipley et al. 2006). Assumptions made were that trait values can be approximated as species-specific attributes, and that intraspecific genotype evolution of traits is insignificant relative to pre-existing interspecific variation.

The study focused on environmental filters sorting species by their functional traits to determine community assembly at a location in a given time-frame. Nonrandom processes determined by functional traits between species include seed dispersal, growth, survival, and reproduction. These processes greatly affect the community structure in a site (Shipley et al. 2006).

This study will use species functional traits (seed mass, seed shape, seed maturation date, specific leaf area, leaf mass and maximum plant height) to determine whether it is possible to determine the relative percent cover of the different species of prairie plants in different aged prairie restorations using the statistical mechanics model developed by Shipley et al. (2006).

*Study Area* – The study area consists of 11 sites in 8 locations with the age of the sites ranging from 3- 35 years.




**Study Area:** Google Earth 2012 i.

**Fermilab Prairie –** Fermilab is a 2750 ha site commissioned in 1967 by the U. S. Atomic Energy Commission as a particle accelerator with 486 ha involved in prairie restoration. The Fermilab prairie is 35 years of age at the time of this study. Fermilab is located near Batavia in Will County Illinois (41° 50' 10.43"N, 88° 15' 16.94" W) with an elevation of 225.25 m (Fermilab 2005 Google Earth 2012 a). Prairie restoration began in 1975, and in 1989 Fermilab was designated a National Environmental Research Park (Fermilab 2005). An area of 80.94 ha initially was seeded with seeds collected from 70 locations within 80.47 km of Fermilab (Sluis 1997). The seeds were planted by using a

Nisbit drill and later using a highway salt spreader (Scherer 1998). This location is reseeded annually to increase species diversity, through hand seed collection, machine harvesting and trading seeds with other sites (Fermilab 2005. The prairies are frequently burned with planned burns for both the fall and spring contingent on environmental factors as well as available manpower. The site is divided up into 29 fire management areas (Fermilab 2000. Each fire management area is burned approximately every one to three years (Sluis 1997).

Table 1. Dominant Soil Types Present in Fermilab and Approximate Percentage of Site (greater than 10 % of site).

| Soil Symbol | Soil Type | Percentage Present |
|---|---|---|
| 152A | Drummer silty clay loam, 0 to 2 percent slopes | 22% |
| 442A | Mundelein silt loam, 0 to 2 percent slopes | 20% |
| 531B | Markham silt loam, 2 to 4 percent slopes | 10% |

Soil Survey Staff, Natural Resources Conservation Service 2015

**Gensburg – Markham Prairie and Indian Paintbrush Prairie** remnants are part of the Indian Boundary Prairies located near Markham IL. Gensburg – Markham Prairie and Indian Paintbrush Prairie remnants were assigned an age of 100 years for this study as they are remnants. Gensburg Markham Prairie is located at 41° 36’ 24.10N, 87° 42’ 11.33”W (Google Earth 2012 b) with an elevation of 185.31 m. Indian Paintbrush Prairie is located at 41° 36’35.72”N, 87° 42’ 13.16”W (Google Earth 2012 c.) with an elevation of 186.54 m. Gensburg – Markham Prairie is approximately 40 ha and Indian Paintbrush Prairie is approximately 24 ha in size (The Nature Conservatory 2011). Both prairies are managed by the Nature Conservancy. These prairies became protected when the Gensburg brothers donated 12.14 ha to Northeastern Illinois University (The Nature Conservancy 2011). The Nature Conservancy divides up the different areas of the prairies into burn units on a three year burn rotation. Entire prairies are not usually burnt at the same time but are burnt in similar habitats. Burn units are not the same from year to year (K. Gnaedinger, personal communication).

Table 2. Dominant Soil Types Present in Gensburg-Markham and Approximate Percentage of Site (greater than 10 % of site).

| Soil Symbol | Soil Type | Percentage Present |
|---|---|---|
| 49A | Watseka loamy fine sand, 0 to 2 percent slopes | 39% |
| 125A | Selma loam, 0 to 2 percent slopes | 42% |
| 172A | Hoopeston fine sandy loam, 0 to 2 percent slopes | 18% |

Soil Survey Staff, Natural Resources Conservation Service 2015

Table 3. Dominant Soil Types Present in Paintbrush Prairie and Approximate Percentage of Site (greater than 10 % of site).

| Soil Symbol | Soil Type | Percentage Present |
|---|---|---|
| 125A | Selma Loam 0 to 2 percent slopes | 64% |
| 172A | Hoopeston fine sandy loam, 0 to 2 percent slopes | 36% |

Soil Survey Staff, Natural Resources Conservation Service 2015

**Midewin National Tallgrass Prairie** is an approximately 7375 ha preserve established in 1996 by the Illinois Land Conservation Act, managed by the United States Forest Service, and located near Elwood Illinois at the site of the former Joliet Army Ammunition Plant (USDA 2002). Midewin Tallgrass Prairie is four years of age at the time of this study. Midewin Tallgrass Prairie is located at 41° 22' 35.53"N, 88° 06' 44.69"W with an elevation of 195.68 m (Google Earth 2012 d). Midewin is burned based on conditions to restore fire as a natural disturbance. Two sites were used at this location with the following soil types:

Table 4. Dominant Soil Types Present in Midewin National Tallgrass Prairie Northeast Site and Approximate Percentage of site (greater than 10 % of site).

| Soil Symbol | Soil Type | Percentage Present |
|---|---|---|
| 314A | Joliet Silt Loam 0 to 2 percent slopes | 55% |
| 315A | Channahon silt loam, 0 to 2 percent slopes | 20% |
| 523A | Dunham silty clay loam, 0 to 2 percent slopes | 10% |

Soil Survey Staff, Natural Resources Conservation Service 2015

Table 5. Dominant Soil Types Present in Midewin National Tallgrass Prairie Southwest Site and Approximate Percentage of site (greater than 10 % of site).

| Soil Symbol | Soil Type | Percentage Present |
|---|---|---|
| 523A | Dunham silty clay loam, 0 to 2 percent slopes | 81% |
| 526A | Grundelein silt loam, 0 to 2 percent slopes | 13% |

Soil Survey Staff, Natural Resources Conservation Service 2015

**Monee Reservoir** is located in Monee Illinois, owned by the Will County Forest Preserve District (Forest Preserve District of Will County 2011) and is 103.2 ha in size with a 19 ha lake. The Monee reservoir prairie is 14 years of age at the time of the study. It is located at 41° 23’ 10.39” N, 87° 45’ 56.85” with an approximate elevation of 228.9 m (Google Earth 2012 e).

Table 6. Dominant Soil Types Present in the Monee Reservoir and Approximate Percentage of Site (greater than 10 % of site.

| Soil Symbol | Soil Type | Percentage Present |
|---|---|---|
| 232A | Ashkum silty clay loam, 0 to 2 percent slopes | 28% |
| 298B | Beecher silt loam, 2 to 4 percent slopes | 28% |
| 531C2 | Markham silt loam, 4 to 6 percent slopes, eroded | 44% |

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**Park Forest Gardens** is a restored prairie found in University Park Illinois in an area formally used for community gardens. The Park Forest Gardens are three years of age at the time of the study. The Park Forest Gardens are maintained by the Will County Forest Preserve District (Forest Preserve District of Will County 2011). The Park Forest Gardens are located at 41° 27'06.66N, 87° 42' 33.50"W with an elevation of 233.48 m (Google Earth 2012 f).

Table 7. Dominant Soil Types Present in Park Forest Gardens and Approximate Percentage of Site (greater than 10 % of site).

| Soil Symbol | Soil Type | Percentage Present |
|---|---|---|
| 235A | Bryce silty clay, 0 to 2 percent slopes | 26% |
| 241D3 | Chatsworth silty clay, 6 to 12 percent slopes, severely eroded | 36% |
| 320B | Frankfort silt loam, 2 to 4 percent slopes | 21% |
| 320C2 | Frankfort silt loam, 4 to 6 percent slopes, eroded | 16% |

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**Perry Farm Park** is a 69 ha prairie restoration located in Bourbonnais Illinois, and managed by the Bourbonnais Park District (Bourbonnais Park District 2011). Perry Farm prairie restoration is 13 years of age at the time of this study. Perry Farm is located at 41° 08’ 43.51” N, 87° 53’ 09.63” W with an elevation of 199.95 m (Google Earth 2012g). Perry Farm was created in 1835 and willed to the state to become a park in 1961 by Lormira Perry. Prairie restoration at Perry Farm began in 1994 with bare root planting. Currently they are using a seed drill in the areas that are being planted. Perry Farm personnel also collect and sow seeds by hand. Beginning in 1994, individual sections of the park have been burned every year or every other year (H. Clark, personal communication).

Table 8. Dominant Soil Types Present in Perry Farm and Approximate Percentage of Site (greater than 10 % of site).

| Soil Symbol | Soil Type | Percentage Present |
|---|---|---|
| 298B | Beecher silt loam, 0 to 2 percent slopes | 12% |
| 530B | Ozaukee silt loam, 2 to 4 percent slopes | 28% |
| 530C3 | Ozaukee silt loam, 4 to 6 percent slopes, severely eroded | 11% |

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**Schulenberg Prairie** is managed by Morton Arboretum and is located in Lisle Illinois on approximately 688 ha. It is located at 41° 48’ 56.68 N, 87° 53’ 09.63” with an elevation of 225.55 m (Google Earth 2012h). Schulenberg Prairie is one of the oldest planted prairies in the Midwest (Morton Arboretum 2009). There are three different aged sites at Schulenburg Prairie:

**Schulenberg Prairie (youngest)** This site was established by planting seedlings and spreading seeds by hand into tilled soil during the late 1970s through the early 1980s (Egan 1997). Schulenberg Prairie (youngest) is 30 years of age at the time of this study.

Table 9. Dominant Soil Types Present in Schulenberg youngest (Morton Arboretum) and Approximate Percentage of Site (greater than 10 % of site).

| Soil Symbol | Soil Type | Percentage Present |
|---|---|---|
| 531B | Markham silty loam, 2 to 4 percent slopes | 85% |

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**Schulenberg Prairie (early 1970's)** this site was established by planting seedlings into tilled soil and spreading seeds by hand in the early 1970s is 35 years of age at the time of this study.

Table 10. Dominant Soil Types Present in Schulenberg early 1970's (Morton Arboretum) and Approximate Percentage of site (greater than 10 % of site):

| Soil Symbol | Soil Type | Percentage Present |
|---|---|---|
| 298B | Beecher silt loam, 0 to 2 percent slopes | 28% |
| 530B | Ozaukee silt loam, 2 to 4 percent slopes | 56% |
| 530C2 | Ozaukee silt loam, 4 to 6 percent slopes, eroded | 13% |

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**Schulenberg Prairie (Acre)** This site was established by planting seedlings in strips and by broadcasting seeds by hand in 1963 (Egan 1997), making this site 45 years of age at the time of this study.

Table 11. Dominant Soil Types Present in Schulenberg Acre (Morton Arboretum) and Approximate Percentage of Site (greater than 10 % of site).

| Soil Symbol | Soil Type | Percentage Present |
|---|---|---|
| 146B | Elliot silt loam, 2 to 4 percent slopes | 17% |
| 232A | Ashkum silty clay loam, 0 to 2 percent slope | 15% |
| 530D2 | Ozaukee silt loam, 6 to 12 percent slopes, eroded | 24% |
| 531B | Markham silty loam, 2 to 4 percent slopes | 43% |

Soil Survey Staff, Natural Resources Conservation Service 2015

The plant species used in this study are the dominant perennial plant species present in each site. Dominant species were identified in each site by using species abundance and frequency at the plot and site levels from data collected in 2008. During the summer of 2008, plant species were identified at each site in 20 plots, 0.5m by 0.5m, located on two transects at each site. The transects were placed to avoid water, dense shrubs and disturbed areas (mowed paths or gravel lanes). All plants rooted within the plots were identified, and percent cover was estimated for each species. Dominant species at each site had at least 80% combined coverage in at least two plots and at least 10% coverage within individual plots.

Plants used for measurement of functional traits were healthy adult plants without evidence of parasites, herbivore damage or fire damage. For species that live in full sun the plants with the most exposure to the sun were used **(**Cornelissen et al. 2003). The traits measured and analyzed were the following: seed mass, seed shape, seed maturation date, specific leaf area, leaf mass and maximum plant height.

