8-2014

The Initial Effects of Community Variables on Sand Prairie Restoration: Species Establishment and Community Responses

Robert Christopher Roos
Grand Valley State University

The Initial Effects of Community Variables on Sand Prairie Restoration: Species Establishment and Community Responses

Robert Christopher Roos

A Thesis Submitted to the Graduate Faculty of

GRAND VALLEY STATE UNIVERSITY

In

Partial Fulfillment of the Requirements

For the Degree of

Master of Science in Biology

Biology Department

August 2014

ACKNOWLEDGEMENTS

I would like to thank all those who have stuck with me through this long journey. To my Graduate Committee, thank you for your support and advice along this winding road. Over the years you have taught me life lessons that go beyond the realm of academia. It is for this that I am truly grateful. I would also like to thank those who dedicated time and effort out of their already busy schedules to assist me in completing my own dream. Finally, I would like to thank my family - my foundation. Without each and every one of you this voyage would not have been possible.

All of the lessons and teachings that each and every one of you have embedded within me will continue to be reflected within my professional and personal life. It is my hope to pass these wisdoms onto others as I continue to explore what this marvelous and mysterious world has in store for me.

ABSTRACT

THE INITIAL EFFECTS OF COMMUNITY VARIABLES ON SAND PRAIRIE RESTORATION: SPECIES ESTABLISHMENT AND COMMUNITY RESPONSES

By Robert Christopher Roos

We established a sand prairie restoration experiment in northern Lower Michigan's pine-oak barrens to analyze the effect of different community variables (vegetative cover, species richness, biomass, diversity, and floristic quality) when comparing: (1) how our restoration efforts (seeded treatments) compare to natural community succession (control plots), (2) how different seeding treatments affect these community variables, specifically when evaluating (2a) the effect of grass seeding densities; and (2b) the effect of different forb guilds (early flowering, late flowering, and legumes) during the initial two growing seasons of restoration establishment. In general, a comparison between seeded treatments and non-seeded control treatments indicates that our efforts may be more successful in the restoration of native sand prairie than would have resulted from succession alone. Restoration attempts displayed a significant decrease in invasive, resident species richness and increased diversity compared to succession. Treatments that included a high concentration of grass and/or an early season forb component had the greatest overall impact on plant community development. These treatments exhibited significantly higher plant biomass, diversity, and floristic quality

than most other treatments. Conversely, these seeded treatments displayed less non-native or invasive cover than other treatments. The benefit of high concentrations of grasses and early season forbs may play a critical role in initial species establishment of a sand prairie restoration due to the facilitative and competitive advantages they may provide in these harsh environments. However, it remains to be seen if these initially successful communities will have continued success over long periods of time.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

INTRODUCTION

The tallgrass prairie was one of the most wide-ranging and diverse ecosystems across North America. Today, approximately 0.1% of its original extent remains, making tallgrass prairie one of North America's most endangered ecosystems (Samson and Knopf 1994). The extensive loss and rapid decline of this ecosystem can be attributed primarily to European settlers. The tallgrass prairie's dark, rich, tree-free and easily manipulated Mollic soils made them prime targets for agricultural use (Howe 1994). This ecosystem has also experienced many other hardships as a result of human development. Fire, which was once commonplace in the Midwestern United States, became actively managed and suppressed (Anderson 1990). Habitat fragmentation, the introduction of invasive non-native, and increased establishment of invasive native species also promoted habitat degradation (Noss et al. 1995; Cully et al. 2003).

The reduction of tallgrass prairie and associated biodiversity has resulted in a substantial loss of ecosystem function. Higher levels of plant diversity are associated with greater ecosystem productivity (Tilman and Downing 1994; Hector et al. 1999; Tilman 1999), nutrient use efficiency (Risser 1988; Tilman 1997), resistance to invasion by exotic species (Tilman and Downing 1994; Kennedy et al. 2002; Pokorny et al. 2005), and resistance to environmental change (Ives et al. 2000). According to the insurance hypothesis (Yachi and Loreau 1999), high levels of biodiversity insures ecosystems against declines in their functioning because the presence of many species guarantees that some will remain functioning even if others fail (Ives et al. 2000). Ecosystem functions that are associated with tallgrass prairie include carbon sequestration, water filtration,

erosion control, soil enhancement, and nutrient cycling (Raison 1979; Wedin and Tilman 1990; Seastedt and Knapp 1993). Therefore, diversity is a beneficial and necessary attribute that drives a fully-functioning, healthy ecosystem.

The tallgrass prairie ecosystem is comprised of a mosaic of prairie types that include xeric, mesic, and wet components that also transition into barrens and savannah ecosystems. Tallgrass prairie historically extended eastward through Indiana and into areas of Michigan, Ohio, and Kentucky. This region is referred to as the prairie peninsula. These fingers of grassland followed areas where climate fluctuated enough to support a mosaic of prairie community types, including oak-pine barrens and oak savanna (Transeau 1935; Anderson 1990). In northern Lower Michigan, north of the tension zone (43ºN latitude), grassland was predominantly dry sand prairie (McCann 1991; Kost 2004). As a component of these open, upland mosaics, sand prairie was part of roughly 5,000 hectares in northern Michigan in the early to mid-1800s (Comer et al. 1995). This droughty grassland is considered the driest ecosystem east of the Mississippi River (Schaetzl and Anderson 2005). Plant species are similar to that of a xeric tallgrass prairie, but due to water, heat, and nutrient stresses, vegetation is typically shorter in stature and separated by patches of bare-ground. The combination of wildfires, droughty and well-drained soils, and the harsh frosts that are associated with northern Michigan historically maintained these ecosystems (Kost et al. 2007).

As a result of fire suppression, silvicultural and agricultural activities, and degradation by invasive species, approximately 4% of the original extent of sand prairie remains intact in the state (Hauser 1953; Albert and Comer 2008). Consequently, sand

prairie is considered one of Michigan's most endangered ecosystems. Today, less than 200 hectares of high quality sand prairie still exist in Michigan (Kost 2004).

The loss and degradation of the sand prairie has had negative consequences for species that are associated with these ecosystems. Over 25 plant and 30 animal species are dependent on these dry grasslands for either all or part of their lives (Kost 2004). This includes the federally endangered *Lycaeides melissa samuelis* (Karner blue butterfly), a species that depends on *Lupinus perennis* L. Grassland birds have shown a decline that is greater than any other group of North American species (Knopf 1994). *Dendroica kirtlandii* (Kirtland's warbler) is a species that depends solely on the matrix of sand prairie and pine barrens in northern Michigan for survival (Kost et al. 2007).

Despite the important ecological role and increasing scarcity of sand prairie, restoration and management of this ecosystem has been severely understudied. Published research on sand prairies within the eastern prairie peninsula, including Michigan, is sparse. Instead, the majority of sand prairie literature has focused on the Great Plain's prairie regions (Gleason 1910; Plumb-Mentjes and Center 1990; Cole and Taylor 1995; Bowles et al. 2003). Studies that have addressed the Michigan sand prairies have focused on descriptive analyses (Hauser 1953; Albert 1995; Comer et al. 1995; Kost 2004), or on comparative assessments with other community types such as dunes and jack-pine barrens (Houseman and Anderson 2002; Emery et al. 2012). To date there have been no studies that have focused on the restoration of Michigan's true sand prairies.

Restoration projects in general tend to place an emphasis on many aspects of community structure and ecosystem processes. Although certain components of restoration projects have been successful, they have yet to achieve the goal of creating a

historic, natural community (Martin et al. 2005). Current methods of restoring prairie communities have weak scientific rationale that is not consistent with the history of how grasslands formed, and in fact may threaten biodiversity (Howe 1994). Although plant community restoration has the potential to help re-establish lost diversity and ecosystem function (Foster et al. 2007), many plant community restoration attempts have not fully re-established the diversity and function found in remnant prairie communities (Sluis 2002, Polley et al. 2005).

Sub-optimal results have led ecologists to examine different theories of plant community succession and species coexistence in order to identify more successful approaches to restoration (Cairns and Heckman 1996). Community assembly theory is one approach that asks how species arriving at a site form an initial community (Belyea and Lancaster 1999). This approach integrates aspects of succession and species coexistence in an effort to examine how species introductions, biotic interactions (e.g. competition), and abiotic conditions (e.g. soil nutrients) influence community development (Lockwood 1997; Belya and Lancaster 1999; Young et al. 2001).

The influence of environmental (abiotic) factors on plant communities is complex, with multiple factors influencing plant diversity and community development (Grace 1999). The environment influences plant community succession (Tilman 1988; Howe 1995), the frequency and intensity of disturbance (Collins et al. 1995; Suding 1999; Collins 2000), competitive intraspecific and interspecific interactions and the plant's ability to respond (Grime 1974; Goldberg and Barton 1992; Smith et al. 1999), available nutrients (Raison 1979; Ojima et al. 1994), and the ability to be productive in both growth and reproduction (Zimmerman and Kucera 1977; Gough et al. 1994; Tilman

et al. 1996). A better understanding of how all of these factors influence community development will allow for more practical approaches to community restoration.

We established a restoration experiment on a site previously occupied by sand prairie in northern Lower Michigan in 2009. We introduced several native plant functional groups (legumes, early flowering forbs, late flowering forbs, and warm-season grasses) at different seeding concentrations in an attempt to see how these initial seeding treatments affect plant community development over time.

Here we present the initial results of a sand prairie restoration experiment and address the following questions: (1) How do the results of our restoration efforts (seeded treatments) compare to natural community succession (control plots)? (2) How do different seeding treatments affect community variables (vegetative cover, species richness, biomass, diversity, and floristic quality)?

METHODS

Study Area

The study site is located at the historic Chittenden Nursery in the Manistee-Huron National Forest, Manistee County, Michigan (Figure 1). The nursery site is approximately 23 hectares and consists of 13 adjacent 1 to 2 hectare open fields (Figure 1).

