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Comparing Species Composition and Soil Characteristics in a Chronosequence of Restored Tallgrass Prairie Ecosystems

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Abstract
With less than one percent of remnant prairie remaining in the world, tallgrass prairie restoration efforts are particularly important in maintaining the integrity of the endangered ecosystem. Four prairie sections with replanting dates spaced out over the past two decades were sampled for species richness, diversity and evenness, as well as some soil characteristics. Species composition differed between planting years. A few common species, such as big bluestem and yellow indiangrass mostly dominated the landscape, with a few unique and less common species in each plot. While big bluestem was present at high densities in the two oldest sites, it became less common in younger sites, while yellow indiangrass increased as prairie age decreased. This may be due to competitive interactions following replanting and the late successional nature of bluestem in restoration efforts. Additionally, this could be related to the fire regime, with the oldest sites being most recently burned, and bluestem's ability to flourish after fire. Big bluestem is able to outcompete other colonizing grass species after disturbance due to its growth and reproduction strategies, namely it's proliferation via seed and rhizomes. These results suggest that replanting date and fire regime exert an influence on species composition in restored tallgrass prairies. Species diversity and soil characteristics are the building blocks of a prairie ecosystem and carry a number of implications for the suitability of habitat and the development of community structure.

Introduction

Tallgrass prairie is among one of the world's most endangered ecosystems, with less than one percent of original prairie remaining (Samson and Knopf 2004). Hoekstra et al. (2005) found the disparity between habitat loss and protection and restoration in temperate grasslands to be "especially stark." Remnant prairies are often small and fragmented, and cannot solely support the tallgrass ecosystem's biodiversity (Connor and McCoy 1979). Conservation of this ecosystem therefore depends upon expanding viable habitat through restoration efforts, rather than simply preserving original prairie sites (Frischie and Rowe 2012).

Species richness and evenness are important factors in evaluating the progress of prairie rehabilitation (Heslinga and Grese 2010). Reestablishing diversity in a tallgrass prairie remains an elusive and desired goal among conservationists (Camil et al. 2004). Species richness is expected to decline over time, but researchers have been unable to identify the extent or timetable of change over the first decades after replanting (Camil et. al 2004).

While many soil characteristics should remain consistent, a review of certain properties can be beneficial to understand nutrient availability and carbon cycling in the restored habitat (Craine et al. 2002). Organic matter and litter decomposition are important portions of nutrient cycling in terrestrial ecosystems and are one marker of the changes that occur in soils over time (Aerts et al. 2003).

The huge loss of tallgrass prairie to agriculture and industrialization has destroyed the diversity and habitat of the Great Plains. Replanting projects are an invaluable contribution to restoration efforts. The conversion of agricultural land to tallgrass prairie is a valuable effort in the movement to restore some of the grandeur and diversity of the Great Plains ecosystems. The differing dates of farmland acquisition and restoration on the St. Olaf College Natural Lands create an excellent opportunity to look into a chronosequence, or a set of prairie sites that share many similar attributes but differ in origin date,. The planting schedule created a diverse range of prairie segment ages that span the first few formative decades in a restored prairie. The oldest restored prairie studied was planted in 1989, and the most recent in 2004.

The purpose of this study was to better understand the changes that occur over time in a restored prairie relating to species abundance and diversity as well as soil characteristics. This chronosequence was chosen for its spaced origin dates and consistency in climatic conditions and management as a part of the St. Olaf Natural Lands. The specific objectives of this research were to compare dominant prairie species and supplementary soil data between four prairie sites. Additional factors such as soil conditions and disturbance were studied to improve knowledge of the prairie ecosystems and help explain the differences and similarities between sites.

Methods

In each of the four different prairie sections of the St. Olaf College Natural Lands in Northfield, MN, three 1 meter^2 square plots. Each section had a differing date of origin: 1989, 1993, 1998, and 2004. Each prairie section was planted in their respective spring seasons and sampling locations were chosen for similarly flat slopes and sun exposure. Every plot was be more than 10 meters away from any walking trails or obvious human perturbations and was randomly chosen.