Study Species by Family

**Fabaceae** is the pea or legume family, including 236 genera and 2500 species (USDA 2011). These plants are commonly herbs, trees, shrubs or climbing plants with a high nitrogen demanding metabolism. Plants in this family commonly have nitrogen-fixing nodules containing nitrogen-fixing bacteria (*Rhizobium*; Judd et al. 1999). Species included in this study are white wild indigo (*Baptisia leucantha*), lead plant (*Amorpha canescens*), white prairie clover (*Dalea candida*), purple prairie clover (*Dalea purpurea),* round-headed bush clover (*Lespedeza capitata*), and red clover (*Trifolium pratense*; USDA 2011).

**Poaceae** is the grass family and includes 338 genera and 1935 species (USDA 2011). The Poaceae family is found world over and is considered the most economically important family due to livestock grazing and crop production. It also is considered the most dominant of the flowering plant families, with species found on all continents and in all habitats. These plants are annuals and perennial herbs, with fibrous roots, long hollow stems and linear leaves that wrap around the stem (Judd et al. 1999). Big bluestem (*Andropogon gerardii*), switch grass (*Panicum virgatum*), timothy grass (*Phleum pratense*), Kentucky bluegrass (*Poa pratensis*), little bluestem (*Schizachyrium scoparium*), Indian grass (*Sorghastrum nutans*), prairie dropseed (*Sporobolus heterolepis*) and prairie cordgrass (*Spartina pectinata*) are species included in this study.

**Asteraceae** has 477 genera and 4159 species (USDA 2011), and is the second largest family of dicots. Most species are herbaceous, and include food crops such as lettuce and sunflowers (Judd et al. 1999). Species included in the study are heath aster (*Aster ericoides*), smooth blue aster (*Aster laevis*), prairie coreopsis (*Coreopsis palmata*), tall coreopsis (*Coreopsis tripteris*), false sunflower (*Heliopsis helianthoides*), marsh blazingstar (*Liatris spicata*), wild quinine (*Parthenium integrifolium*), grey headed coneflower (*Ratibida pinnata*), rosinweed (*Silphium integrifolium*), compass plant (*Silphium laciniatum*) prairie dock (*Silphium terebinthinaceum*), tall goldenrod (*Solidago altissima)* and stiff goldenrod (*Solidago rigida*).

**Lamiaceae** is the mint family and contains 76 genera and 817 species. One species from this family, wild bergamot (*Monarda fistulosa*), is included in this study (USDA 2011).

**Gentianaceae** has 17 genera and 158 species (USDA 2011).These plants are herbs, shrubs and small trees, with some species considered mycoparasites. One species from this family, cream gentian (*Gentiana flavida*), is included in this study (Judd et al. 1999).

**Apiaceae (Umbelliferae)** is the carrot family with approximately 91 genera and 616 species (USDA 2011). Apiaceae is considered one of the best known of the flowering plant families, with members having a distinctive odor, flavor and toxicity (Downie et. al. 1996). One species from this family, rattlesnake master (*Eryngium yuccifolium*), is included in this study.

## Chapter 2 Synthesis of Research

### Introduction

Although prairies have been a focus of study since the dustbowl of the 1930s, currently 82-99% of former prairies have been destroyed (Sampson and Knopf 1994). What remains of the prairies is fragmented and being threatened with development and woody vegetation encroachment (McLachlan and Knispel 2005). By the restoration of prairie we gain better understanding of succession, competition, plant population dynamics, ecological processes and prairie ecosystem management (Kindscher and Tieszen 1998).

Quantitative traits of the dominant species in an ecosystem have the most effect on the processes of an ecosystem, and species traits have more effect on the ecosystem than on the number of species present (Garnier et al. 2004). To compete, each plant species allocates its energy differently. Seed mass, seed structure, seed maturation date, specific leaf area, leaf mass and maximum plant height are some of the traits that this allocation of energy determines (Cornelissen et al. 2003).

Estimating prairie plant types and populations that should be in a restored area during an established time-frame would be of great help to restoration biologists as well as private citizens. Schramm (1990) found that the restorer should try to mimic the natural mosaic of prairie plants in a restoration project. Quantitative models formed from a trait study could be used to determine the success of a restoration project when compared to other sites of the same age and type.

In a recent study, a statistical mechanics model was used to predict species composition and relative abundances from functional traits of species. The study was conducted using a chronosequence of 12 former vineyards in France. The 12 sites were abandoned from 2 to 42 years before the study (Garnier et al. 2004, Shipley et al. 2006). Eight functional traits from 30 different herbaceous species were measured. The traits studied were proportion of the species that were perennial, seed number per plant, seed maturation date, specific leaf area (SLA), above ground vegetative mass, stem mass, leaf mass and maximum height of the plant (Shipley et al. 2006). Assumptions made were that trait values can be approximated as species-specific attributes, and that intraspecific genotype evolution of traits is insignificant relative to pre-existing interspecific variation.

The study focused on environmental filters sorting species by their functional traits to determine community assembly at a location in a given time-frame. Nonrandom processes determined by functional traits between species include seed dispersal, growth, survival, and reproduction. These processes greatly affect the community structure in a site (Shipley et al. 2006).

This present study used species functional traits (seed mass, seed shape, seed maturation date, specific leaf area, leaf mass and maximum plant height) to determine whether it is possible to determine the relative percent cover of the different species of prairie plants in different aged prairie restorations using the statistical mechanics model developed by Shipley et al. (2006).

## Methods

Study Area – The study area consists of 11 sites in 8 locations with the age of the sites ranging from 3- 35 years:

Park Forest Gardens- Park Forest Gardens is a prairie restoration in University Park, Illinois in an area formally used for community gardens; and is maintained by the Will County Forest Preserve District (Forest Preserve District of Will County 2011). The Park Forest Gardens restoration is three years of age at the time of the study.

Midewin National Tallgrass Prairie- Midewin National Tallgrass Prairie is an approximately 7375 ha preserve established in 1996 by the Illinois Land Conservation Act, managed by the United States Forest Service, and located near Elwood, Illinois at the site of the former Joliet Army Ammunition Plant (USDA 2002). Midewin National Tall Grass Prairie has two study sites--northeast and southwest--both four years of age at the time of this study.

Perry Farm- Perry Farm Park is a 69-ha prairie restoration located in Bourbonnais Illinois and managed by the Bourbonnais Park District (Bourbonnais Park District 2011). The Perry Farm prairie restoration is 13 years of age at the time of this study.

Monee Reservoir- Monee Reservoir is 103.2 ha in size with a 19 ha lake and it is owned by the Will County Forest Preserve District (Forest Preserve District of Will County 2011). The Monee Reservoir prairie restoration is 14 years of age at the time of the study.

Fermilab Prairie – Fermilab is a 2750 ha site commissioned in 1967 by the U. S. Atomic Energy Commission as a particle accelerator with 486 ha involved in prairie restoration. The Fermilab prairie is 35 years of age at the time of this study. Fermilab is located near Batavia in Will County Illinois.

Schulenberg Prairie- Schulenberg Prairie is managed by Morton Arboretum and is located in Lisle, Illinois on approximately 688 ha. The three restoration sites (Youngest, Early 1970s and Acre) within Schulenberg Prairie are 30, 35 and 45 years old at the time of this study.

Gensburg – Markham Prairie and Indian Paintbrush Prairies- Both prairie remnants are part of the Indian Boundary Prairies located near Markham, Illinois. Gensburg – Markham Prairie and Indian Paintbrush Prairies were assigned an age of 100 years for this study as they are remnants. Gensburg – Markham Prairie is approximately 40 ha and Indian Paintbrush Prairie is approximately 24 ha in size (The Nature Conservatory 2011).

The plant species used in this study are the dominant perennial plant species present in each site. Dominant species were identified in each site by using species abundance and frequency at the plot and site levels from data collected in 2008. During the summer of 2008, plant species were identified at each site in 20 plots, 0.5m by 0.5m, located on two transects at each site. The transects were placed to avoid water, dense shrubs and disturbed areas (mowed paths or gravel lanes). All plants rooted within the plots were identified, and percent cover was estimated for each species. Dominant species at each site had at least 80% combined coverage in at least two plots and at least 10% percent coverage within individual plots.

Plants used for measurement of functional traits were healthy adult plants without evidence of parasites, herbivore damage or fire damage. For species that live in full sun the plants with the most exposure to the sun were used (Cornelissen et al. 2003). The traits measured and analyzed were the following: seed mass, seed shape, seed maturation date, specific leaf area, leaf mass and maximum plant height. Thirty-one plant species were measured in this study.

## Seed mass and seed shape

Seeds were collected upon maturation, dried and weighed. Seeds were cleaned by removing parts such as pappus that fall off easily (Weiher et. al. 1999). Seeds were measured on three axes: length, width and breadth. Seed shape was calculated as the statistical variance of length, width and breadth measurements. For this study we used a minimum of 20 seeds from a minimum of four different plants. Seeds were weighed after drying for 24 hours at $80^o$ C to determine mass of the seed.

## Seed maturation date

Seed maturation date was obtained through observation and literature and recorded as its Julian date.

## Specific leaf area

Specific leaf area (SLA) is determined by the area of one side of a fresh leaf divided by its dried mass. The SLA was measured as $m^2$/kg. Most of the SLA data had been collected. For SLA measurement, leaves were chosen from mature plants without blemishes, parasites or fire damage. One leaf was collected from ten different plants growing in full sun. The youngest mature leaf (fully expanded) was collected from each plant. All leaves from each species were placed in a plastic bag and then placed on ice in a cooler. Leaves then were placed in bags was filled with reverse osmosis water and left for 24 hours at room temperature. Leaves were handled with forceps upon removal from each bag. Each leaf was blotted until all surface water was absorbed. Each leaf then was weighed to record the wet weight. Using a Canon CanoScan LiDE color image scanner with Winfolia software, each leaf was scanned for its leaf area. Each measured leaf was then put into a labeled paper bag and dried at 80$^{o}$ C in an oven for 24 hours. Each leaf was then weighed, and its dry weight recorded. Each leaf's SLA was then calculated.

### Leaf mass

Leaf mass was determined using leaves that were mature and without blemishes or parasites, dried for 24 hours at 80$^{o}$ Celsius and then weighed to determine mass.

### Maximum Plant height

The plant height was taken from the highest portion of the plant above ground that conducts photosynthesis or the main stem if above the leaves (seeds and fruit if at the highest point were not used in the measurement), to the ground at the base of the plant (Cornelissen et al. 2003).

### Analysis

The plant traits seed mass, seed shape, seed maturation date (Julian date), specific leaf area, leaf mass and maximum plant height were analyzed using the Maxent program in R to determine if it is possible to determine the make-up of a prairie plant community during a specific time period in restoration (Shipley et al. 2006, R Developmental Core Team 2011).

For this study a constraint matrix was developed to include the mean or median trait value for each individual species, and was be entered as the first input to the Maxent program. The community aggregate trait value for each trait was calculated by adding (species trait value) x (relative abundance) products for all species at a site. The second input to the program was a vector of all community aggregate trait values for the site.