The study site was historically part of the oak-pine barrens ecosystem which included pockets of sand prairie (Albert and Comer 2008). In 1934, the area was converted into the Chittenden Nursery, a tree nursery for the United States Forest Service (USFS). The tree nursery was shut down in the 1970s and has since been used for USFS housing, conferences, and training activities (e.g. wildfire training, prescribed burns, all-terrain vehicle instruction, etc.).

Historically, average high temperatures between June and August were 23.9 C and average rainfall was 20.1 centimeters (National Weather Service 2011). During the course of this study, average temperature highs for June through August were 23.1C and average rainfall was 17.5 centimeters. Site soils are mapped as Plainfield sands with a very deep water table (USDA Web Soil Survey 2012). The fields are level, tree-free, and dominated by invasive native and non-native species. Weather and soil conditions are consistent with oak-pine barren and sand prairie ecosystems while vegetation is characteristic of a degraded ecosystem (Albert and Comer 2008).

Experimental Design

Prior to the initiation of our experiment, mowing and foliar herbicide treatments (glyphosate) were applied to the entire study area in 2007 and 2008 in an attempt to reduce the abundance of invasive species (e.g. *Centaurea maculosa* Lam.).

In March 2009, a total of 228 1 m^2 treatment plots were established. All plots were separated by a 0.5 m border along all four sides to avoid edge affects and prevent trampling while taking measurements. Typical sand prairie species used in local U.S. Forest Service restorations were chosen to be planted based on their specific guild and historic presence in Michigan sand prairies (Table 1). Three species per guild were selected. Selection criteria reflect a balance of conservative versus less-conservative native species. Delineation among guilds was based on timing of growth and reproduction (late vs. early season flowering), photosynthetic pathway (C4 vs. C3 photosynthesis (grasses)), and soil nutrient relationships (nitrogen fixers vs. nitrogen extractors). Treatments consisted of one of three functional groups (e.g. legumes, early season flowering forbs, and late season flowering forbs) paired with the one grass group for a total of six seeded species. In addition to guild-specific seed treatments, plots were also seeded with seven 'background species' in order to mimic a more traditional species rich and diverse seed mixture similar to those used in sand prairie restoration activities. Therefore, a maximum of 13 species were seeded in the experimental plots.

Seed concentrations were manipulated to compare 'high' (10,000 seeds/m^2) and 'low' (1,000 seeds/m^2) seeding densities (Table 2). All non-target (background) species were seeded at a density of 500 seeds/m^2. Seeding densities were equally divided for

each species so that an equal number of seeds per species were represented in the mix. Seeds were obtained from Michigan Wildflower Farm, Portland, Michigan. All seeds are of local Michigan genotypes.

In January of 2009, seeds were counted and weighed to determine the number of seeds per gram for each species. The appropriate number of seeds were mixed with clean, moist sand and placed in a freezer to simulate cold-moist stratification before being sown into the field. In March of 2009, all seed mixes, except those containing legumes, were sown evenly by hand into treatment plots. Due to unavailability of seed in the spring, legume seed treatments (including their grass and background species components) were sown in December of 2009. All seeded group comparisons and control plots were randomly assigned. Each treatment was replicated 12 times for a total of 228 plots (Table 2).

Baseline Floristic Inventory

In July 2009, before the growth of any of our seed treatments, ocular estimates of percent cover of vegetation for each plot were conducted. Additionally, plots were measured for aboveground biomass. These initial measurements are provided in Table 3 and are used to compare our restoration efforts to pre-restoration conditions. Species nomenclature follows The Taxonomic Name Resolution Service: an Online Tool for Automated Standardization of Plant Names (Boyle et al. 2013). In late-August 2009, a floristic quality assessment (FQA) was completed for the one-half hectare area that surrounds the study site. This area was not affected by the site-preparation herbicide

treatments. The surrounding area included a mix of disturbed, developed land, mesic-mixed forest, and xeric open fields. This information provides baseline data for species that occur in the immediate area adjacent to the study site and may provide information for future measures (e.g. seed bank germination and colonization). Plants that could not be readily identified were trimmed with scissors at the base and placed into plastic bags. The bags were labeled with key plant and environmental characteristics (e.g. soil conditions, exposure to shade/sun). The plants were transported on ice back to Grand Valley State University (GVSU), Allendale, Michigan where they could further be identified. The collected species list is provided in Table 4. It is important to note that only species that were identifiable in the fall were included in the list. Many native and non-native plants, especially early season forbs and grasses, may have been excluded in this initial sampling due to their absence of key reproductive structures.

Data Collection

Data on species cover, species richness (SR), above-ground biomass, and soil organic carbon were collected from study plots once per year in the month of July from 2009 through 2011. Based on these data, floristic quality (FQI) and diversity (Shannon H') indexes were calculated for each plot. All variables were measured in mid-July. If species identification was not possible due to the plant's early life stage, it was flagged for later identification. Unidentified species were only used in calculations of SR.

Species, bare-ground, and litter percent cover was measured by ocular estimation of percent foliage cover of each species in 2009 and 2010. In 2009, only non-legume

plots were evaluated for a total of 144 plots. In 2010 and 2011, all 228 plots were evaluated. Estimates of percent cover for each plant species, and bare-ground and litter variables were averaged between the same two researchers, for each plot, in each year comparison. In order to provide more objective quantitative data, in 2011 percent cover was derived by using the point-intercept method. Using this method, a metal pin was dropped at 50 points along an evenly spaced grid that covered the entire plot. Any vegetative part of a plant that touched the pin was counted as an occurrence of that plant at that particular point. Any piece of litter or bare-ground that touched the pin was also accounted for. Total occurrences of an individual species throughout the entire plot were then divided by the total number of occurrences of all species in the plot to provide a relative percent cover. Any species that were not encountered by the point-intercept method were marked as being a trace amount occurrence (0.0625% cover) of the plot.

Above-ground biomass was measured as an additional way to quantify the composition of plants in each study plot. Samples were taken in late July of each year from 10cm x 1m strips in a sub-set of all plots. Plants were cut at the base of their shoots at the soil-plant interface with an electric trimmer. Strips were taken along different sections of the plots in consecutive years to avoid sampling of previously disturbed vegetation. Samples were refrigerated and then sorted at the GVSU laboratory within one week of collection. In 2009, samples were only taken from 10 control plots and vegetation was sorted between grasses, forbs, and dead standing litter material for each plot. In 2010 and 2011, samples were taken from the same 64 plots representing 4 plots for each treatment. Samples were sorted by individual species and total litter for each plot. Each sample was dried at 50 C to a constant weight and weighed.

Floristic quality index (FQI) measures the overall quality of an area (Swink and Wilhelm 1994) based on coefficient of conservatism (CC) values provided by the Michigan DNR (Hermann et al. 1996). Assigning CC values to individual plant species provides an approach to ranking the quality of plant communities (Swink and Wilhelm 1994). These values range from 0 to 10 and are assigned only to native species. A plant with a low value would represent a species that is common, can persist in highly degraded areas, and is likely not indicative of a high quality remnant community [e.g. *Solidago Canadensis* L., CC = 0; *Rudbeckia hirta* L., CC=1]. Conversely, a species with a high value represents a species that would be found in a place indicative of an intact remnant of a natural ecosystem [e.g. *Lithospermum canescens* (Michx.) Lehm.) , CC=10; *Ceanothus americanus* L., CC = 9] (Swink and Wilhelm 1994, Hermann et al. 1996). Equation 1 describes the calculation, where C is the average of CC values from native plants species in the sampled community, and N is the total number of native species. Non-native plant species are not included in this calculation.

Equation 1: $FQI = C\sqrt{N}$

According to Hermann et al. (1996), an FQI greater than 50 represents an area of high conservatism and an area with an FQI greater than 35 is considered floristically important in Michigan.

Diversity was calculated using the Shannon diversity index (*H* ') (Shannon 1948; Equation 2) where the sum of species richness (SR) for each species (*i*) is multiplied by the relative cover (p_i) and its natural log.

Equation 2: $$H' = -\sum_{i=1}^{SR} pi \ln pi$$

Statistical Analysis

Percent vegetative cover, species richness (SR), and biomass measurements were broken down into seven different subcategories in order to further explore the differences in each treatment group. These measures include total (all species encountered), non-native (all non-native species encountered), native (all native species encountered), resident (all non-seeded species encountered, both native and non-native), planted (all seeded species encountered), grass (all grass species encountered), and forb (all forb species encountered).

Treatments were compared based on their individual treatment group (Table 2). Percent cover, species richness, and diversity were compared among all early season flowering forb (n=12), late season flowering forb (n=12), and legume (n=12) treatment groups. These measures were also compared for the grass-only and background-only species treatments (n=24). Biomass and soil organic carbon were also compared, but at a smaller sample size (n=4) for all treatments except for the no forb treatment with high grass (n=5) and background-only species (n=3) due to sampling error where the wrong plot was measured due to misidentification.

Treatments were compared after being partitioned into grass groupings. Percent cover, species richness, and diversity in control plots (n=12), background-only treatments with no grass (n=24), forb treatment with no grass (n=36), high grass (n=60), and low grass (n=96) treatments were compared. Biomass and soil organic carbon were also compared but at a smaller sample size in control plots (n=4), background-only treatments with no grass (n=4), forb treatment with no grass (n=11), high grass (n=17), and low

grass (n=28). High forbs with no grass groups were not added as a treatment due to lack of available forb seeds.

Treatments were compared after being partitioned into forb groupings. Percent cover, species richness, and diversity in control plots (n=12), background only treatments (n=72), legumes (n=48), early season flowering forbs (n=48), and late season flowering forbs (n=48) treatments were compared. Biomass and soil organic carbon were also compared but at a smaller sample size in control plots (n=4), background- only treatments (n=12), legumes (n=16), early season flowering forbs (n=16), and late season flowering forbs (n=16).