A count of the different types of species and their prevalence was based upon their stem frequency in the plot. Each individual stem was counted towards a measure of species richness. The most prevalent species, big bluestem, was measured in height as well, to better understand its overall abundance and size in each plot. One soil core was collected in tins from each plot for various analyses. In the lab, percent moisture was determined, as well as bulk density and percent organic matter.

Data Analysis

A few calculations were made to improve our understanding of species composition. Simpson and Shannon diversity indices were calculated using the community diversity calculator developed by Mike Farris and formulas outlined by Brower, Zar, and von Ende (1998). Using R, a contingency table was created to compare proportion of common prairie species between sites, as well as analyses of variance for species abundance, Simpson and Shannon diversity indices, big bluestem height, soil density, percent moisture, and percent organic matter between sites (R Core Team 2014). Additionally, regressions were used to look at the functional relationship that species abundance, bluestem height, soil density, percent moisture, and percent organic matter have with time.

Results

Species Composition

Prairie species composition between the four Natural Lands sites differed in one major way. While almost all were populated by *Andropogon gerardi* (big bluestem) and *Sorghastrum nutans* (yellow indiangrass), the balance and number of each species changed dramatically with the age of the site (Table 1). Overall, the oldest sites consist predominantly of big bluestem, while the youngest sites were mostly yellow switchgrass (Fig. 1). A contingency table of the common species between the four locations revealed that there was a statistically significant difference (p-value $< 2.2e-16$) when looking at the proportion of each common species (Table 2).

A comparison of the three prevalent species revealed the dominance of big bluestem in the 1989 section and the prevalence of switchgrass in the 2004 section (Figure 1). Additionally, calculation of the Shannon and Simpson diversity indices and ANOVAs of the data reveal no significant differences in overall diversity between sites (Shannon p-value = 0.2468; Simpson p-value = 0.3414) (Fig. 2).

Differing size structure of the prairies was confirmed using a regression, showing greater average big bluestem height in older sections ($R^2 = 0.6864$) and an ANOVA demonstrated the significance of differing mean bluestem height (p-value = 0.0345) (Fig. 3).

Soils

Soil properties differed slightly between the two sites, but not always significantly (Table 3). ANOVAs revealed they had insignificantly different percent moisture (p-value = 0.0973) and bulk density (p-value = 0.194), and linear regressions showed the inconsequential relationship between year and percent moisture, and year and bulk density (Figs. 4, 5). Older sections had significantly more organic matter (p-value = 0.0006) and a linear regression demonstrated the close relationship to year and percent organic matter (Fig. 6).

Discussion

Prairie Species Composition

The results of this study reveal that the four tallgrass prairie sites varied in some slight and some major ways from one another. Most significantly was the dominance of big bluestem in the oldest sections, and the significant presence of switchgrass in the youngest sections. While measures of diversity were rendered insignificantly different among sites, the balance of the most prevalent species was shown to vary considerably with prairie age.

Big bluestem's success in the oldest of prairie sections could be attributed to the fire regime of the St. Olaf Natural Lands. The 1989 section was most recently burned in 2014, while the 2004 section was least recently burned in 2010. Some studies found that fire may increase rate of succession by enhancing the ability of big bluestem to invade and dominate areas of exposed soil (Collins and Gibson 1990). Additionally, big bluestem is found to be very productive throughout the next growing season following a fire (Peet et al. 1975). Prescribed burns occasionally reduce seed viability of other species, and affect a number of outside factors including resource partitioning and limitations to non-native seed dispersal (Polley et al. 2005,Vermiere and Rinella 2009). These factors may have contributed to big bluestem's success over other prairie plant species and it's considerably larger height in the 1989 prairie section

Species richness and Simpson diversity index values were expected to decline, as the overall number of native species present would decrease (Carter and Blair 2012). While species abundance was expected to decrease, species evenness, and the Shannon diversity index, was purported to increase with time (Heslinga and Grese 2010). These results may have been obscured by the limits to sampling and the measurements being taken late in the autumn season, when not all species could be identified.