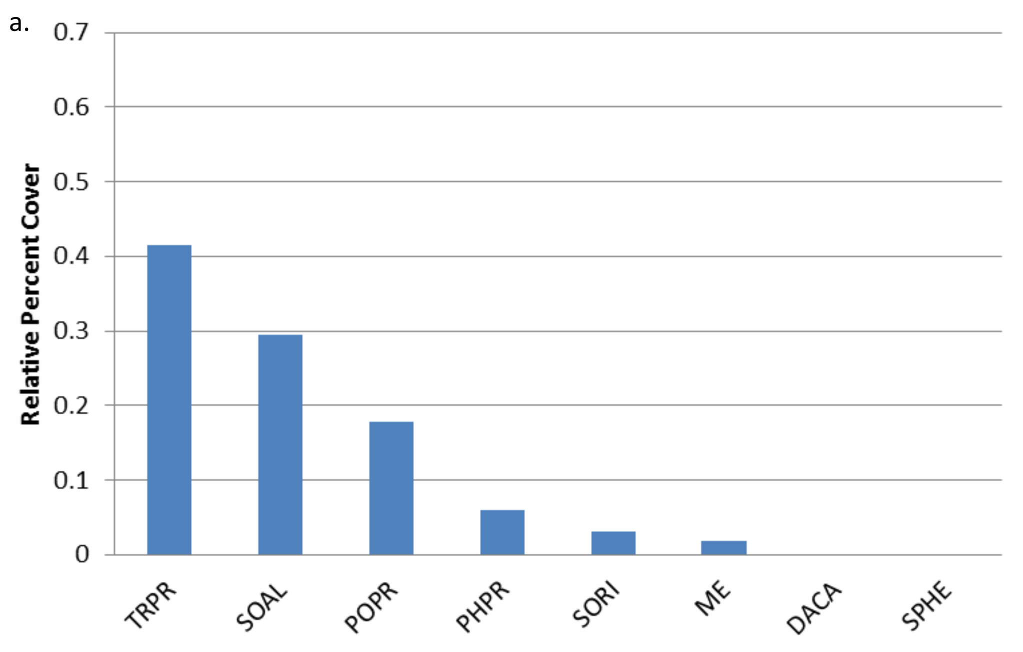
The output from the Maxent R program for a single site was the probability of each species at the site, based on the site's aggregate trait values. Analysis was a regression and correlation analysis. Performance of the Maxent program was assessed by comparing the observed percent cover to the estimated percent cover from the Maxent program at each site and over all the sites. A regression was used to determine how well the Maxent program predicted percent cover only of plant species present in sites. Correlation analyses conducted separately for each site were used to compare percent cover of dominant species present at a site with percent cover of dominant species predicted by the Maxent program (which frequently included species predicted as dominant species by Maxent, but not among dominant species observed at a site).

Results

Table 12. Species code, scientific name, common name and family name of study species

| Species Code | Scientific Name | Common Name | Family |
|---|---|---|---|
| AMCA | *Amorpha canescens* | lead plant | Fabaceae |
| ANGE | *Andropogon gerardii* | big bluestem | Poaceae |
| ASER | *Aster ericoides* | heath aster | Asteraceae |
| ASLA | *Aster laevis* | blue aster | Asteraceae |
| BALE | *Baptisia leucantha* | white wild indigo | Fabaceae |
| COPA | *Coreopsis palmata* | prairie coreopsis | Asteraceae |
| COTR | *Coreopsis tripteris* | tall coreopsis | Asteraceae |
| DACA | *Dalea candida* | white prairie clover | Fabaceae |
| DAPU | *Dalea purpurea* | purple prairie clover | Fabaceae |
| ERYU | *Eryngium yuccifolium* | rattlesnake master | Apiaceae |
| GEFL | *Gentiana flavida* | cream gentian | Gentianaceae |
| HEHE | *Heliopsis helianthoides* | false sunflower | Asteraceae |
| LECA | *Lespedeza capitata* | round-headed bush clover | Fabaceae |
| LISP | *Liatris spicata* | marsh blazingstar | Asteraceae |
| ME | *Melilotus* sp. | sweet clover | Fabaceae |
| MOFI | *Monarda fistulosa* | wild bergamot | Lamiaceae |
| PAIN | *Parthenium integrifolium* | wild quinine | Asteraceae |
| PAVI | *Panicum virgatum* | switch grass | Poaceae |
| PHPR | *Phleum pratense* | timothy grass | Poaceae |
| POPR | *Poa pratensis* | Kentucky bluegrass | Poaceae |
| RAPI | *Ratibida pinnata* | grey-headed coneflower | |
| SCSC | *Schizachyrium scoparium* | little bluestem | Poaceae |
| SIIN | *Siphium integrifolium* | rosinweed | Asteraceae |
| SILA | *Silphium laciniatum* | compass plant | Asteraceae |
| SITE | *Silphium terebinthinaceum* | prairie dock | Asteraceae |
| SOAL | *Solidago altissma* | Canadian goldenrod | Asteraceae |
| SONU | *Sorghastrum nutans* | Indian grass | Poaceae |
| SORI | *Solidago rigida* | stiff goldenrod | Asteraceae |
| SPHE | *Sporobolus heterolepis* | prairie dropseed | Poaceae |
| SPPE | *Spartina pectinata* | prairie cordgrass | Poaceae |
| TRPR | *Trifolium pratense* | red clover | Fabaceae |

Site Comparison Data



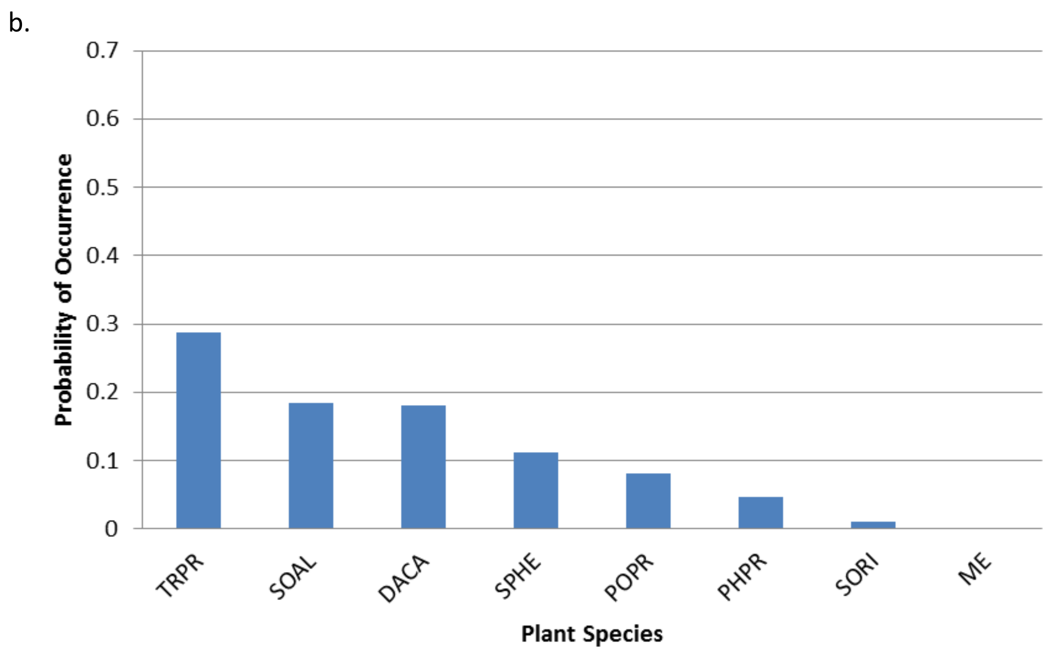




Fig.1. Park Forest Gardens restoration (age 3 years) observed (a) and predicted (b) dominant plant species. Species in (a) include six dominant species at the site plus two additional species predicted by Maxent as among the six most abundant but not present as dominant species at the site. Species in (b) include the six most abundant species predicted by Maxent plus two species present as dominant species at the site, but not ranked among the top six predicted species.

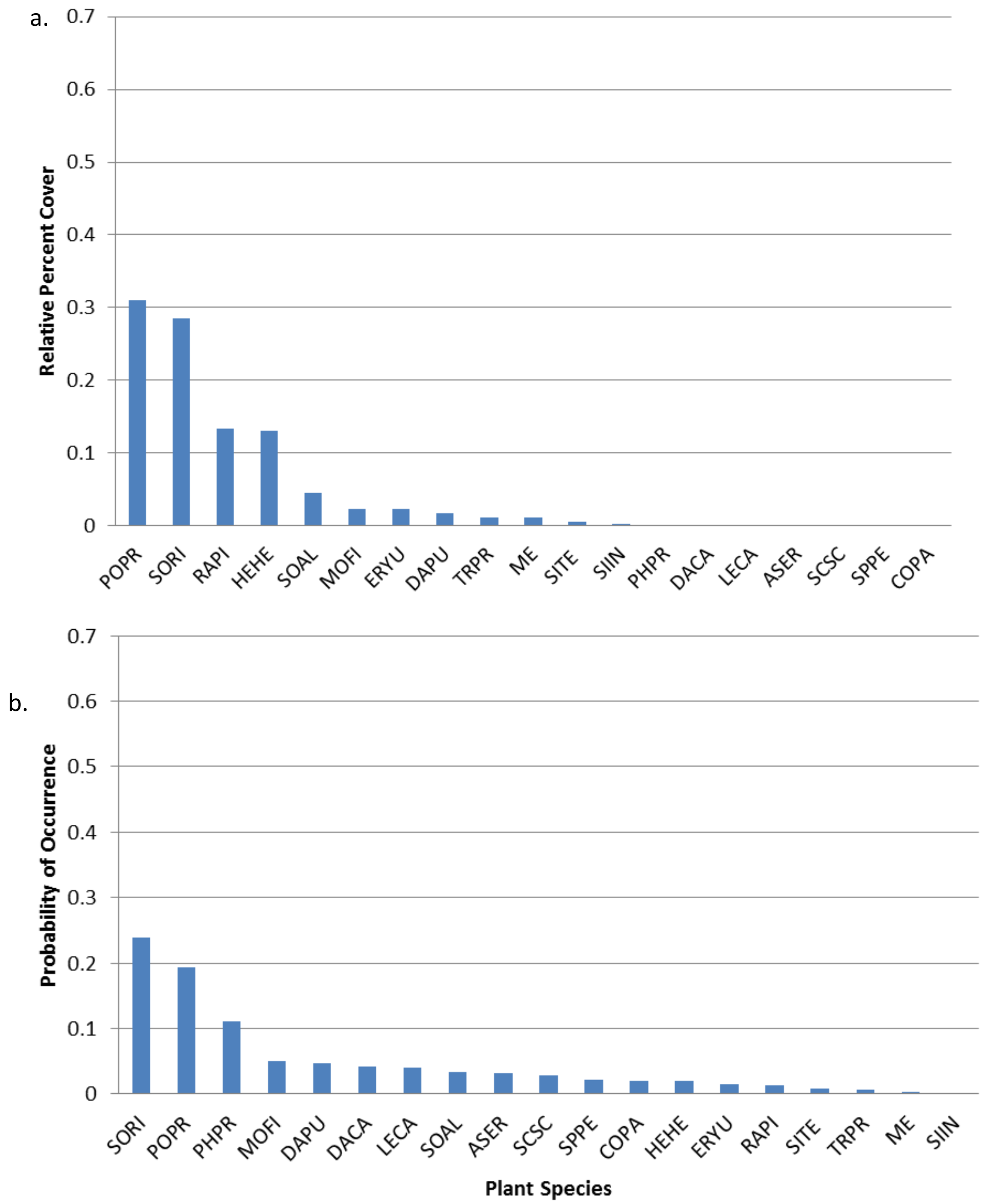



Fig.2. Midewin National Tallgrass Prairie Northwest site restoration (age 4 years) observed (a) and predicted (b) dominant plant species. Species in (a) include 12 dominant species at the site plus seven additional species predicted by Maxent as among the 12 most abundant but not present as dominant species at the site. Species in (b) include the 12 most abundant species predicted by Maxent plus seven species present as dominant species at the site, but not ranked among the top 12 predicted species.