Exploratory analysis for percent cover revealed that bare-ground and litter cover values were normally distributed. In order to produce normality in the other variables, a variety of transformations were used. Native, planted, and grass percent cover values were square root transformed in order to correct for their positive skew. Non-native, resident, and forb percent cover values were transformed by using the formula, $Normal\ Value\ (X) = \sqrt{K - X}$ (where K is a constant from which each score is subtracted so that the smallest score is 1), to correct for their negative skew (Tabachnick and Fidell 2007). Once all data were normalized, a one-way analysis of variance (ANOVA) was used to test whether there were significant differences in percent cover between treatment groups in 2011. In order to further compare the differences among multiple comparison groups, Tukey post-hoc tests were run between all treatment groups. Comparisons were considered significantly different at $p \leq 0.05$ after taking into account the Bonferroni correction. All statistical analyses were performed using PASW 18 (SPSS Inc. 2011). Data are reported as non-transformed values.

Exploratory analysis for species richness and diversity values revealed that they were normally distributed. A one-way ANOVA was used to test whether there were significant differences among treatment groups in species richness and diversity in 2011. In order to further compare the differences among multiple comparison groups, Tukey post-hoc tests were run between all treatment groups. Comparisons were considered significantly different at $p \leq 0.05$ after taking into account the Bonferroni correction. All statistical analyses were performed using PASW 18 (SPSS Inc. 2011).

Exploratory analysis for biomass values revealed that all data were not normal. Therefore, a Kruskal Wallis statistical test was used to test whether there were significant differences in biomass between treatment groups in 2011. In order to further compare the differences among multiple comparison groups, a Mann-Whitney U post-hoc test was run between all treatment groups. Comparisons were considered significantly different at $p \leq 0.05$ after taking into account the Mann-Whitney U correction. All statistical analyses were performed using PASW 18 (SPSS Inc. 2011).

An independent sample T-Test was used to determine if there were significant differences in measured variables between spring seeded groupings and fall seeded legume groups. All treatments were revealed to be statistically similar.

RESULTS

Baseline Floristic Quality Assessment

A total of 50 different plant species were encountered during the baseline floristic quality assessment of the study site's surrounding areas in 2009, including 31 native and 19 non-native species (Table 4). The average coefficient of conservatism (CC) value was 2.94 resulting in a calculated floristic quality index (FQI) of 16.37, indicating that the area was not considered a floristically high quality site (Hermann et al. 1996).

Baseline vegetative cover data indicate that the most prevalent species were *Conyza canadensis* (L.) Cronquist (mean = 41%), *Centaurea maculosa* Lam. (mean = 23%), and *Potentilla argentea* L. (mean = 22%). The most prevalent grass species were *Bromus inermis* Leyss. (mean = 1%) and *Agrostis hyemalis* (Walter) Britton, Sterns & Poggen (mean = 1%).

Comparison among Treatments after Three Years

Percent Cover

Significant differences ($p<0.050$) were found among treatment groups after 3 years in bare-ground cover ($F_{15,227}=3.72$, $p<0.001$), native ($F_{15,227}=5.49$, $p<0.001$), non-native ($F_{15,227}=5.30$, $p<0.001$), resident ($F_{15,227}=10.02$, $p<0.001$), planted ($F_{15,227}=11.18$, $p<0.001$), grass ($F_{15,227}=9.43$, $p<0.001$), and forb species cover ($F_{15,227}=8.58$, $p<0.001$). Litter cover averaged 17.97% in 2011 and did not differ significantly among treatments ($F_{15,227}=1.24$, $p=0.241$).

Bare ground cover averaged 35.32% among all plots in 2011 with the low early forbs/no grass treatment exhibiting the highest bare ground cover (mean = 38.68%). Mean bare-ground cover was significantly lower ($p<0.050$) in the low early forb/high grass treatment and the low late forbs/high grass treatment and (27. 41% and 27.61%, respectively; Table 5) compared to 6 other treatments.

Native species cover averaged 23.44% among all plots with the low early forb/high grass treatment exhibiting the highest native species cover at 46.60%. Native cover in this treatment and in the low late forbs/high grass treatment were significantly higher ($p<0.050$) than the low late forbs/no grass (mean = 12.66%), high legume/low grass (mean = 17.81%), low legume/low grass (mean = 8.70%), low legume/no grass (mean = 12.00%), background species only (mean = 13.73%), and control treatments (mean = 8.01%; Table 5).

Non-native percent cover averaged 76.40% in 2011 and differed significantly among treatments. The control treatment exhibited the highest non-native cover (mean = 91.99%), which was significantly higher ($p<0.050$) than the high early forbs/low grass (mean = 62.19%), low early forbs/high grass (mean = 53.40%), low late forbs/high grass (mean = 55.16%), and high grass only treatments (mean = 68.27%; Table 5).

Resident species cover averaged 82.02%, was highest in the control treatment (mean = 99.83%), and was significantly higher ($p<0.050$) than 10 other treatments. This includes all high grass treatments (mean range: 55.29%-78.44%), all low grass treatments except for those with legumes (mean range: 67.51%-85.51%), and the low early forbs/ no grass treatment (mean = 84.23%; Table 5).

Vegetative cover of planted species averaged 17.98%. Planted cover was lowest in the control plots (mean = 0.17%), which was significantly lower ($p<0.050$) than 11 other treatments. The high grass treatments tended to have higher planted cover (mean range: 18.55%-44.71%); Low grass treatments that did not contain legumes were significantly higher ($p<0.050$) than control treatments (mean range: 14.49%-32.49%). Planted cover in the low late forbs/no grass (mean = 9.21%) and the low early forbs/no grass (mean = 15.77%) treatments was also significantly higher ($p<0.50$) than the control treatment (Table 5).

Mean grass cover averaged 13.55%, a majority of which consisted of planted species (mean = 10.62% vs. 2.93% for non-planted species). Grass cover in all high grass treatments (mean range: 25.94%-36.97%), except for the low legume/high grass treatment (mean =17.76%), was significantly higher than most other treatments (mean range: 3.32%-6.50%; Table 5).

Mean forb cover averaged 86.45%, a majority of which consisted of non-planted species (mean = 79.09% vs. 7.36% for planted species). Forb cover was highest in the control treatment (mean = 96.68%), which was significantly higher ($p<0.050$) than the low early forbs/high grass (mean = 64.25%), low late forbs/high grass (mean = 63.03%) and high grass only treatments (mean = 74.06%; Table 5).

Species Richness

Results indicate significant differences ($p<0.050$) among treatment groups in total ($F_{15,227}=5.74$, $p<0.001$), native ($F_{15,227}=7.83$, $p<0.001$), planted ($F_{15,227}=16.29$, $p<0.001$), grass ($F_{15,227}=14.68$, $p<0.001$), and forb ($F_{15,227}=3.25$, $p<0.001$) species richness. There

were no significant differences among treatment groups in non-native ($F_{15,227}$=1.40, p=0.150) and resident ($F_{15,227}$=0.74, p=0.747) species richness (Table 6).

Mean total species richness averaged 11.78 species across all seeded treatments. All fully seeded treatments (e.g. contained both a forb and grass group) were significantly higher in species richness than control plots (mean = 8.50, p<0.050) except for the high legumes/low grass treatment (mean=11.25 species). High grass and low grass only treatments had significantly higher (p<0.050) total species richness (mean = 13.00 and 13.75, respectively) than control plots. All treatments with high grass (mean range: 12.00-15.00 species) had significantly greater (p<0.050) species richness than control plots (Table 6).

Native species richness averaged 6.35 species. Control plots had significantly lower (p<0.050) native species richness (mean = 2.25 species) compared to all treatment groups except for background only, low late forbs/no grass, and low legumes/no grass treatments (mean range: 4.5-5.67 species). All treatments that were seeded with grasses (mean range: 5.75-8.80 species), were significantly higher (p<0.050) than control plots in total native species richness (Table 6).

Planted species richness showed the most significant differences among treatments. Planted species richness averaged 4.43 species across all treatments. Control plots were significantly lower (mean = 0.50 species, p<0.050) in planted species richness compared to all other treatments. High grass treatments ranged from a mean of 5.50-7.20 species, low grass treatments ranged from a mean of 4.00-6.50 species, and no grass or background only treatments ranged from a mean of 2.75-5.00 species (Table 6).

Mean grass species richness averaged 2.30 species, a majority of which consisted of planted species (mean = 1.60 vs. 0.70 for non-planted species). Control plots had significantly lower (p<0.050) grass species richness (mean = 1.0 species) than all groups except for treatments not seeded with grasses, and the high legume/low grass treatment and background only treatments (Table 6).

Mean forb species richness averaged 9.49 species, a majority of which consisted of non-planted species (mean = 6.65 vs. 2.83 for planted species). Early forb treatments were significantly higher (p<0.050) in forb species richness (mean range: 9.5-11.25 species) than control plots (mean = 7.5 species). The only other treatments that were significantly higher (p<0.050) in forb species richness than the control plots were those seeded with low legumes and high grass (mean = 11.8 species), as well as low late forbs with low grass (mean = 9.75 species; (Table 6).

Above-ground Biomass

Results indicate significant differences (p<0.050) among treatment groups in grass aboveground biomass (X^2=29.02, df=15, 227, p=0.048). There were no significant differences (p>0.050) among litter (X^2=25.95, df=15, 227, p=0.101, mean = 6.73g), aboveground biomass for native (X^2=21.56, df=15, 227, p=0.252, mean = 3.34g), non-native (X^2=9.00, df=15, 227, p=0.960, mean = 10.69g), resident (X^2=9.60, df=15, 227, p=0.944, mean = 10.98g), planted (X^2=27.95, df=15, 227, p=0.063, mean =3.05g), or forb species (X^2=8.96, df=15, 227, p=0.961, mean = 11.36g; Table 7).