Soil Characteristics

The greater accumulation of organic matter in the oldest sites may be the result of a number of factors. As a restored prairie sees a boom in productivity within the first few decades of regrowth, the material decomposes and I would expect it to lead to an increased amount of organic material available in the soil (McCain et al. 2010). Additionally, the oldest sections were most densely populated with big bluestem, whose vast root systems may have contributed to both organic matter and density measurements (Collins and Gibson 1990).

While soil density was insignificantly different among sections, the 1989 section had two largely dense outlier samples. As soil remains relatively undisturbed, it settles and packs into denser horizons (Hanson 2010). As expected, soil moisture was found to remain reasonably constant throughout the sections sampled, as all plots fall within one square mile (Knapp et al. 1993). These factors may not have had a large role to play in species diversity and soil organic material, but they are constants worth monitoring for prairie consistency (Hanson 2010).

Future for Tallgrass Prairie Restorations

This study found differing species composition between four different ages of restored tallgrass prairie. Due to the older date of origin and supplemented by the fire regime, big bluestem dominates the oldest studied prairie communities. In the youngest prairie sections, less recent fire disturbance and younger plant age contribute to a shorter, less bluestem-dominated community. As these prairies age, and experience relatively frequent fires, they will increase big bluestem and other native grass populations. Studying prairie species composition in response to aging after restoration is an important part of understanding the foundation of restored prairie ecosystems and monitoring their rehabilitation. Future research would be well served looking at the combination of origin date and fire over longer periods of time, as well as incorporating more measurements that are indicators of ecosystem health, such as biomass production. Additionally, analyzing soil carbon and nitrogen would be interesting contributions to research regarding the conversion of agricultural land to tallgrass prairie.

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Tables and Figures

Table 1. Table of the density of prairie plant species (in stems/m^2) found in different sections with differing planting dates of the St. Olaf Natural Lands in Northfield, Minnesota, United States.

	Year			
Plant Species	*1989*	*1993*	*1998*	*2004*
Big Bluestem	73	46	12	2
Indiangrass	38	47	36	77
Reed Canary		14		
Kentucky bluegrass		7		
Goldenrod		18	11	23
Thistle		1		1
Golden Alexanders	8			
Leadplant	3			
Purple Prairie Clover				5
Milkweed			2	

Table 2. A comparison of the number of the three most abundant prairie plant species sampled in different sections with differing planting dates of the St. Olaf Natural Lands in Northfield, Minnesota, United States. Contingency table analyses show a significant difference in frequency of plant species between the four sites (p-value < 2.2e-16).

	1989	1993	1998	2004
Big Bluestem	73	46	12	2
Indiangrass	38	47	36	77
Goldenrod	0	18	11	23

Table 3. Mean soil data for four different sections with differing planting dates of the St. Olaf Natural Lands in Northfield, Minnesota, United States.

	Year			
	1989	1993	1998	2004
Percent Moisture	19.90	26.32	25.61	21.10
Bulk Density (g/cm^3)	0.753	0.629	0.655	0.678
Percent Organic Matter	4.05	4.02	3.86	3.52