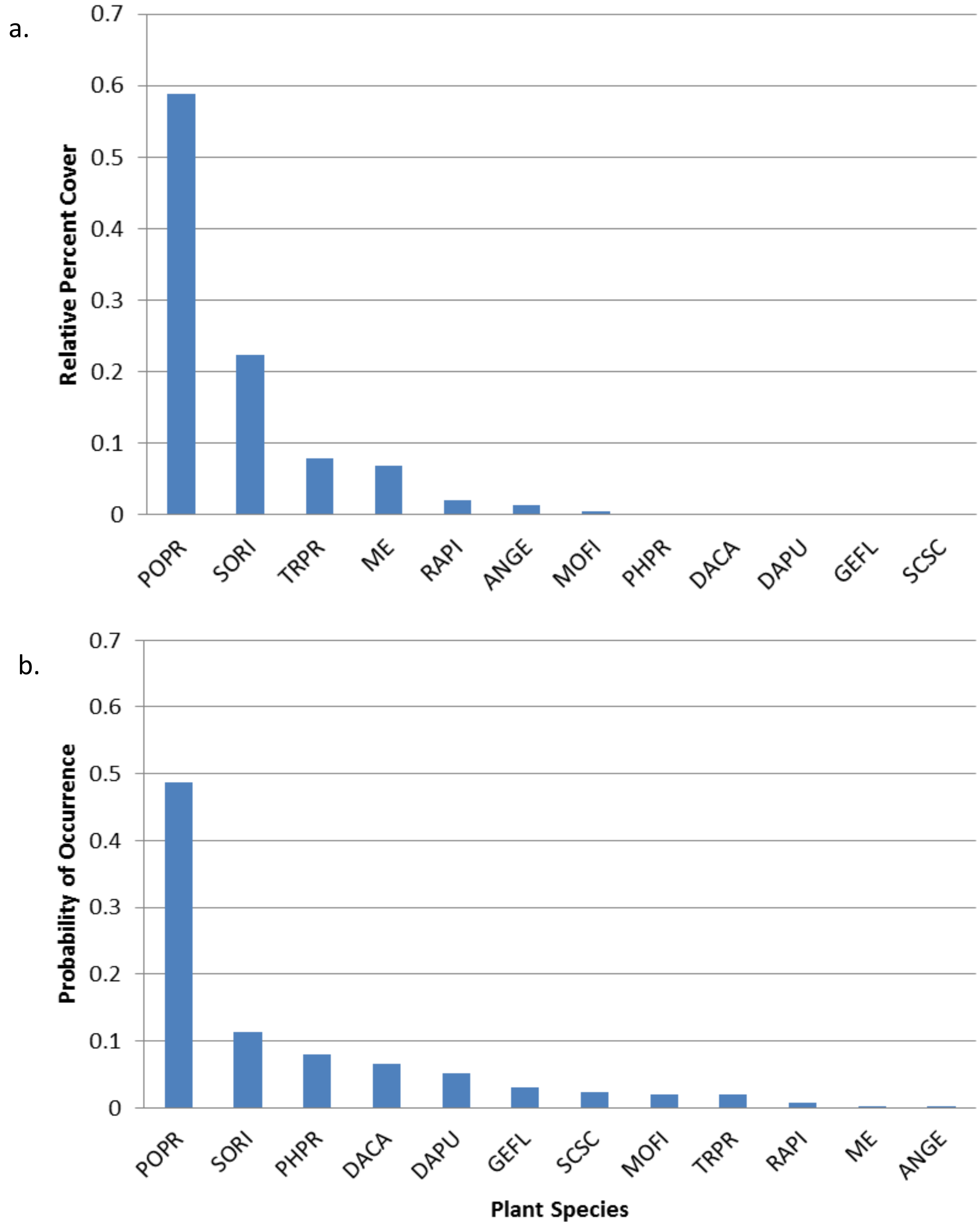
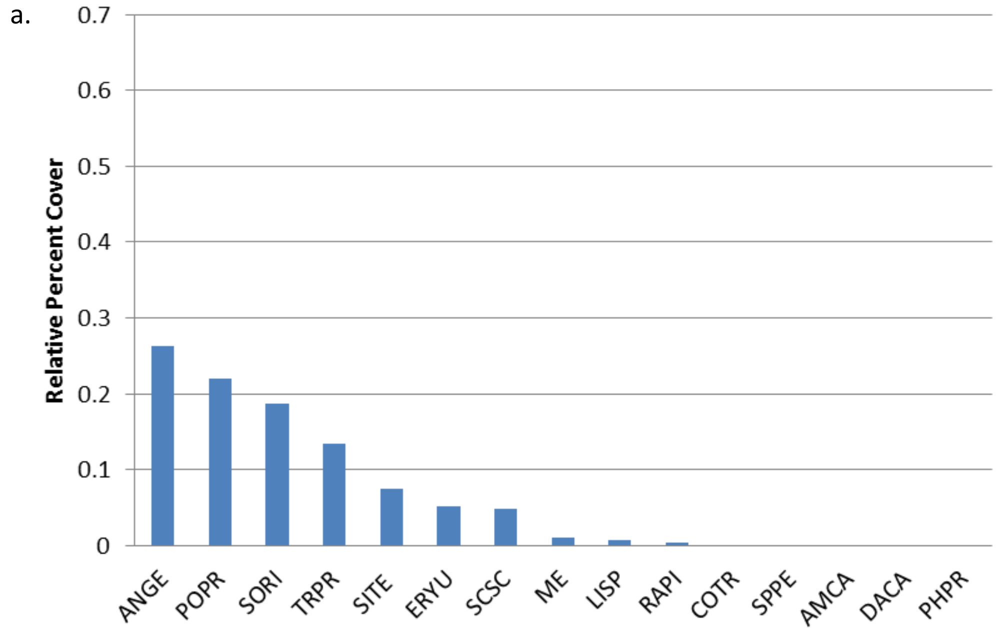



Fig.3. Midewin National Tallgrass Prairie Southeast site restoration (age 4 years) observed (a) and predicted (b) dominant plant species. Species in (a) include seven dominant species at the site plus five additional species predicted by Maxent as among the seven most abundant but not present as dominant species at the site. Species in (b) include the seven most abundant species predicted by Maxent plus five species present as dominant species at the site, but not ranked among the top seven predicted species.



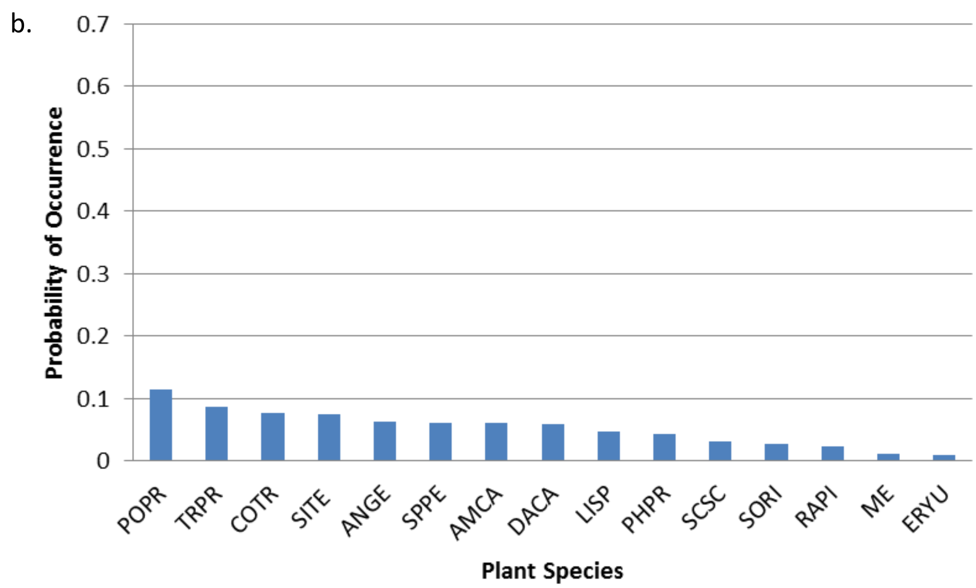




Fig.4. Perry Farm restoration (age 13 years) observed (a) and predicted (b) dominant plant species. Species in (a) include 10 dominant species at the site plus five additional species predicted by Maxent as among the 10 most abundant but not present as dominant species at the site. Species in (b) include the 10 most abundant species predicted by Maxent plus five species present as dominant species at the site, but not ranked among the top 10 predicted species.

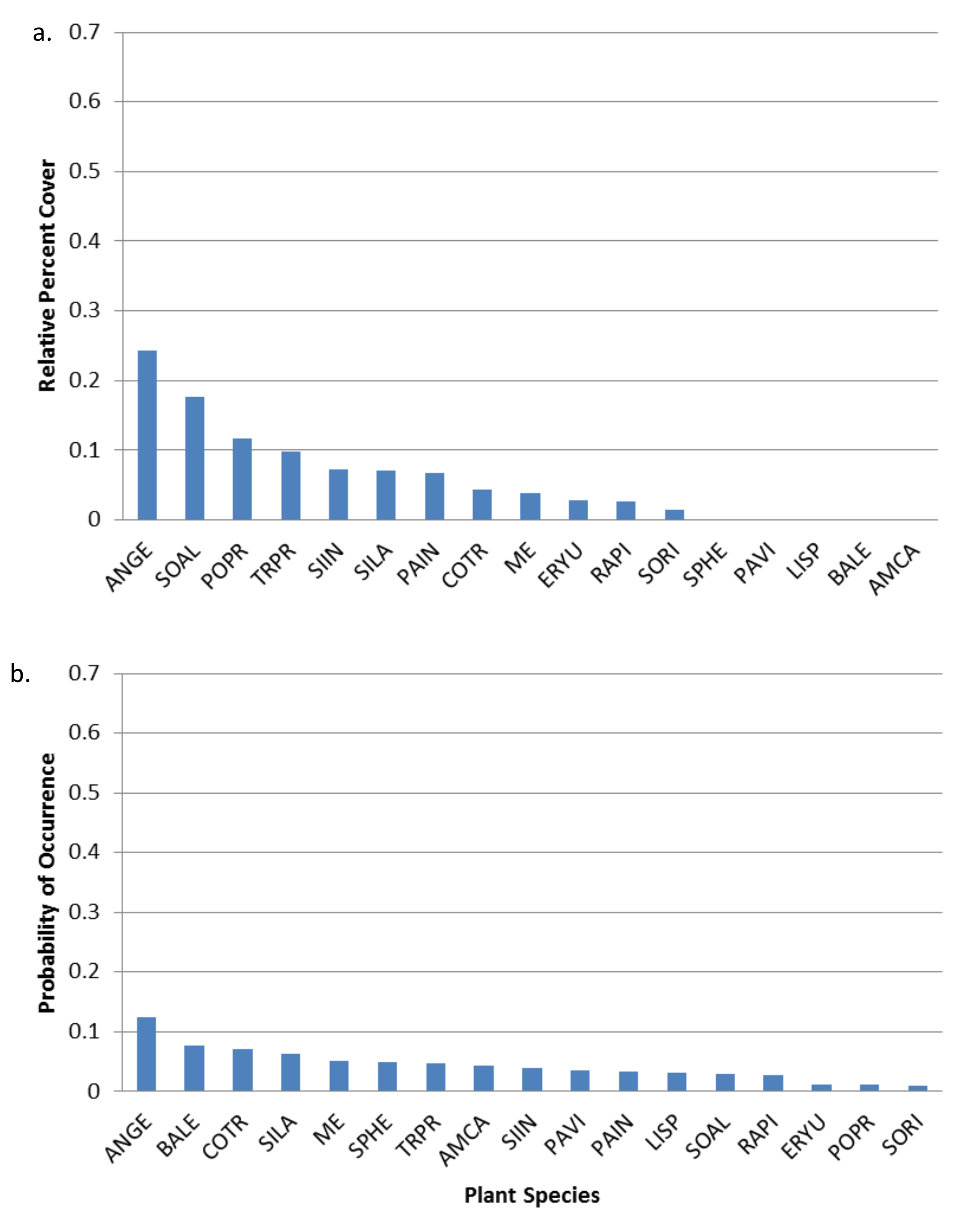



Fig.5. Monee Reservoir restoration (age 14 years) observed (a) and predicted (b) dominant plant species. Species in (a) include 12 dominant species at the site plus five additional species predicted by Maxent as among the 12 most abundant but not present as dominant species at the site. Species in (b) include the 12 most abundant species predicted by Maxent plus five species present as dominant species at the site, but not ranked among the top 12 predicted species.