Grass aboveground biomass averaged 2.71g. The high grass/low late forb treatment group had significantly more (p<0.050) grass aboveground biomass (mean = 13.06g) than any other treatment (mean range: 0.00-5.78g; Table 7).

Floristic Quality and Diversity

Results indicate significant differences among treatment groups in floristic quality index (FQI) values ($F_{15,227}$=29.09, p<0.001). Mean FQI values across all treatments averaged 8.49. The FQI of the control treatment in 2011 was significantly lower (mean = 1.56, p<0.050) than all other treatments (mean range: 5.78-11.39). All treatments that included high grass seeding had a significantly higher FQI (mean range: 9.57-11.39, p<0.050) than treatments that had no grass component (mean range: 5.78-8.53; Table 8).

Results indicate significant differences among treatment groups in Shannon diversity (H') ($F_{15,227}$=2.74, p=0.001). Mean H' values of all treatments averaged 1.48. Mean H' of the low legumes with low grass treatment (mean = 1.16) was significantly lower (p<0.050) than the H' of treatments with high grass only (mean = 1.61), high early forbs with low grass (mean = 1.71), and low early forbs with high grass (mean = 1.73; Table 8).

Comparison among Grass Treatment Groups after Three Years

Percent Cover

Results indicate significant differences (p<0.050) among treatment groups in bare-ground ($F_{4,227}$=5.79, p<0.001), native ($F_{4,227}$=11.20, p<0.001), non-native ($F_{4,227}$=11.41, p<0.001), resident ($F_{4,227}$=24.09, p<0.001), planted ($F_{4,227}$=23.90, p<0.001), grass ($F_{4,227}$=30.39, p=0.014), and forb ($F_{4,227}$=30.39, p=0.014) cover. There were no significant differences (p>0.050) among treatment groups in litter cover ($F_{4,227}$=0.70, p=0.595, mean = 17.86%; Table 9).

Bare-ground cover averaged 36.03% across all grass treatment groups. High grass treatments had significantly lower bare-ground cover (mean = 31.85%, $p<0.050$) than all treatment groups except for control plots (mean = 37.20%), which showed high variability.

Native cover averaged 19.34% across all grass treatment groups. High grass treatments had significantly higher native cover (mean = 35.02%, $p<0.050$) than all other treatment groups. Low grass treatments had significantly higher native cover (mean = 22.99%, $p<0.050$) than all treatment groups except for high grass treatments. All other treatment groups did not differ significantly (mean range: 8.01-16.94%; Table 9; Figure 2).

Non-native cover averaged 80.54% across all grass treatment groups. High grass treatments had significantly lower non-native cover (mean = 64.38%, $p<0.050$) than all treatment groups, while low grass treatments had significantly lower cover (mean = 77.01%, $p<0.050$) than all treatment groups except for the high grass treatment. There were no significant differences among all other treatment groups (mean range: 83.06-91.99%; Table 9; Figure 3).

Resident cover averaged 86.45% across all grass treatment groups. Resident cover in control plots (mean = 99.83%) was significantly greater ($p<0.050$) than all other treatments (mean range: 68.00-91.12%). High grass treatments had significantly lower resident cover (mean = 68.00%, $p<0.050$) than all other treatments. Low grass treatments had significantly lower (mean = 82.71%, $p<0.050$) resident cover than background only species with no grass treatment and control plots (Table 9).

Planted cover averaged 13.43% across all grass treatment groups. Control plots had significantly less planted cover (mean = 0.17%, $p<0.050$) than all other treatment groups (mean range: 8.88-31.40%). High grass treatments had significantly higher planted cover (mean = 31.40%, $p<0.050$) than all other treatment groups. Low grass treatments had significantly higher planted cover (mean = 17.29%, $p<0.050$) than background only with no grass treatments (mean = 8.88%), but was not significantly different ($p>0.050$ than forb treatments with no grass (mean = 9.43%; Table 9).

Grass cover averaged 10.35% across all grass treatment groups. High grass treatments had significantly more grass cover (mean = 28.47%, $p<0.050$) than all other treatment groups. Low grass treatments had significantly higher grass cover (mean = 11.14%, $p<0.050$) than all treatment groups except for the high grass treatments (Table 9).

Forb cover averaged 89.65% across all grass treatment groups. High grass treatments had significantly less forb cover (mean = 71.53%, $p<0.050$) than all other treatment groups. Low grass treatments had significantly less forb cover (mean = 88.86%, $p<0.050$) than all treatment groups except for the high grass treatments (Table 9).

Species Richness

Results indicate significant differences ($p<0.050$) among treatment groups in total ($F_{4,227}=16.09$, $p<0.001$), native ($F_{4,227}=19.78$, $p<0.001$), planted ($F_{4,227}=40.16$, $p<0.001$), grass ($F_{4,227}=51.68$, $p<0.001$), and forb ($F_{4,227}=5.32$, $p<0.001$) species richness. There

were no significant differences (p>0.050) among grass treatment groups in non-native ($F_{4,227}$=0.26, p=0.905, mean = 5.33 species) and resident ($F_{4,227}$=0.21, p=0.932, mean = 7.27 species) species richness (Table 10).

Total species richness averaged 10.73 species across all grass treatment groups. Control plots averaged significantly less total species richness (mean = 7.75 species, p<0.050) than all forb treatments with no grass (mean = 10.61 species), high grass treatments (mean = 12.88 species), and low grass treatments (mean = 12.49 species). High grass and low grass treatments exhibited significantly higher total species richness than all other grass treatment groups (p<0.050; Table 10; Figure 4).

Native species richness averaged 5.35 species across all grass treatment groups. Control plots had significantly lower native species richness (mean = 2.33 species, p<0.050) than all other treatment groups (mean range: 4.63-7.48 species). High grass and low grass treatments had significantly higher native species richness (mean = 7.48 and 6.96 species, respectively, p<0.050) compared to all other treatment groups (Table 10; Figure 5).

Planted species richness averaged 3.41 species across all grass treatment groups. All treatment groups had significantly higher planted species richness (mean range: 2.79-5.60 species, p<0.050) than the control plots (mean = 0.25 species). High grass and low grass treatments had significantly higher planted species richness (mean = 5.60 and 5.03 species, respectively, p<0.050) compared to all other treatment groups (Table 10).

Grass species richness averaged 1.73 species across all grass treatment groups. High grass treatments had significantly higher grass species richness (mean = 3.50 species, p<0.050) than all other treatments. Low grass treatments had significantly

higher grass species richness (mean = 2.63 species, $p<0.050$) compared to all other treatments (Table 10).

Forb species richness averaged 9.01 species across all grass treatment groups. All treatment groups had significantly higher forb species richness (mean range: 9.17-9.86 species, $p<0.050$) than control plots (mean = 6.92 species; Table 10).

Above-ground Biomass

Results indicate significant differences among treatment groups in planted (X^2=14.97, df=4, 227, p=0.005) and grass (X^2=16.50, df=4, 227, p=0.002) aboveground biomass among grass treatment groups. There were no significant differences among litter (X^2=8.16, df=4, 227, p=0.086, mean = 5.98g), native (X^2=7.75, df=4, 227, p=0.101, mean = 2.35g), non-native (X^2=1.22, df=4, 227, p=0.875, mean = 10.93g), resident (X^2=1.51, df=4, 227, p=0.825, mean = 11.23g), and forb (X^2=0.75, df=4, 227, p=0.945, mean = 11.23g) aboveground biomass (Table 11).

Planted aboveground biomass averaged 2.04g among grass treatment groups. Treatments with high grass exhibited significantly higher ($p<0.050$) mean planted aboveground biomass than all other treatments (Table 11).

Grass aboveground biomass averaged 2.04g among grass treatment groups. Treatments with high grass exhibited significantly higher ($p<0.050$) mean grass aboveground biomass than all other treatments (Table 11).

Floristic Quality and Diversity

Results indicate significant differences among treatment groups in FQI values ($F_{4,227}$=87.83, $p<0.001$). The mean FQI of grass treatment groups was 6.87. The FQI of the control plots in 2011 was significantly lower (mean = 1.37) than all other treatments

(mean range: 6.56-10.37). The high grass treatments had a significantly higher FQI (mean = 10.37) than all other treatment groups while low grass treatments had a significantly higher FQI (mean = 9.35) than all treatments except the high grass treatments (Table 12; Figure 6).

Results indicate significant differences among treatment groups in Shannon diversity (H') ($F_{4,227}$=4.43, p=0.002) (Table 12). The mean H' of grass treatment groups was 1.42. Mean H' of the high grass treatments was significantly higher (mean = 1.61) than all treatments except for the background species only with no grass treatment (mean = 1.40) and the low grass treatment (mean = 1.49; Table 12; Figure 7).

Comparison among Forb Treatment Groups after Three Years

Percent Cover

Results indicate significant differences (p<0.050) among treatment groups in bare-ground ($F_{4,227}$=2.99, p=0.020), native ($F_{4,227}$=8.75, p<0.001), non-native ($F_{4,227}$=8.33, p<0.001), resident ($F_{4,227}$=17.72, p<0.001), planted ($F_{4,227}$=18.51, p<0.001), grass ($F_{4,227}$=3.21, p=0.014), and forb ($F_{4,227}$=3.21, p=0.014) cover. There were no significant differences (p>0.050) among treatment groups in litter cover ($F_{4,227}$=0.16, p=0.959, mean = 18.04%; Table 13).

Bare-ground cover averaged 35.59% among forb treatment groups. The late season flowering forb treatment had significantly less (p<0.050) bare-ground cover than the legume treatments (mean = 33.40% and 37.96%, respectively; Table 13).