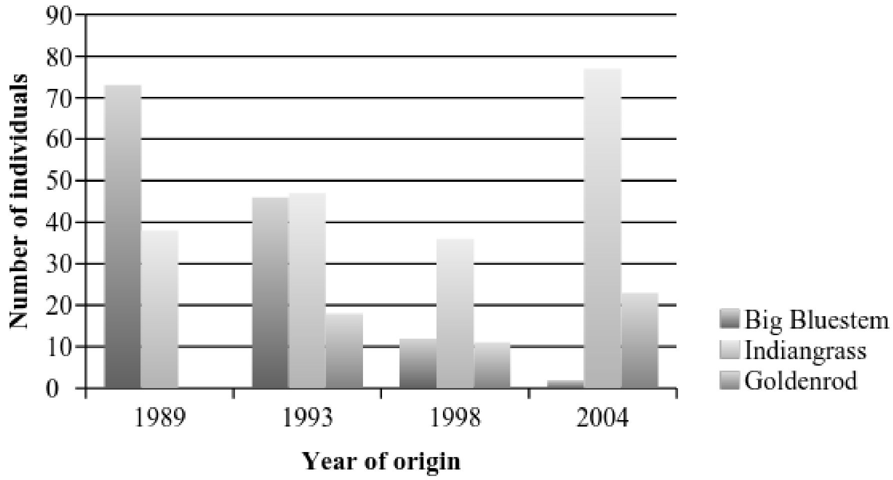

Figure 1. A comparison of the number of the three most abundant prairie plant species sampled in different sections with differing planting dates of the St. Olaf Natural Lands in Northfield, Minnesota, United States. Contingency table analyses show a significant difference in frequency of plant species between the four sites (p-value < 2.2e-16).

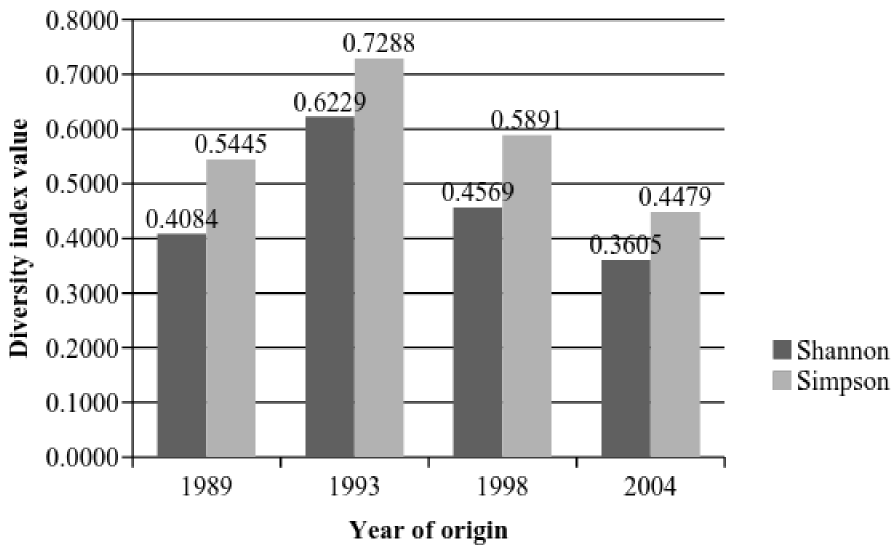

Figure 2. Shannon and Simpson diversity index values for four different sections with differing planting dates of the St. Olaf Natural Lands in Northfield, Minnesota, United States. ANOVAs reveal no significant differences in values among years (Shannon p-value = 0.2468; Simpson p-value = 0.3414)