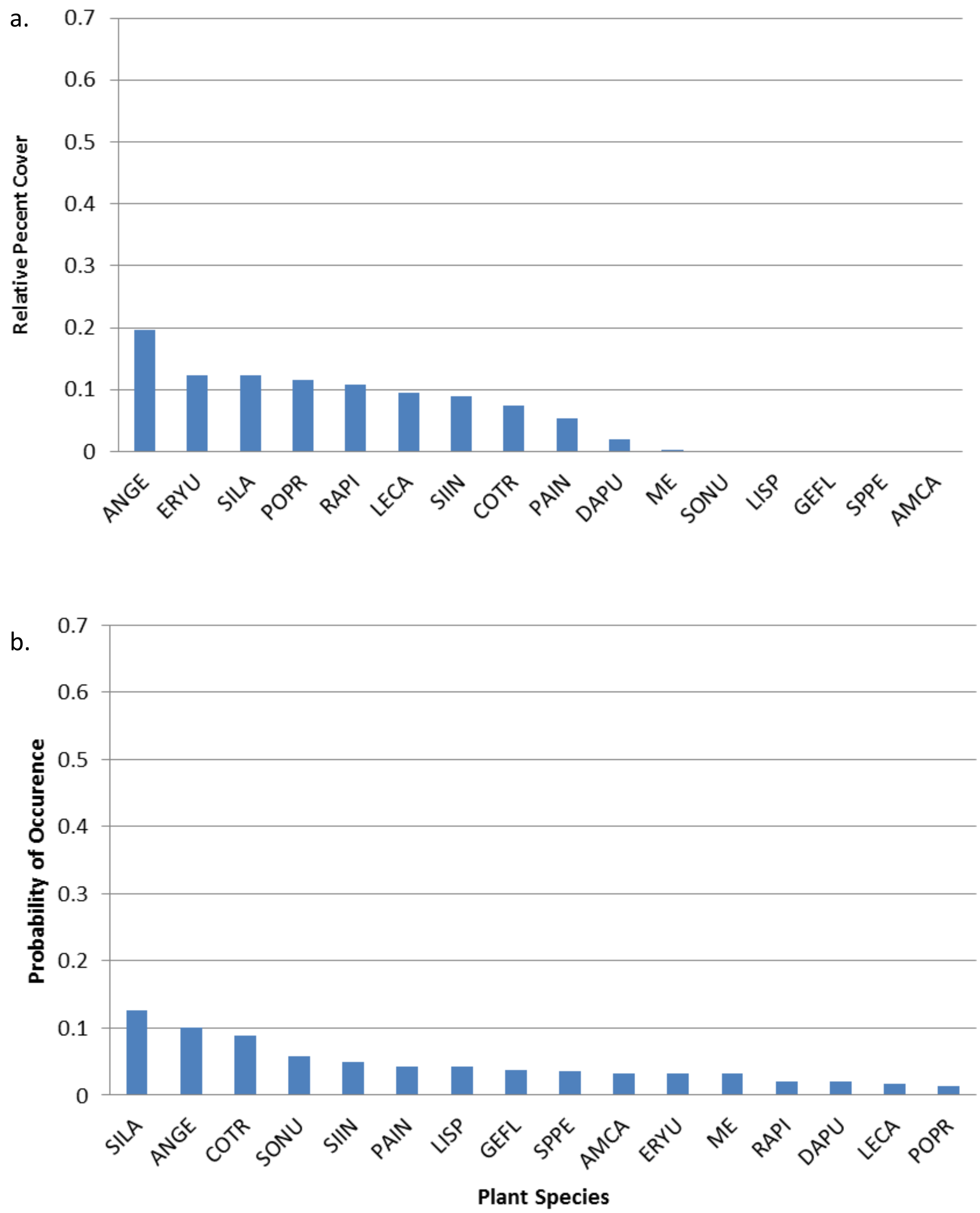



Fig.6. Schulenberg Prairie Youngest restoration (age 30 years) observed (a) and predicted (b) dominant plant species. Species in (a) include 11 dominant species at the site plus five additional species predicted by Maxent as among the 11 most abundant but not present as dominant species at the site. Species in (b) include the 11 most abundant species predicted by Maxent plus five species present as dominant species at the site, but not ranked among the top 11 predicted species.

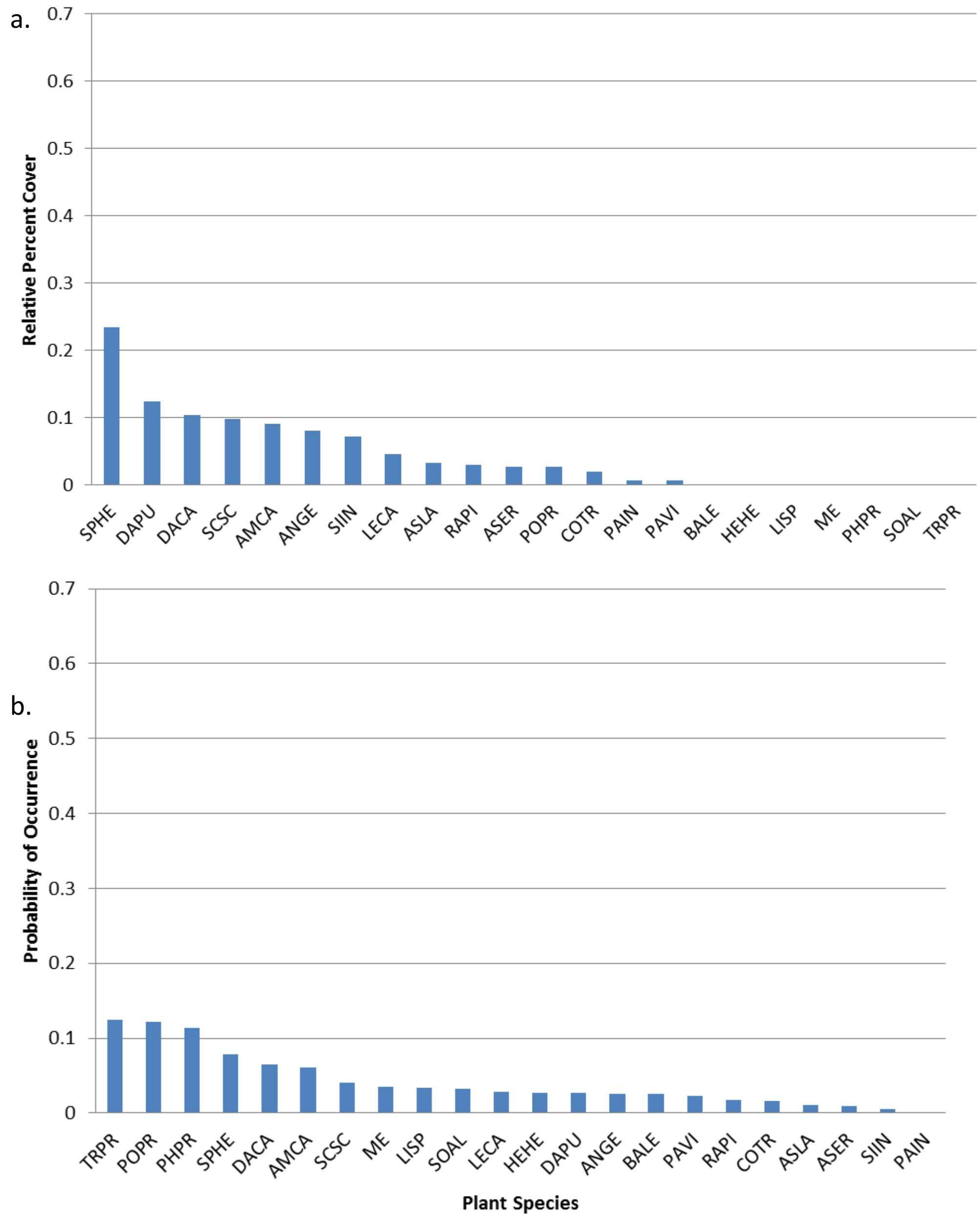
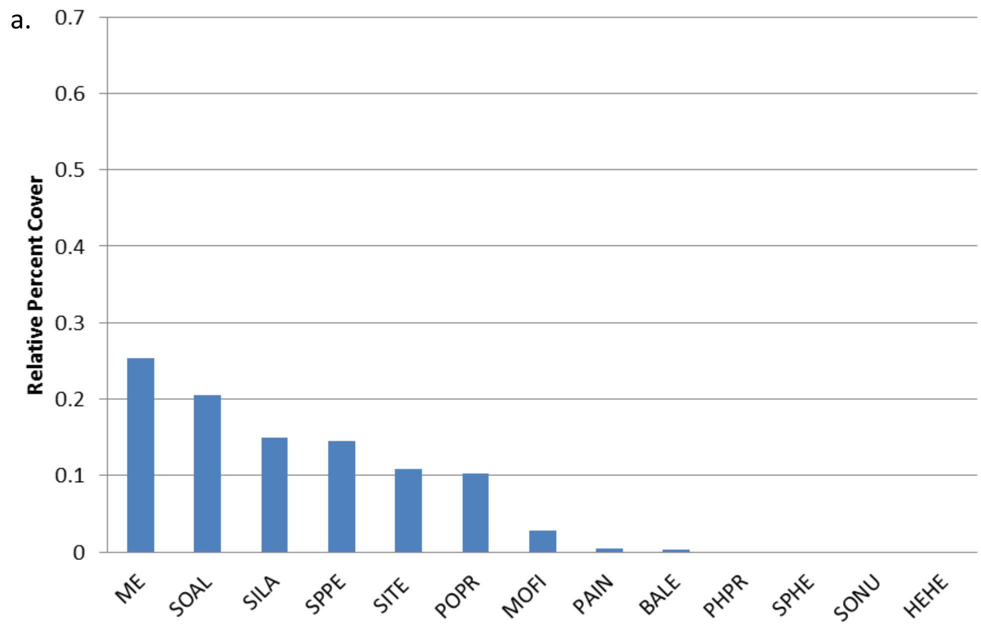



Fig.7. Schulenberg Prairie 1970s restoration (age 35 years) observed (a) and predicted (b) dominant plant species. Species in (a) include 15 dominant species at the site plus seven additional species predicted by Maxent as among the 15 most abundant but not present as dominant species at the site. Species in (b) include the 15 most abundant species predicted by Maxent plus seven species present as dominant species at the site, but not ranked among the top 15 predicted species.



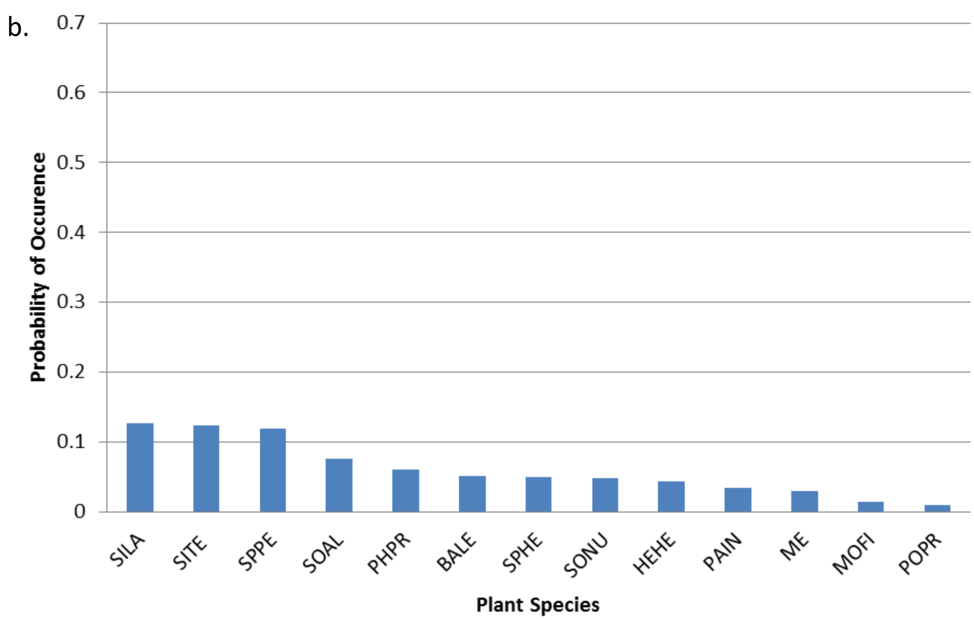




Fig.8. Fermilab restoration (age 35 years) observed (a) and predicted (b) dominant plant species. Species in (a) include nine dominant species at the site plus four additional species predicted by Maxent as among the nine most abundant but not present as dominant species at the site. Species in (b) include the nine most abundant species predicted by Maxent plus four species present as dominant species at the site, but not ranked among the top nine predicted species.