Native cover averaged 21.24% among forb treatment groups. Treatments of early season flowering forbs and late season flowering forbs showed significantly higher percent native cover (mean = 34.10% and 27.19%, respectively, $p<0.050$) than control plots (mean = 8.01%) and legume treatments (mean = 14.68%; Table 13; Figure 8).

Non-native cover averaged 78.61% among forb treatment groups. The control plots and legume treatments showed significantly higher non-native cover (mean = 91.99% and 84.57%, respectively, $p<0.050$) than early season and late season flowering forb treatments (mean = 65.90%, 72.81%, respectively; Table 13; Figure 9).

Resident cover averaged 84.39% among forb treatment groups. Control plot cover (mean = 99.83%) was significantly greater ($p<0.050$) than resident cover in all other treatments (mean range: 71.16%-90.96%). Early season flowering forbs and late season flowering forbs (mean = 71.16% and 76.46%, respectively) had significantly lower ($p<0.050$) resident cover than all other treatments (Table 13).

Planted cover averaged 15.46% among forb treatment groups. Control plots had significantly less planted cover (mean = 0.17%, $p<0.050$) than all other treatment groups (mean range: 8.29%-28.84%). Early season flowering forb and late season flowering forb treatments (mean = 28.84% and 23.54%, respectively) had significantly more ($p<0.050$) planted cover than all other treatment groups (Table 13).

Grass cover averaged 11.93% among forb treatment groups. All treatment groups had significantly higher grass relative cover (mean range: 8.30%-17.48%, $p<0.050$) than the control plots (mean = 3.32%). Early season flowering forbs and late season flowering forbs had significantly higher grass cover (mean = 17.48% and 16.18%, respectively,

$p<0.050$) than all treatment groups except for background only treatments (mean = 14.36%; Table 13).

Forb cover averaged 88.07% among forb treatment groups. All treatment groups had significantly lower ($p<0.050$) forb (mean range: 82.52%-91.70%) relative cover than the control plots (mean = 96.68%). Early season flowering forbs and late season flowering forbs had significantly lower forb cover (mean = 82.52% and 83.82%, respectively) than all other treatment groups except for background only treatments (mean = 85.64%; Table 13).

Species Richness

Results indicate significant differences ($p<0.050$) among treatment groups in total ($F_{4,227}=9.99$, $p<0.001$), native ($F_{4,227}=15.77$, $p<0.001$), planted ($F_{4,227}=26.28$, $p<0.001$), grass ($F_{4,227}=3.98$, $p=0.004$), and forb ($F_{4,227}=9.96$, $p<0.001$) species richness. There were no significant differences ($p>0.050$) among forb treatment groups in mean non-native ($F_{4,227}=0.65$, $p=0.629$, mean = 5.35 species) and resident ($F_{4,227}=0.38$, $p=0.825$, mean = 7.29 species) species richness (Table 14).

Total species richness averaged 11.20 species among forb treatment groups. Control plots averaged significantly less total species richness (mean = 7.75 species, $p<0.050$) than all other treatments. The early season flowering forb treatment had significantly higher total species richness (mean = 13.25 species, $p<0.050$) than all other treatments except for legumes (mean = 11.83 species; Table 14; Figure 10).

Native species richness averaged 5.79 species among forb treatment groups. Control plots had significantly lower native species richness (mean = 2.33 species, $p<0.050$) than all other treatment groups. The early season flowering forb treatment

group had significantly higher native species richness (mean = 8.06 species, $p<0.050$) than all other treatment groups (mean range: 5.93-6.46 species; Table 14; Figure 11).

Planted species richness averaged 3.85 species among forb treatment groups. All treatment groups had significantly higher ($p<0.050$) planted species richness than the control plots (mean = 0.25 species). The early season flowering forbs had significantly greater planted species richness (mean = 5.92 species, $p<0.050$) than all other treatment groups (mean range: 4.00-4.60 species; Table 14).

Grass species richness averaged 2.06 species among forb treatment groups. All treatments except for legumes (mean = 2.06 species) exhibited significantly higher grass species richness (mean range: 2.40-2.56 species, $p<0.050$) than control plots (mean = 0.83 species; Table 14).

Forb species richness averaged 9.14 species among forb treatment groups. Control plots had significantly less forb species richness (mean = 6.92 species, $p<0.050$) than all forb treatment groups (mean range: 9.08-10.71 species). The early season flowering forbs had significantly higher (mean = 10.71 species, $p<0.050$) forb species richness than all other treatment groups except for legumes (mean = 9.77 species; Table 14).

Above-ground Biomass

Results indicate significant differences among treatment groups in planted aboveground biomass ($X^2=12.582$, $df=4$, 227, $p=0.014$) among forb treatment groups. Planted aboveground biomass averaged 2.60g among forb treatment groups. Legume treatments (mean = 0.51g) and the control plots (mean = 0.00g) exhibited significantly lower ($p<0.050$) aboveground biomass than all other treatments (Table 15).

There were no significant differences (p>0.050) among litter (X^2=2.71, df=4, 227, p=0.608, mean = 6.74g), native (X^2=8.26, df=4, 227, p=0.083, mean = 2.92g), non-native (X^2=1.41, df=4, 227, p=0.843, mean = 11.02g), resident (X^2=1.79, df=4, 227, p=0.774, mean = 11.34g), grass (X^2=2.83, df=4, 227, p=0.587, mean = 2.39g), and forb (X^2=0.56, df=4, 227, p=0.967, mean = 11.56g) aboveground biomass (Table 15).

Floristic Quality and Diversity

Results indicate significant differences among treatment groups in FQI values ($F_{4,227}$=37.96, p<0.001). The mean FQI of forb treatment groups was 7.43. The FQI of the control plots in 2011 was significantly lower (mean = 1.37, p<0.050) than all other forb treatments (mean range: 8.39-9.99). The early season flowering forbs had a significantly higher FQI (mean = 9.99, p<0.050) than all other treatments except for legumes (mean = 8.89; Table 16; Figure 12).

Results indicate significant differences among treatment groups in Shannon diversity (H') ($F_{4,227}$=4.86, p=0.001) (Table 16). The mean H' of forb treatment groups was 1.44. Mean H' of the control plots and legume treatments (mean = 1.26, 1.33, respectively) was significantly lower (p<0.050) than the early season flowering forb treatments (mean = 1.62) (Table 16; Figure 13).

DISCUSSION

Impacts of Succession versus Restoration

Several plant community variables improved significantly as a result of our restoration efforts. In general, the prevalence of resident species - including *Centaurea maculosa* Lam.– decreased, while productivity, native species richness and diversity increased since the initiation of our experiment in 2009. When comparing differences among grass treatments and forb treatments, the high grass and the early season forb treatments had the greatest overall impact on plant community development. A comparison between seeded treatments and the non-seeded control treatment indicates that our efforts have been more successful in the restoration of native sand prairie than would have resulted from succession alone.

Comparison among All Treatment Groups

Resident species richness was significantly lower in all seeded treatments compared to control plots. Resident species richness may be higher in control plots because of more available niche space due to the lack of seed additions (Shea and Chesson 2002; Funk et al. 2008). Early successional species and invasive species typically spread into areas or germinate from a dormant seed bank shortly following a disturbance (Tramer 1975; Bazzaz 1979). Therefore, herbicide applications during the two years prior to seeding may have played an important role in promoting this flux of species by creating open spaces for resident species to germinate from the seed bank or

colonize from the surrounding area. Species recruitment in 2009 may have been followed by further colonization by new resident species in 2010 and 2011 due to remaining availability of niche space. Conversely, the lower resident species richness in the seeded treatments may be due to a change in competitive balance (Connell 1983, Fargione and Tilman 2006). As seeded species begin to establish, they may outcompete existing resident species for available nutrients (Zimmerman and Kucera 1977, Raison 1979, Ojima et al. 1994, Tilman et al. 1996).

Another positive result due to the establishment of seeded species is the increase in FQI in seeded plots compared to control plots. The addition of species with higher CC values (i.e. more "conservative" species) compared to the resident species increases the FQI of the degraded plant community. Although the mean FQI of seeded plots at 9.10 does not yet reflect the FQI of 43.47 to 80.00 found in native sand prairie (Ebinger et al. 2006), it does represent a significant improvement over the mean FQI of the control plots (i.e. FQI = 1.56). This increase is still, by comparison, less than the FQI of the baseline floristic inventory (FQI = 16.37).

Comparison among Grass Treatment and Forb Treatment Groups

Similarly, resident species cover was significantly lower in all grass seeded treatments (i.e. no, low, and high grass) also likely due to a change in competitive balance (Connell 1983, Fargione and Tilman 2006). Planted cover, native and planted species richness, and FQI were significantly higher in all seeded grass plots compared to control plots due, in part, to an increase in forb species richness in the grass treatments.

Baseline data indicated that the community was heavily forb dominated in 2009, however, native forb species included in the grass treatments further increased forb species richness. Although some grass treatments included forbs, grass-only treatments also had significantly greater forb species richness than control plots. Forb species may be benefiting from seeded treatments because as seeded species grow, they may facilitate the growth of other seeded species around them (Callaway and Walker 1997, Peltzer and Kochy 2001). This may also apply to non-seeded species in the surrounding area. Species presently on or nearby the site, as well as those species whose seeds are currently dormant in the seed bank may realize more favorable conditions for germination from the establishment of seeded species, and hence increase forb species richness.

Resident and forb cover were significantly higher in control plots than in seeded forb treatments. Conversely, planted cover, total, native, planted, and forb species richness, and FQI were all significantly higher in all seeded forb treatments compared to control plots. Resident cover may be higher in control plots due to reduced competition for available open niche space resulting from the lack of seed additions in these plots. Contrary to the grass-only treatments, forb cover was higher in treatments that included the addition of forbs. Similarly, planted cover was higher in seeded plots than in the control plots due to addition of native seed. Total, native, and planted species richness and FQI increased with the addition of seeded forbs.