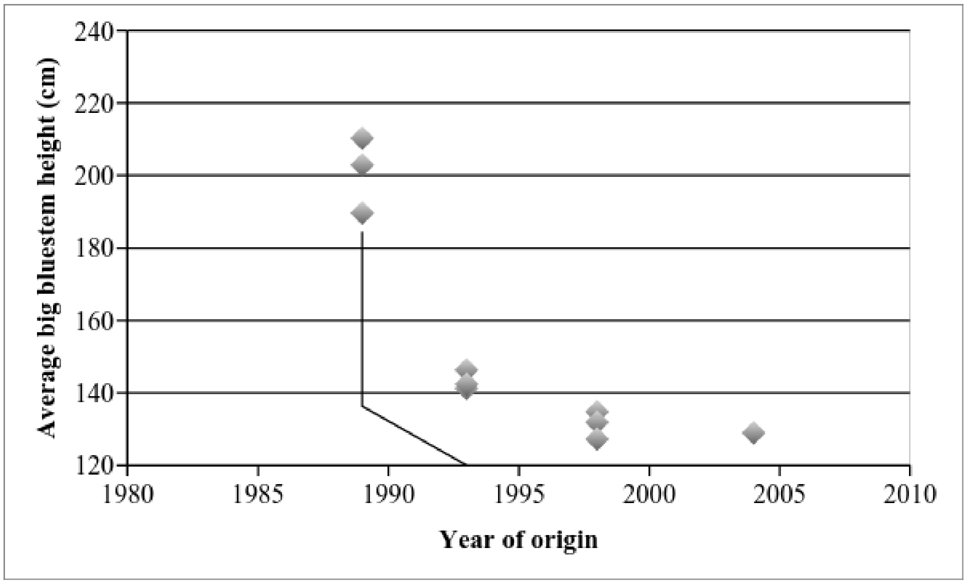

Figure 3. A scatterplot demonstrating the linear relationship between year of origin and big bluestem height for four different sections of the St. Olaf Natural Lands in Northfield, Minnesota, United States. A regression reveals an R^2 value of 0.6864 and an ANOVA shows a p-value of 0.0345).

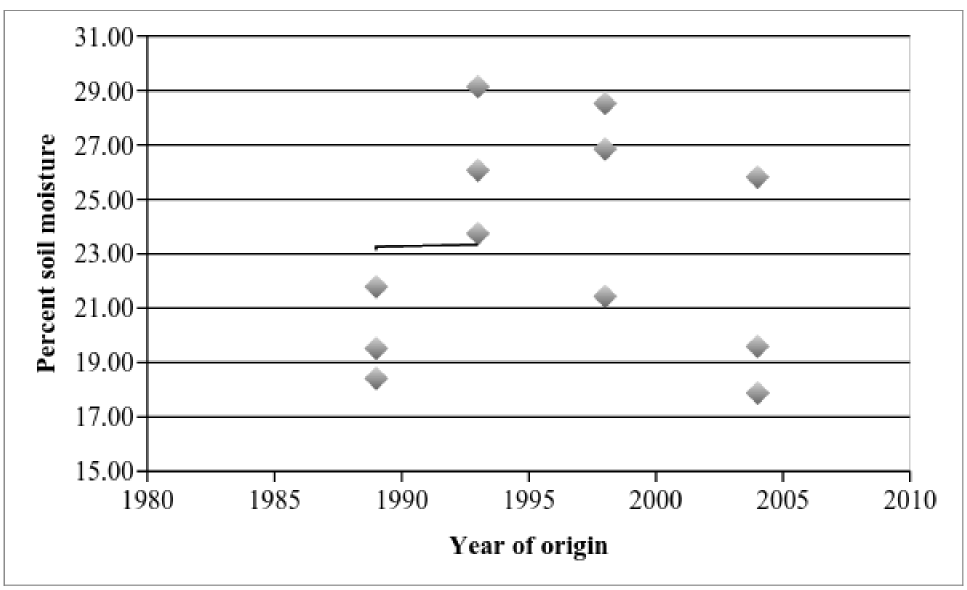

Figure 4. A scatterplot demonstrating the linear relationship between year of origin and percent soil moisture for four different sections of the St. Olaf Natural Lands in Northfield, Minnesota, United States. A regression reveals and R^2 value of 0.00038 and an ANOVA shows a p-value of 0.0973.