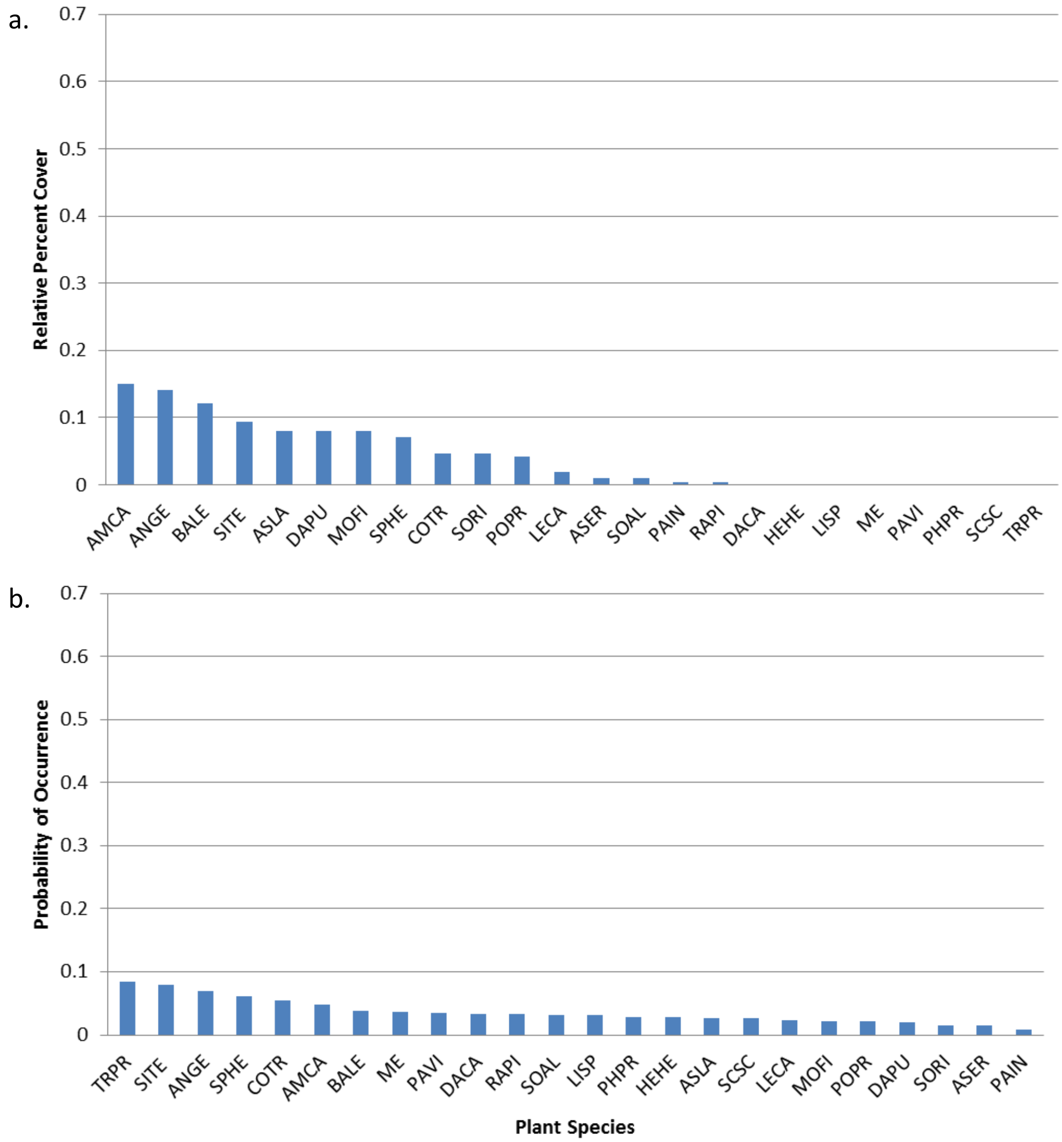



Fig.9. Schulenberg Prairie Acre restoration (age 45 years) observed (a) and predicted (b) dominant plant species. Species in (a) include 17 dominant species at the site plus seven additional species predicted by Maxent as among the 17 most abundant but not present as dominant species at the site. Species in (b) include the 17 most abundant species predicted by Maxent plus seven species present as dominant species at the site, but not ranked among the top 17 predicted species.

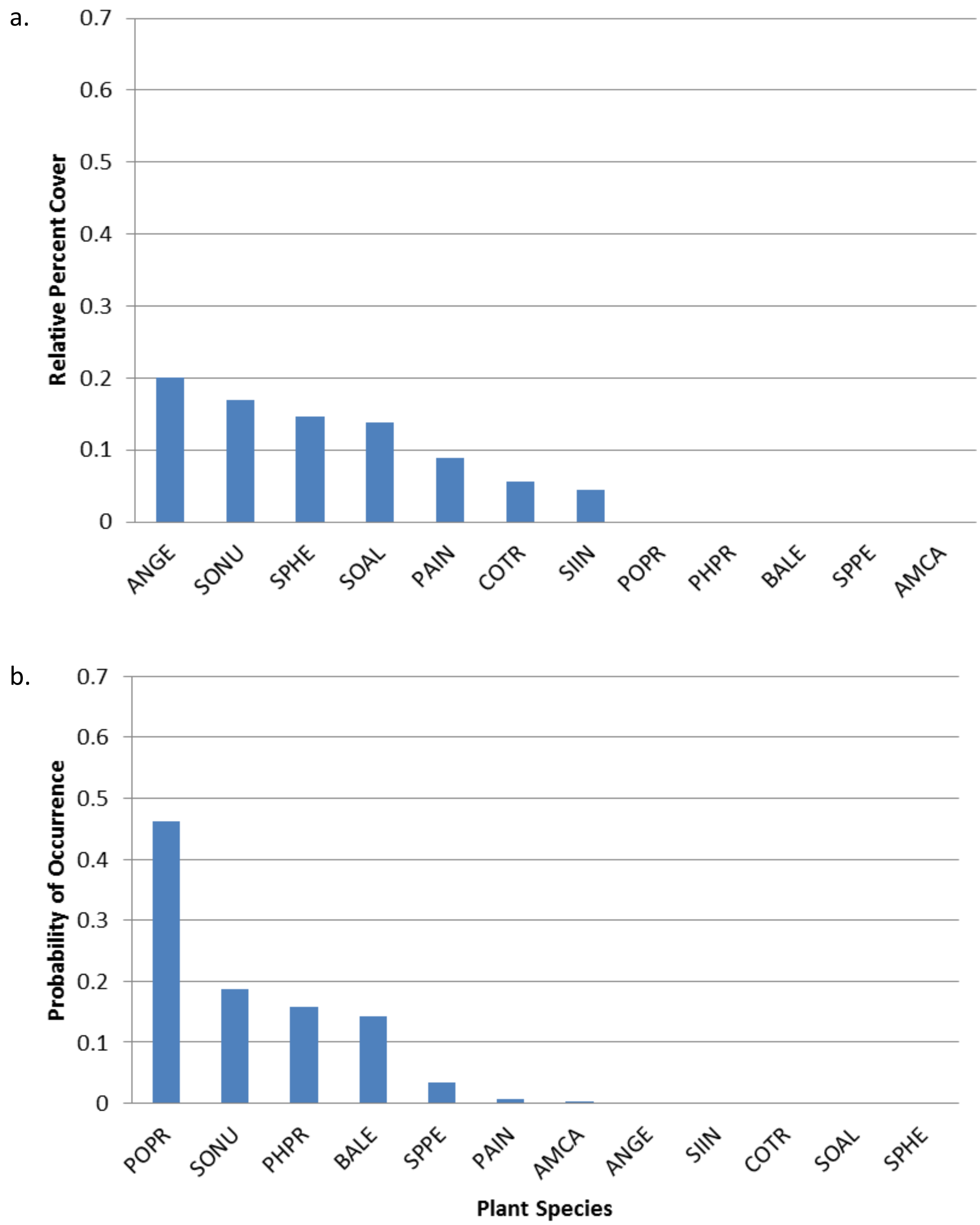



Fig.10. Indian Paintbrush Prairie remnant observed (a) and predicted (b) dominant plant species. Species in (a) include seven dominant species at the site plus four additional species predicted by Maxent as among the seven most abundant but not present as dominant species at the site. Species in (b) include the seven most abundant species predicted by Maxent plus four species present as dominant species at the site, but not ranked among the top seven predicted species.

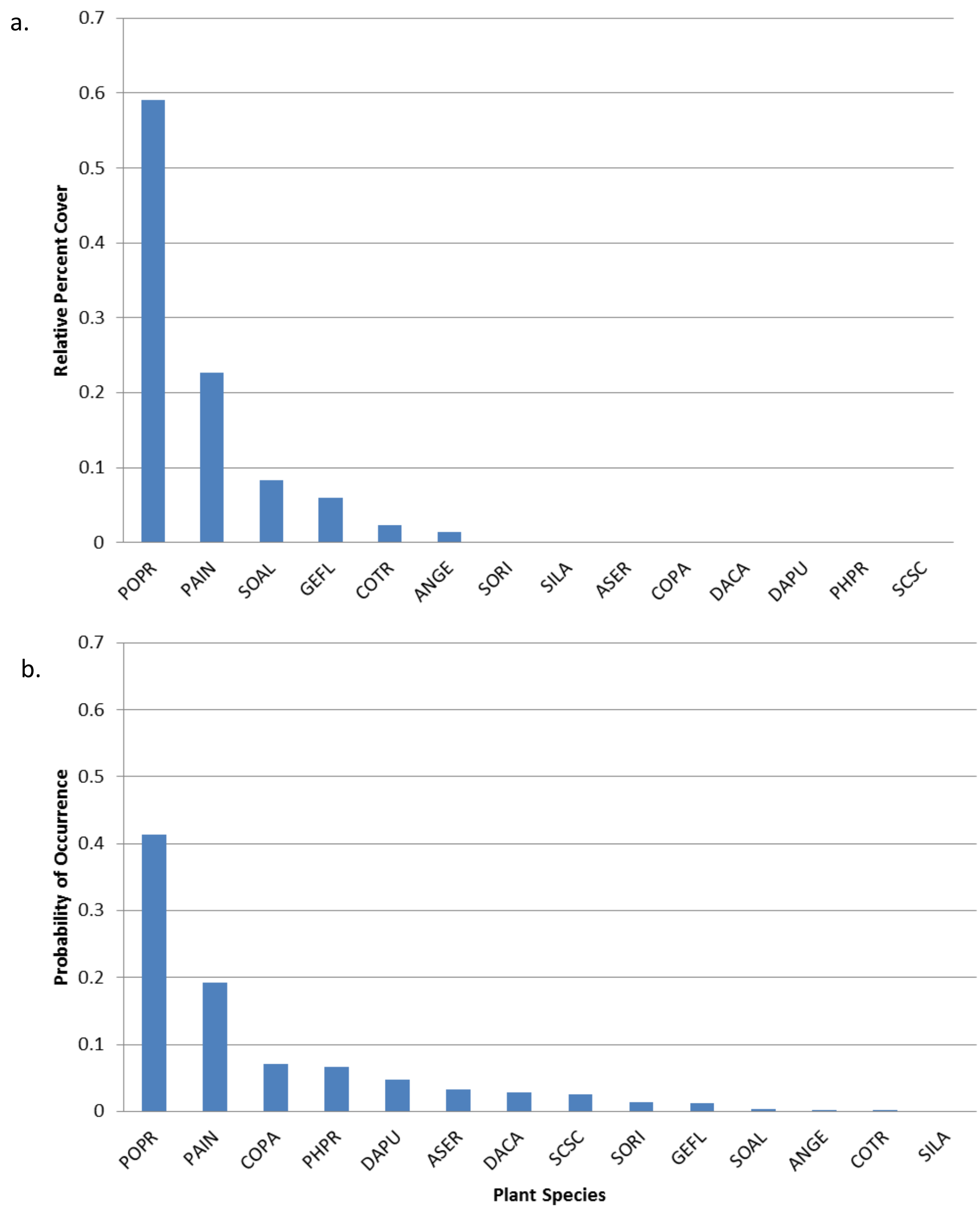



Fig. 11. Gensburg-Markham Prairie remnant observed (a) and predicted (b) dominant plant species. Species in (a) include eight dominant species at the site plus six additional species predicted by Maxent as among the eight most abundant but not present as dominant species at the site. Species in (b) include the eight most abundant species predicted by Maxent plus six species present as dominant species at the site, but not ranked among the top eight predicted species.