Community Responses to Grass Seeding and Forb Seeding Efforts

Treatments with either high or low concentrations of grasses were not significantly different from each other across any measure of species richness other than grass species richness. High grass treatments had significantly more grass species richness than both low and no grass treatments. Both low and high grass treatments had significantly more total and planted species richness than treatments with no grass.

Aboveground biomass was similar among most grass treatments. The only difference was that planted biomass was significantly higher in the high grass treatments. High grass treatments were also more effective in covering more ground and hence had lower bare-ground cover than all other treatments except for the highly variable control plots. High grass treatments also had a significantly higher FQI. Diversity (H') did not differ significantly between high and low grass treatments. However, these treatments were significantly more diverse than all other treatments except for the background only species with no grass treatment.

Although cover was dominated by grasses, high grass plots displayed significantly higher native and planted cover than any other treatment. This may be attributed to the inclusion of native species within these planting groups. However, high grass only plots consisting of no planted forb species still exhibited significantly greater native and planted cover than treatments that included forbs and low grass concentrations. High grass treatments also had significantly lower non-native and resident cover than all other treatments.

Aboveground biomass was similar among most forb treatments. The only difference was that planted biomass was significantly higher in early season, late season, and background only forb treatments than control and legume treatments. Native and planted covers were significantly greater in the early season forb and late season forb treatments than all other forb treatments. Conversely, non-native and resident covers were significantly less in early season and late season forb treatments compared to all other treatments.

Early season forb treatments had significantly higher native and planted species richness than all other treatments. Although early season forb treatments had a significantly higher FQI than most other treatments, legume treatments were not significantly different. Early season forb treatments also were significantly more diverse (H') than most other treatments except for background only and late season forb treatments.

Facilitation

Results suggest that seed additions may facilitate plant community development in the relatively hot and dry conditions of a sand prairie during the first few years of community development. The increased growth of native species within the grass treatments - especially within high grass seed treatments - compared to treatments that did not contain grass suggests that seeded grasses may provide suitable microclimatic conditions for native seed growth such as shade for reduced heat stress and moisture capture (Plumb-Mentjes and Center 1990; Smith and Huston 1990; Peltzer and Kochy

2001). Similarly, the growth of early season forbs may create greater cover and biomass early in the year which could result in greater shade and moisture capture for late season forb and grass species (Henderson et al. 1988; Callaway and Walker 1997; Brooker et al. 2007).

Similar results indicating a facilitative effect from seed additions have been shown in an experiment where bunchgrasses protected rare plant species during dry years (Greenlee and Callaway 1996) and in other studies where adult plants provided a facilitative response during restoration in arid ecosystems (Maestre et al. 2001; Barchuk et al. 2005). Studies have also attempted to model light and moisture capture of species in dry, harsh environments such as sand prairies. Holmgren et al. (1997) and Smith and Huston (1990) studied the role facilitation plays in community development by modeling the positive and negative effects that "nurse plant" or mature plant canopy cover plays on establishment of new plants in dry communities. This model shows that increased availability of water due to facilitation outweighs the detrimental effect of shade (decreased light, photosynthesis) in harsh conditions. Therefore, facilitative effects may outweigh competitive effects of neighboring plants in such environments.

Competition

Results also indicate that competition resulting from seed additions may play a key role in promoting initial community development. Individual resident species respond in different ways to species additions based on their ability to compete for limited resources (Grime 1974, Goldberg and Barton 1992, Smith et al. 1999). However,

the overall decrease in resident species growth within the grass treatments – especially within high grass seed treatments – suggests that resident species are at a competitive disadvantage compared to seeded species. Conversely, the overall increased growth of seeded species in the grass treatments suggests that species that are native to the sand prairie may be better able to compete for the limited resources compared to other early successional, weedy, or non-native resident species such as *Centaurea maculosa* Lam.

Similar results indicating a competitive effect from grass seed additions have been shown by Jordan et al. (2008), where they found that native grasses were less affected by invasive species. This study found that grasses are relatively insensitive to altered soil biota from invasive plants, and in turn, may shift the competitive balance of restoration efforts on an ecosystem. Similar studies suggest that grasses in prairie restoration enhance overall diversity and reduce exotic species cover (Middleton et al. 2009; Carter and Blair 2012). These studies also indicate that native grasses in restoration may represent an effective management strategy to reduce exotic plant density. Although grass seeding in restorations has been shown to be beneficial, long-term studies have shown that grasses can dominate and exclude other native species over time (Schramm 1990).

These results also express that forb additions – particularly a benefit of early season forb treatments and a lack of response from legume treatments – may play a key role in influencing community competitive balance (Howe 1994; Dukes 2001). Additions of early season forb species may provide an initial, early-in-the-year increase in species cover and richness that may in turn directly affect the competitive balance of a community by providing greater resistance or buffer capability to further invasions by

invasive species which in turn may show increased diversity from other native seeded species later in the growing season (Dukes 2001; Kennedy et al. 2002; Naeem and Wright 2003). Contrary to early season forb treatments, legume treatments, although expected to be highly competitive in a nutrient-poor sand prairie ecosystem due to their ability to fix nitrogen, had little effect on plant community composition. Three competitive reasons may explain why we did not see significant establishment of seeded legume species. The dominant and widespread resident legume species *Trifolium arvense* L. may have adverse impacts on seeded legumes. It may suppress seed additions either via interspecific competition, being temporally competitive due to its annual life cycle and producing large amounts of seeds both in the spring and summer, or possibly because nitrogen fixing niche space is already being consumed by *Trifolium arvense* L. (Dukes 2001; Fargione et al. 2003).

Similar experimental results have alluded to the idea that seeding of early season forbs within a restoration may provide positive competitive effects to a community. Martin et al. (2005) suggested that restoration seeding efforts that contain early season forbs may be more diverse because these species are better able to co-exist with other, later growing seeded species because they come to occupy an early season niche. Thus, early season forbs will ultimately increase diversity, species richness, and other important community variables. Similarly, a study by Foster and Tilman (2003) suggests that early season forb seeding (as part of a complete restoration seed mix) presents an opportunity for transient coexistence through competition-colonization trade-offs, thus allowing many species to coexist at the community scale. Additionally, Seabloom et al. (2003) proposed that a single seeding of native forbs (including early season forb species), even in the

presence of high densities of exotic species, may be sufficient to create viable populations of native species in areas that are currently dominated by exotic species.

Similar results showing a lack of legume establishment after seed additions have been found. In a twenty-five year study of prairie establishment following restoration, Schramm (1990) found that legumes did not become a major component of restorations until later phases of restoration succession. However, after legumes became more established in later years of restoration, it was found that they had greater staying power. This could be due to a lack of competitive ability during their early establishment periods (Schramm 1990). This may also be due to interspecific competition for limiting resources among legumes with neighboring plants belonging to the same functional group (Nemec et al. 2013). Most studies that have shown minimal impacts of legumes (species cover and richness) on restorations have been in response to herbivory. Restoration attempts that were not excluded by fencing and had populations of deer or voles saw high mortality or reduced fruiting in legume species due to their grazing preference by these animals (Howe et al. 2002; Diaz et al. 2003).

CONCLUSION

In general, a comparison between seeded treatments and non-seeded control treatments indicates that our efforts have been more successful in the restoration of native sand prairie than would have resulted from succession alone. Restoration attempts displayed a significant decrease in invasive, resident species richness and increased diversity compared to succession. Treatments that included a high concentration of grass and/or an early season forb component had the greatest overall positive impact on plant community development. These treatments exhibited significantly higher planted biomass, diversity, and floristic quality than most other treatments. Conversely, these seeded treatments typically displayed less non-native or invasive cover than most other treatments. The benefit of high concentrations of grasses and early season forbs may play a critical role in initial species establishment of a sand prairie restoration due to the facilitative and competitive advantages they may provide in these harsh environments. However, it remains to be seen if these initially successful communities will have continued success over long periods of time.

LITERATURE CITED

Abrams, M.D., and L.C. Hulbert. 1987. Effect of topographic position and fire on species composition in tallgrass prairie in northeast Kansas. American Midland Naturalist 117: 442-445.

Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. Gen. Tech. Rep. NC-178. St. Paul, MN: USDA, Forest Service, North Central Forest Experiment Station, t. Paul, MN. http://nr.fs.fed.us/pubs/242 (Version 03UN1998). 250pp.

Albert, D.A., and P.J. Comer. 2008. Atlas of early Michigan's forests, grasslands, and wetlands. Michigan State University Press, East Lansing, MI.

Anderson, R.C. 1990. The historic role of fire. Fire in North American tallgrass prairies. University of Oklahoma Press, Norman, OK.

Barchuck, A.H., A. Valiente-Banuet, and M.P. Diaz. 2005. Effect of shrubs and seasonal variability of rainfall on the establishment of Aspidosperma quebrachoblanco in two edaphically contrasting environments. Austral Ecology 30:695-705.

Bazzaz, F.A. 1979. The physiological ecology of plant succession. Annual Review of Ecology and Systematics 10:351-371.

Belyea, L.R., and J. Lancaster. 1999. Assembly rules within a contingent ecology. Oikos 86:402-416.

Bowles, M.L., M.D. Jones, and J.L. McBride. 2003. Twenty-year changes in burned and unburned sand prairie remnants in northwestern Illinois and implications for management. The American Midland Naturalist 149:35-45.

Boyle, B., et al. 2013. The Taxonomic Name Resolution Service: an Online Tool for Automated Standardization of Plant Names. BMC Bioinformatics 14:16.

Brooker, R.W., F.T. Maestre, R.M. Callaway, C.L. Lortie, L.A. Cavieres, G. Kunstler, P. Liancourt, K. Tielborger, J.M.J. Travis, F. Anthelme, C. Armas, L. Coll, E. Corcket, S. Delzon, E. Forey, Z. Kikvidze, J. Olofsson, F. Pugnaire, C.L. Quiroz, P. Saccone, K. Schiffers, M. Seifan, B. Touzard, and R. Michalet. 2007. Facilitation in plant communities: the past, the present, and the future. Journal of Ecology 96:18-34.