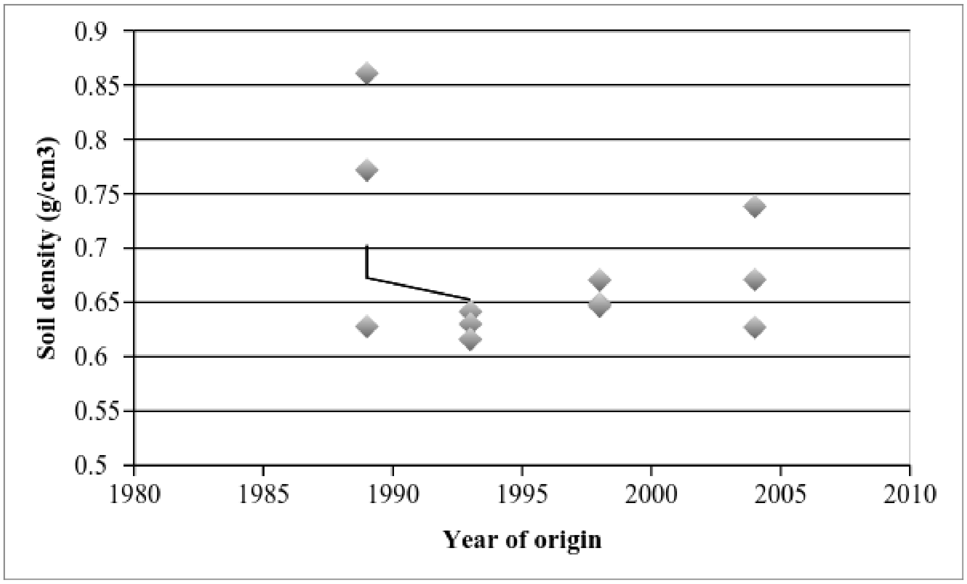

Figure 5. A scatterplot demonstrating the linear relationship between year of origin and bulk soil density for four different sections of the St. Olaf Natural Lands in Northfield, Minnesota, United States. A regression reveals and R^2 value of 0.06992 and an ANOVA shows a p-value of 0.194.

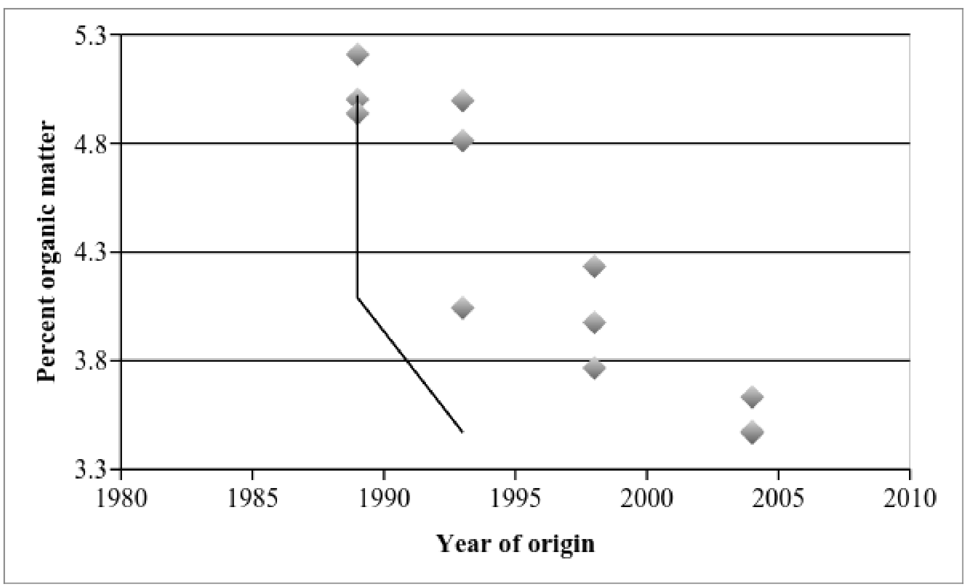

Figure 6. A scatterplot demonstrating the linear relationship between year of origin and percent soil organic matter for four different sections of the St. Olaf Natural Lands in Northfield, Minnesota, United States. A regression reveals and R^2 value of 0.8486 and an ANOVA shows a p-value of 0.0006.