**Aggregate Trait Values**

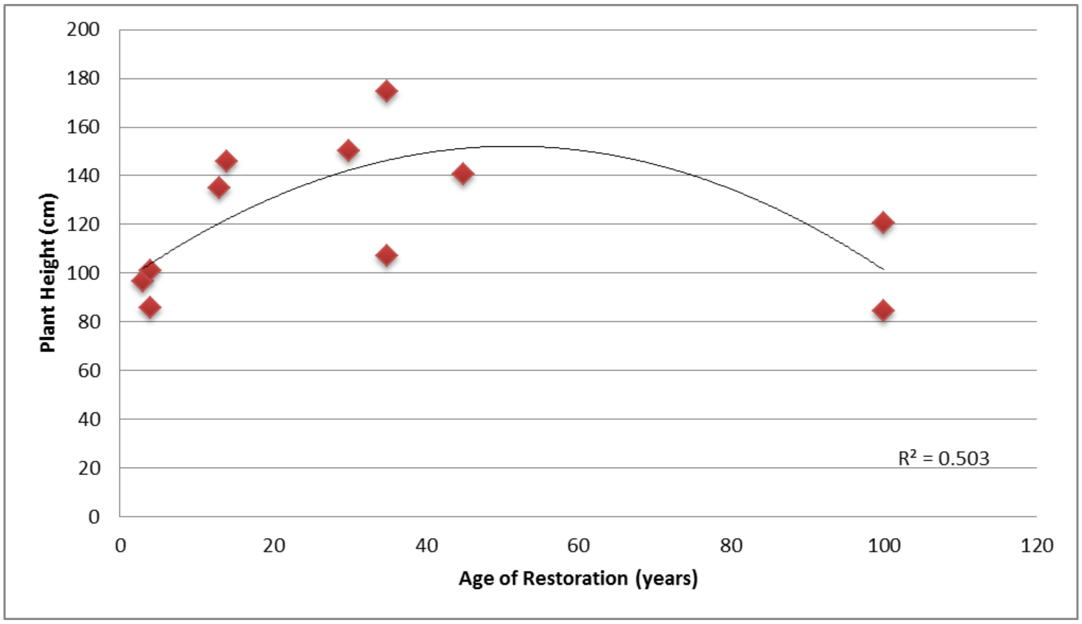



Fig. 12. Aggregate trait values for plant height. Each point represents nine prairie restorations of differing ages, and two prairie remnants (each assigned an age of 100 years). The line represents a quadratic regression.

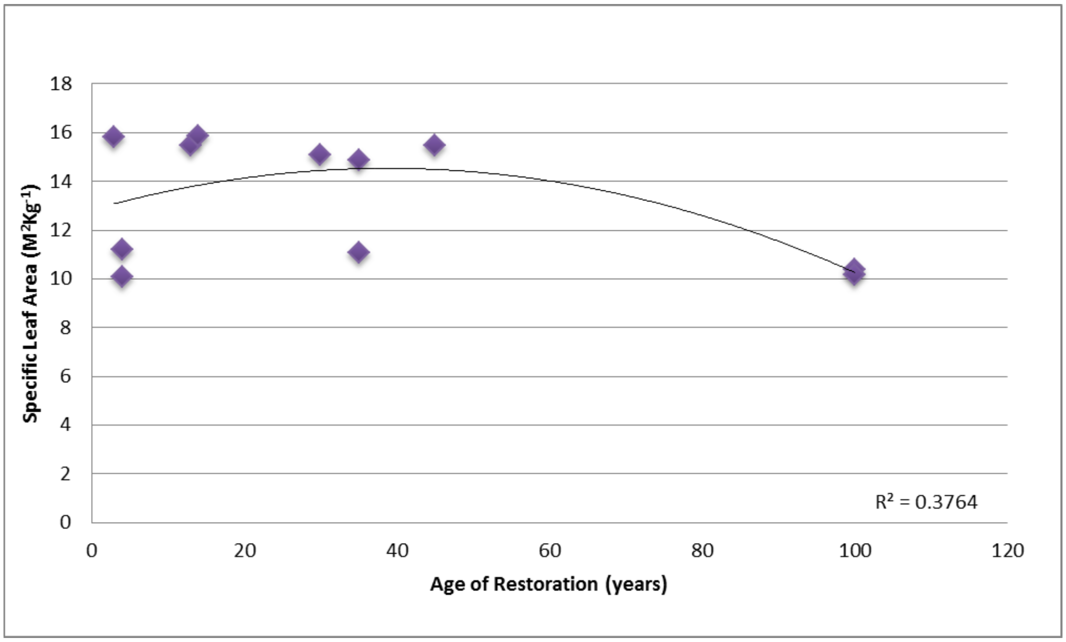



Fig. 13. Aggregate trait values for specific leaf area. Each point represents nine prairie restorations of differing ages, and two prairie remnants (each assigned an age of 100 years). The line represents a quadratic regression.

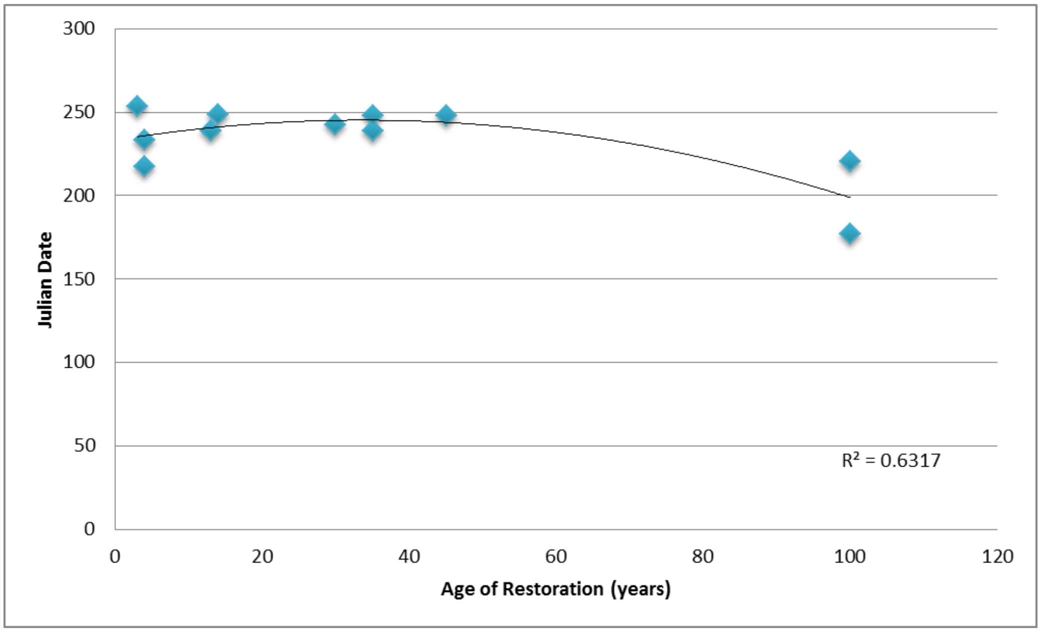



Fig. 14. Aggregate trait value for seed maturation (Julian) date. Each point represents nine prairie restorations of differing ages, and two prairie remnants (each assigned an age of 100 years). The line represents a quadratic regression.


Fig. 15. Aggregate trait value for seed mass. Each point represents nine prairie restorations of differing ages, and two prairie remnants (each assigned an age of 100 years). The line represents a quadratic regression.

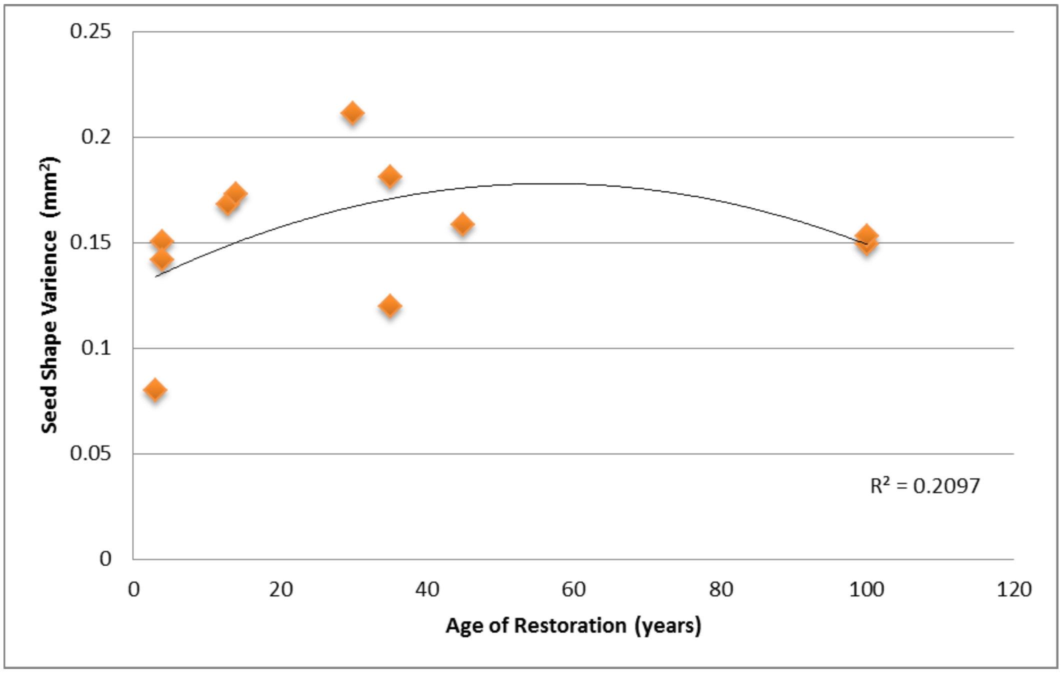



Fig. 16. Aggregate trait value for seed shape, calculated as the variance of length, width and depth measurements. Each point represents nine prairie restorations of differing ages, and two prairie remnants (each assigned an age of 100 years). The line represents a quadratic regression.

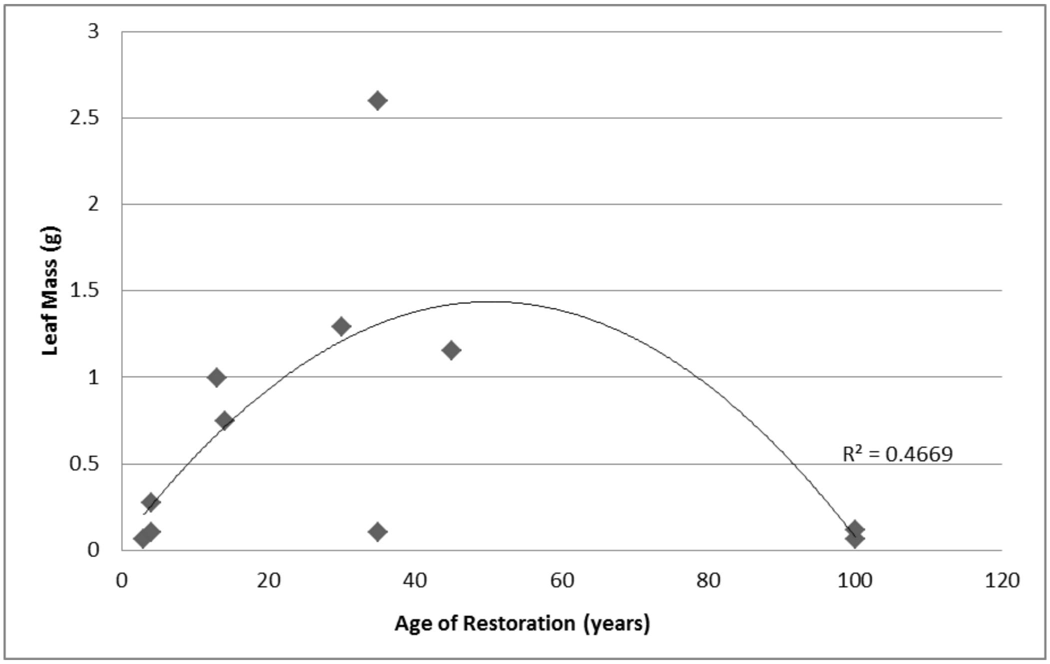



Fig. 17. Aggregate trait value for leaf mass. Each point represents nine prairie restorations of differing ages, and two prairie remnants (each assigned an age of 100 years). The line represents a quadratic regression.