Cairns, J., and J.R. Heckman. 1996. Restoration ecology: the state of an emerging field. Annual Review of Energy and the Environment 21:167-189.

Callaway, R.M. and L.R. Walker. 1997. Competition and facilitation: a synthetic approach to interactions in plant communities. Ecology 78:1958-1965.

Carter, D.L. and J.M. Blair. 2012. High richness and dense seeding enhance grassland restoration establishment but have little effect on drought response. Ecological Applications 22:1308-1319.

Catchpole, W.R., and C.J. Wheeler. 1992. Estimating plant biomass: A review of techniques. Australian Journal of Ecology 17: 121-131.

Chapin, F.S., L.R. Walker, C.L. Fastie, and L.C. Sharman. 1994. Mechanisms of primary succession following deglaciation at Glacier Bay, Alaska. Ecological Monographs 64: 149-175.

Chapman, K.A. 1984. An ecological investication of native grassland in southern Lower Michigan. M.S. Thesis, Western Michigan University, Kalamazoo, MI. 235 pp.

Cipollini, K.A., A.L. Maruyama, and C.L. Zimmerman. 2005. Planning for restoration: a decision analysis approach to prioritization. Restoration Ecology 13: 460-470.

Cole, K.L., and R.S. Taylor. 1995. Past and current trends of change in a dune prairie/oak savanna reconstructed through a multiple-scale history. Journal of Vegetation Science 6:399-410.

Collins, S.L., and D.J. Gibson. 1990. Effects of fire on community structure in tallgrass and mixed-grass prairie. Excerpt from: Fire in North American Grasslands. Collins, S.L., and L.L. Wallace, eds. University of Oklahoma Pres, Norman, OK. p. 81-97.

Collins, S.L., S.M. Glenn, and D.J. Gibson. 1995. Experimental analysis of intermediate disturbance and initial floristic composition: decoupling cause and effect. Ecology 76: 486-492.

Collins, S.L. 2000. Disturbance frequency and community stability in native tallgrass prairie. The American Naturalist 155: 311-325.

Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's native landscape as interpreted from the General Land Office surveys 1816-1856. Michigan Natural Features Inventory, Lansing, MI. Report n. 1995-07.

Connell, J.H. 1983. On the prevalence and relative importance of interspecific competition: evidence from field experiments. The American Naturalist 122:661-696.

Cully, A.C, J.F. Cully, and R.D. Hiebert. 2003. Invasion of exotic plant species in tallgrass prairie fragments. Conservation Biology 17:990-998.

Diaz, S., A.J. Symstad, F.S. Chapin III, D.A. Wardle, and L.F. Huenneke. 2003. Functional diversity revealed by removal experiments. Trends in Ecology and Evolution 18:140-146.

Dukes, J.S. 2001. Biodiversity and invisibility in grassland microcosms. Oecologia 126:563-568.

Ebinger, J.E., L.R. Phillippe, R.W. Nyboer, W.E. McClain, D.T. Busemeyer, K.R. Robertson, and G.A. Levin. 2006. Vegetation and flora of the sand deposits of the Mississippi River Valley in northwestern Illinois. Illinois Natural History Survey Bulletin 37:191-238.

Emery, S.M., P.J. Doran, J.T. Legge, M. Kleitch, and S. Howard. 2012. Aboveground and belowground impacts following removal of the invasive species Baby's Breath (*Gypsophila paniculata*) on Lake Michigan Sand Dunes. Restoration Ecology.

Fargione, J., C.S. Brown, and D. Tilman. 2003. Community assembly and invasion: an experimental test of neutral versus niche processes. Proceedings of the National Academy of Science 100:8916-8920.

Fargione J. and D. Tilman. 2006. Plant species traits and capacity for resource reduction predict yield and abundance under competition in nitrogen-limited grassland. Functional Ecology 20:533-540.

Farrer, E.C., and D.E. Goldberg. 2011. Patterns and mechanisms of conspecific and heterospecific interactions in a dry perennial grassland. Journal of Ecology 99:265-276.

The Forest History Society. 2009. National Forests in Michigan. http://www.foresthistory.org. Accessed November 2011.

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

Foster, B.L. and D. Tilman. 2003. Seed limitation and the regulation of community structure in oak savanna grassland. Journal of Ecology 91:999-1007.

Funk, J.L., E.E. Cleland, K.N. Suding, and E.S. Zavaleta. 2008. Restoration through reassembly: plant traits and invasion resistance. Trends in Ecology and Evolution 23: 695-703.

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

Gleason, H.A. 1910. The vegetation of the inland sand deposits of Illinois. Volume 9. Illinois State Laboratory of Natural History.

Gleason, H.A., and A. Cronquist. 1991. Manual of vascular plants of northeastern United States and adjacent Canada. The New York Botanical Garden Press, Bronx, NY.

Goldberg, D.E. and A.M. Barton. 1992. Patterns and consequences of interspecific competition in natural communities: a review of field experiments with plants. The American Naturalist 139: 771-801.

Gough, L., J.B. Grace, and K.L. Taylor. 1994. The relationship between species richness and community biomass: the importance of environmental variables. Oikos 70: 271-279.

Grace, J.B. 1999. The factors controlling species density in herbaceous plant communities: an assessment. Perspectives in Plant Ecology, Evolution, and Systematics 2/1: 1-28.

Greenlee, J.T. and R.M. Callaway. 1996. Abiotic stress and the relative importance of interference and facilitation in montane bunchgrass communities in western Montana. The American Naturalist 148:386-396.

Grime, J.P. 1974. Control of species density in herbaceous vegetation. Journal of Environmental Management 1: 151-167.

Hauser, R.S. 1953. An ecological analysis of the isolated prairies of Newaygo County, Michigan. Ph.D. Dissertation. Michigan State College, 168 pp.

Hector, A., B. Schmid, C. Beierkuhnlein, M.C. Caldeira, M. Diemer, and P.G. Dimitrakopoulos. 1999. Plant diversity and productivity experiments in European grasslands. Science 286:1123-1127.

Henderson, C.B., K.E. Petersen, and R.A. Redak. 1988. Spatial and temporal patterns in the seed bank and vegetation of a desert grassland community. Journal of Ecology 76:717-728.

Hermann, K.D., L.A. Masters, M.R. Penskar, A.A. Reznicek, G.S. Wilhelm, and W.W. Brodowicz. 1996. Floristic quality assessment with wetland categories and computer application programs for the state of Michigan. Michigan Department of natural Resources, Wildlife Division, Natural Heritage Program. Lansing, MI.

Holmgren, M., M. Scheffer, and M.A. Huston. 1997. The interplay of facilitation and competition in plant communities. Ecology 78:1966-1975.

Houseman, G.R., and R.C. Anderson. 2002. Effects of jack pine plantation management on barrens flora and potential Kirtland's warbler nest habitat. Restoration Ecology 10:27-36.

Howe, H.F. 1994. Managing species diversity in tallgrass prairie: assumptions and implications. Conservation Biology 8:691-704.

Howe, H.F. 1995. Success and fire season in experimental prairie plantings. Ecology 76: 1917-1925.

Howe, H.F., J.s. Brown, and B. Zorn-Arnold. 2002. A rodent plague on prairie diversity. Ecology Letters 5:30-36.

Ingle, D. 2009. Forest Service Centennial Focus. http://michiganforests.com/mfamag-summer05.htm. Accessed November 2011.

Ives, A.R., J.L. Klug, and K. Gross. 2000. Stability and species richness in complex communities. Ecology Letters 3:399-411.

Jordan, N.R., D.L. Larson, and S.C. Huerd. 2008. Soil modification by invasive plants: effects on native and invasive species of mixed-grass prairies. Biological Invasions 10:177-190.

Kennedy, T.A., S. Naeem, K.M. Howe, J.M. Knops, D. Tilman, and P. Reich. 2002. Biodiversity as a barrier to ecological invasion. Nature 417:636-638.

Kindscher, K., and L.L. Tieszen. 1998. Floristic and soil organic matter changes after five and thirty-five years of native tallgrass prairie restoration. Restoration Ecology 6: 181-196.

Kost, M.A. 2004. Natural community abstract for dry sand prairie. Michigan Natural Features Inventory, Lansing, MI. 9 pp.

Kost, M.A., D.A. Albert, J.G. Cohen, B.S. Slaughter, R.K. Schillo, C.R. Weber, and K.A. Chapman. 2007. Natural Communities of Michigan: Classification and Description. Michigan Natural Features Inventory, Report Number 2007-21, Lansing, MI. 314pp.

Lockwood, J.L. 1997. An alternative to succession: assembly rules offer guide to restoration efforts. Restoration and Management Notes 15:45-50.

Maestre, F.T., S. Bautista, and J. Cortina. 2001. Potential for using facilitation by grasses to establish shrubs on a semiarid degraded steppe. Ecological Applications 11:1641-1655.

Martin, L.m., K.A. Moloney, and B.J. Wilsey. 2005. An assessment of grassland restoration success using species diversity components. Journal of Applied Ecology 42:327-336.

McCann, M.t. 1991. Land, climate, and vegetation of Michigan. In *The Atlas of Breeding Birds of Michigan*, edited by R. Brewer, G.A. McPeek, and R.J. Adams Jr., 15-31, East Lansing: Michigan State University Press.

Michigan Wildlife Conservancy. 2011. Habitat Restoration. http://miwildlife.org/h-prairies.asp. Accessed November 2011.

Middleton, E.L., J.D. Bever, and P.A. Schultz. 2009. The effect of restoration methods on the quality of the restoration and resistance to invasion by exotics. 18:181-187.