To fit trends in site aggregate trait values in response to site age, quadratic equations were used instead of a linear regressions because the $R^2$ values were higher for the quadratic regression, thus giving us a better fit to the data. The traits plant height (Fig.12, $R^2$ = 0.503), seed mass (Fig.15, $R^2$ = 0.424), and leaf mass (Fig.17, $R^2$ = 0.467) have a similar convergence in the shape of their trait arcs. The polynomial trend line has a distinct curve to it with both the initial early restorations and the remnant restorations having similar values, and with the arc starting its decline at about 50 years of age restoration.

The traits SLA (Fig.13, $R^2$ = 0.376), seed maturation date (Julian date; Fig.14, $R^2$ = 0.632) and seed shape (variance; Fig.16, $R^2$ = 0.201) have an arc shape to the polynomial trend line but it is not as distinct as the traits plant height, seed mass and leaf mass.

Table.13. Summary of Maxent performance in predicting composition and abundence of dominant plant species in nine prairie restorations and two prairie remnants..

| Site | Age of Restoration (years)[a] | Number Observed Dominant Species (O) | Number Correctly Predicted (P) in Top (O) Species | P/O | Relative Percent Cover of Two Most Abundant Species | Pearson Correlations | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | $n$[b] | $r$ | $p$ |
| Park Forest Gardens | 3 | 6 | 4 | 0.67 | 0.71 | 8 | 0.72 | 0.021 |
| Midewin Northwest | 4 | 12 | 5 | 0.41 | 0.60 | 19 | 0.79 | <0.001 |
| Midewin Southeast | 4 | 7 | 2 | 0.29 | 0.81 | 12 | 0.94 | <0.001 |
| Perry Farm | 13 | 10 | 5 | 0.50 | 0.48 | 15 | 0.38 | 0.079 |
| Monee Reservoir | 14 | 12 | 7 | 0.58 | 0.42 | 17 | 0.42 | 0.046 |
| Schulenberg Youngest | 30 | 11 | 6 | 0.55 | 0.32 | 16 | 0.39 | 0.066 |
| Schulenberg 1970s | 35 | 15 | 8 | 0.53 | 0.36 | 22 | 0.11 | 0.317 |
| Fermilab | 35 | 9 | 5 | 0.56 | 0.46 | 13 | 0.32 | 0.138 |
| Schulenberg Acre | 45 | 17 | 10 | 0.59 | 0.29 | 24 | 0.35 | 0.047 |
| Indian Paintbrush Prairie | 100 | 7 | 2 | 0.29 | 0.37 | 12 | 0.26 | 0.205 |
| Gensburg-Markham Prairie | 100 | 8 | 2 | 0.25 | 0.82 | 14 | 0.95 | <0.001 |

[a]Indian Paintbrush and Gensburg-Markham Prairies were remnants, and were assigned an age of 100 years.

[b]See Figures 1-11 for explanations of sample size for each site.

The two most abundant species in restoration sites were similar in restoration sites under 30 years old (Fig. 1 – 6). The most abundant species were *Solidago altissma, Poa pratense, Solidago rigida*, and *Andropogon gerardii*.  As the age of restoration sites increased the dominant species became more varied among the sites (Fig. 7- 11).

Maxent correctly predicted at least 50% of the dominant species in 7 out of 11 of the sites (Table 2). The sites with most accurate predictions of species composition were sites from 13 to 45 years in age, with > 50% of the dominant species correctly predicted (Table 2).

Correlation results, however, which should indicate Maxent's combined performance predicting composition and abundance of species, tended to show better performance (i.e., lower *p*-value from correlation) for younger sites, and generally sites with lower numbers of observed dominant species. In these sites, typically one to two species comprised the majority of the relative percent cover. Even if Maxent correctly predicted < 50% of the dominant species, positive correlation of observed with predicted species relative percent cover was more likely to be statistically significant with increasing dominance of the species correctly predicted.

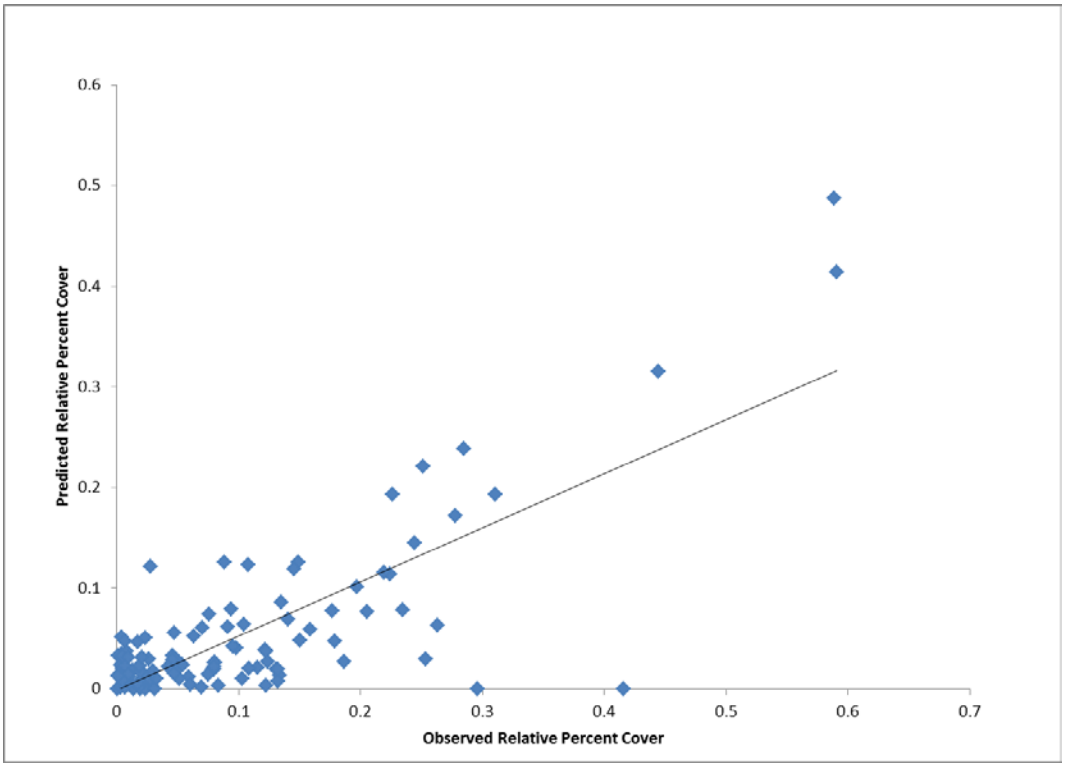



Fig.18. Linear regression between observed and Maxent-predicted relative percent cover of 31 plant species present in nine prairie restoration sites and two prairie remnant sites.

Although Maxent's performance in predicting plant species composition varied among sites (Table 13), its performance in predicting relative percent cover of species present at sites was good ($R^2 = 0.62$, $P < 0.001$).

## Discussion

Restoring and stabilizing natural areas such as prairies has been an ongoing priority in United States society since the Dust Bowl. The creation of prairies, restorations of prairies and reclamation of former prairies is of great interest to scientists and the general public. Less expensive methods to accomplish these goals are desired (Kindscher and Tieszen 1998, Palik et al. 2000). Programs such as Maxent may allow for less expensive restorations in the future, giving restoration managers a less expensive method to determine the health of a restoration when compared to other restorations at the same age. The collection of traits that are established and easier to obtain that full counts of sites will allow for better allocations of the funds for those restorations. The results with Maxent and the six different measured traits with predicting relative percent cover showed promise in identifying the dominant species at most of the 11 sites in this study.

Site aggregate trait values for seed mass, seed shape, seed maturation date, specific leaf area, leaf mass and maximum plant height started at a low values in young prairie restorations. With increasing prairie restoration age, aggregate trait values increased. At an unknown time around 50 years of age, the aggregate values studied began to decrease to numbers similar to the younger sites. The arc shaped curves could be due to succession, competition, plant population dynamics, ecological processes, or prairie ecosystem management practices (Kindscher and Tieszen 1998). The aggregate trait trend (Fig. 12-17) with plant height, seed mass, and leaf mass were similar while SLA, seed maturation date and seed shape did not show a similar convergence to the other traits.

For the traits plant height, seed mass, and leaf mass, aggregate values started at the younger restoration sites (< 20 years), and then increased rapidly until approximately 50 years of age. Then aggregate values declined rapidly to low aggregate trait values of the remnant sites. The shape of the trend line formed a pronounced arc. The arc indicated the values of the remnant sites and the younger sites have similar values in relation to the other sites. This similarity in the patterns of these traits occurred even though sites were established and managed differently. The convergence of the different traits may hold promise for future species prediction and composition using Maxent and other methods.

Aggregate values for SLA, seed maturation date and seed shape did not show the same convergence as for the other traits. While the trend lines for these traits did form arc shapes along the age gradient of the sites, the arcs were not as pronounced as for the traits plant height, seed mass and leaf mass. Values for these traits may have been affected by extreme weather conditions (e.g., excessive rainfall, drought). Estimation of aggregate values and trends for these traits might improve with including measurements from more plant species and more sites. Aggregate values for these traits might converge more strongly if more prairie restoration sites of varying ages are sampled. Plant species such as *Silphium integrifolium*, *Silphium laciniatum*, and *Silphium terebinthinaceum* were very tall, had larger seeds and leaves and were very common in our sites and may have influenced the data. From a restoration perspective managers may be able to look more at the traits plant height, seed mass, and leaf mass when comparing restorations of similar ages.

The traits chosen did differ from the original study. For this study, cost effectiveness and ease of obtaining the measurements was taken into effect when choosing the traits to measure. We did not use the portion of perennial species (all dominant plant species in the study were perennial), seed number, above ground vegetative mass and stem mass. Weiher et al. (1999) suggested that there were three challenges that plants face that must be taken into account when collecting trait data. These challenges are dispersal, establishment and persistence. Traits associated with dispersal that we used were seed mass and seed shape. Seed mass influences dispersal distance, and seed mass and seed shape are correlated with dispersal in time (existence of a persistent seed bank). Traits associated with establishment that we used were SLA, leaf mass and seed mass. Traits associated with persistence that we used were seed mass, maximum plant height, seed maturation date and SLA. Seed number was not used as it is correlated with seed mass. The other two traits not used were above ground vegetative mass and stem mass, both of which have been found to correlate with plant height (McGill et al. 2006).

McCain et al. (2010) looked at removal of dominant plant species, specifically grasses, to increase the diversity of a restoration. McCain et al. (2010) found that dominant grasses were inversely correlated with the species diversity of a restoration. In our study Kentucky bluegrass, big bluestem, tall goldenrod and stiff goldenrod were the dominant species in the early restorations. These grasses and goldenrods may be the cause of a “mismatch” in species diversity and aggregate trait values between the restorations and remnant sites. The grasses and goldenrods may “choke” out the less robust species such as some forb species (McCain et al. 2010). This leads to restorations with lower diversity in community species competition when compared to the remnant sites. Methods of limiting the more dominant grasses may lead to greater diversity. Dominant species such as Kentucky bluegrass, big bluestem, tall goldenrod and stiff goldenrod in the younger sites may indicate a need for restoration management intervention that allows for less competitive species to compete, thus increasing species diversity at the younger sites.

While the Maxent program seems to show promise both in the original study (Shipley et al. 2006) and ours, more research needs to be done. In this study, Maxent did correctly predict many of the dominant species (Fig. 1-12), and performed well predicting relative percent cover of species present at sites (Fig. 18). The variation between Maxent results in the Shipley (2006) study and this study may have been due to the differing ages of sites in the studies, with ours including remnant sites. In addition, differing traits were used in the two studies. We did not include proportion perennial, ln(seed number), above ground vegetative mass or stem mass, while we added the traits seed mass, and seed shape.

Some extremes in weather conditions may have affected the results observed in the study. During the 2011 and 2012 data collection may have been affected by extreme moisture followed by an extreme drought (Angel, 2015). Another variable that may have affected the outcome was variation in methods used to establish and manage the different restorations.

For future studies restorations from 50 – 100 years of age are needed to more accurately predict the species and traits at each of the sites. Expanding the study area to include more prairies in other states and with additional soil types, along with the addition of multiple sites of the same age, would be beneficial in determining the success of this program for future use.

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