Naeem, S. and J.P. Wright. 2003. Disentangling biodiversity effects on ecosystem functioning: deriving solutions to a seemingly insurmountable problem. Ecology Letters 6:567-579.

National Weather Service. 2011. http://www.wunderground.com. Accessed March 11, 2011.

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. Excerpt from: Methods of Soil Analysis, Part 3. Chemical Methods. p. 961-1009.

Nemec, K.T., C.R. Allen, C.J. Helzer, and D.A. Wedin. 2013. Influence of richness and seeding density on invasion resistance in experimental tallgrass prairie restorations. Ecological Restoration 31:168-185.

The Newaygo County Historical Archives. http://ncha.ncats.net. Accessed November 2009.

Noss, R.F., E.T. LaRoe III, and J.M. Scott. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. Biological Report 28. United States Department of Interior, National Biological Service, Washington, D.C.

Ojima, D.S., D.S. chimel, W.J. Parton, and C.E. Owensby. 1994. Long- and short-term effects of fire on nitrogen cycling in tallgrass prairie. Biogeochemistry 24: 67-84.

Peet, R.K. 1974. The measurement of species diversity. Annual Review of Ecology and Systematics 5:285-307.

Peltzer A., and M. Kochy. 2001. Effects of grasses and woody plants in mixed-grass prairie. Ecology 89:519-527.

Plumb-Mentjes, M.L., and G.E. Center. 1990. The dynamics of a sand prairie plant community. p. 123-127.

Pokorny, M.L., R.L. Sheley, C.A. Zabinsky, R.E. Engel, T.J. Svejcar, and J.J. Borkowski. 2005. Plant functional group diversity as a mechanism for invasion resistance. Restoration Ecology 13:448-459.

Polley, H.W., J.D. Derner, and B.J. Wilsey. 2005. Patterns of plant species diversity in remnant and restored tallgrass prairies. Restoration Ecology 13:480-487.

Raison, R.J. 1979. Modification of the soil environment by vegetation fire, with particular reference to nitrogen transformations: a review. Plant and Soil 51: 73-108.

Risser, P.G. 1988. Abiotic controls on primary productivity and nutrient cycles in North American grasslands. Ecological Studies: Analysis and Synthesis 67: 115-130.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. BioScience 4:418-421.

Schaetzl, R.J, and S. Anderson. 2005. Soils: Genesis and Geomorphology. Cambridge University Press.

Schramm, P. 1990. Prairie restoration: a twenty-five year perspective on establishment and management. Proceedings of the Twelfth North American Prairie Conference. Pages 169-178.

Seabloom, E.W., W.S. Harpole, O.J. Reichman, and D. Tilman. 2003. Invasion, competitive dominance, and resource use by exotic and native California grassland species. Proceedings of the National Academy of Science 100:13384-13389.

Seastedt, T.R. 1995. Soil systems and nutrient cycles of the North American prairie. Excerpt from: The Changing Prairie. Joern, A., and K.H. Keeler, eds. p. 157-174.

Seastedt, T.R. and A.K. Knapp. 1993. Consequences of nonequilibrium resource availability across multiple time scales: the transient maxima hypothesis. American Naturalist141: 621-633.

Shannon, C.E.1948. A mathematical theory of communication. Bell System Technical Journal 27:379-423.

Shea, K. and P. Chesson. 2002. Community ecology theory as a framework for biological invasions. Trends in Ecology and Evolution: 17: 170-176.

Sluis, W.J. 2002. Patterns of species richness and composition in re-created grassland. Restoration Ecology 10:677-684.

Smith, M.D., D.C. Hartnett, and G.W.T. Wilson. 1999. Interacting influence of mycorrhizal symbiosis and competition on plant diversity in tallgrass prairie. Oecologia 121: 574-582.

Smith, T. and M. Huston. 1990. A theory of spatial and temporal dynamics of plant communities. Vegetatio 83:49-69.

SPSS Inc. 2009. PASW Statistics 17.0. SPSS Inc., Chicago, IL.

Stohlgren, T.J. 2006. Measuring plant diversity: lessons from the field. Oxford University Press, USA.

Suding, K.N. 1999. Processes responsible for changes in plant species abundance following disturbance. Ph.D. Dissertation, University of Michigan, Ann Arbor, MI.

Swink, F., and G. Wilhelm. 1994. Plants of the Chicago region. Indiana Academy of Science.

Tabachnick, G.G., and L.S. Fidell. 2007. Experimental designs using ANOVA. Belmont, CA: Duxbury.

The Taxonomic Name Resolution Service. iPlant Collaborative. Version 3.2 accessed on 27 June 2014. Available at http://tnrs.iplantcollaborative.org.

Tilman, D. 1987. Secondary succession and the pattern of plant dominance along experimental nitrogen gradients. Ecological Monographs 57:189-214.

Tilman, D. 1988. Plant strategies and the dynamics and structure of plant communities. Princeton University Press, Princeton, NJ.

Tilman, D., and J.A. Downing. 1994. Biodiversity and stability in grasslands. Ecosystem Management: Selected Readings 367:363-365.

Tilman, D., D. Wedin, and J. Knops. 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. Nature 379: 718-720.

Tilman, D. 1997. Community invasibility, recruitment limitation, and grassland biodiversity. Ecology 78:81-92.

Tilman, D. 1999. The ecological consequences of changes in biodiversity: a search for general principles. Ecology 80:1455-1474.

Tilman, D. 2000. Causes, consequences and ethics of biodiversity. Nature 405:208-211.

Tramer, E.J. 1975. The regulation of plant species diversity on an early successional old-field. Ecology 56:905-914.

Transeau, E.N. 1935. The prairie peninsula. Ecology 16:423-437.

United States Department of Agriculture (USDA) Web Soil Survey, Natural Resources Conservation Survey. 2011. http://www.websoilsurvey.nrcs.usda.gov. Accessed March 11, 2011.

Wedin, D.A., and D. Tilman. 1990. Species effects on nitrogen cycling: a test with perennial grasses. Oecologia 84:433-441.

Woodward, A., K.J. Jenkins, and E.G. Schreiner. 1999. The role of ecological theory in long-term ecological monitoring: report on a workshop. Natural Areas Journal 19: 223-233.

Yachi, S., and M. Loreau. 1999. Biodiversity and ecosystem productivity in a fluctuating environment: the insurance hypothesis. Proceedings of the National Academy of Science 96:1463-1468.

Young, T.P., J.M. Chase, and R.T. Huddleston. 2001. Community assembly and succession: comparing, contrasting, and combining paradigms in the context of ecological restoration. Ecological Restoration 19:5-18.

Zimmerman, U.D., and C.L. Kucera. 1977. Effects of composition changes on productivity and biomass relationships in tallgrass prairie. American Midland Naturalist 97: 465-469.

APPENDICES

Appendix A – Tables

Table 1. Seeded Species and Associated Coefficient of Conservatism Values.

Sepcies	CC Value
Legumes	
Lupinus perennis L.	7
Desmodium canadense (L.) DC.	3
Lespedeza capitata Michx.	5
Early Season Forbs	
Penstemon hirsutus (L.) Willd.	5
Asclepias tuberosa L.	5
Anemone virginiana L.	3
Late Season Forbs	
Symphyotrichum leave (L.) Á. Löve & D. Löve	5
Solidago nemoralis Aiton	2
Solidago speciosa Nutt.	5
Grasses	
Andropogon gerardii Vitman	5
Schizachyrium scoparium (Michx.) Nash	5
Sorghastrum nutans (L.) Nash	6
Background Species	
Coreopsis lanceolata L.	8
Euphorbia corollata L.	4
Liatris aspera Michx.	4
Monarda fistulosa L.	2
Oenothera biennis L.	2
Rudbeckia hirta L.	1
Verbena stricta Vent.	4

Table 2. Experimental Design. Study compares high (↑) seeding densities (10,000 seeds/m^2), low (↓) seeding densities (1,000 seeds/m^2), and no (0) seeding of different plant functional groups with a grass group. (n) indicates number of replicates for each treatment. Each comparison also contains non-target background species unless specifically noted. Comparisons marked with an *, **, or *** refer to treatments that only differ between each other based on time of year that they were seeded. Total of 228 plots.

Comparison	n
Early Season Flowering Forbs	
↑ Forbs, ↓ Grasses	12
↓ Forbs, ↑ Grasses	12
↓ Forbs, ↓ Grasses	12
↓ Forbs, 0 Grasses	12
Late Season Flowering Forbs	
↑ Forbs, ↓ Grasses	12
↓ Forbs, ↑ Grasses	12
↓ Forbs, ↓ Grasses	12
↓ Forbs, 0 Grasses	12
Legumes	
↑ Forbs, ↓ Grasses	12
↓ Forbs, ↑ Grasses	12
↓ Forbs, ↓ Grasses	12
↓ Forbs, 0 Grasses	12
Grasses Only	
High Grass Only (No Early/Late)*	12
High Grass Only (No Legumes)*	12
Low Grass Only (No Early/Late)**	12
Low Grass Only (No Legumes)**	12
Background Species Only	
Background Species Only (No Early/Late)***	12
Background Species Only (No Legumes)***	12
Control Plots	12

Table 3. 2009 Study Site Pre-Restoration Baseline Data.

Variable	Value
Cover (%)	
Native	42.22
Non-Native	57.78
Resident	99.97
Planted	0.03
Grass	0.75
Forb	99.25
Species Richness	
Total	6.98
Native	2.08
Non-Native	4.90
Resident	6.92
Planted	0.06
Grass	0.37
Forb	6.61
Above-Ground Biomass (g)	
Total	11.58
Grass	0.04
Forb	11.54
Diversity	
Floristic Quality Index (FQI)	0.99
Shannon Diversity (H')	1.11
Soil Organic Matter (%)	
Organic Matter	2.82

Table 4. Initial Floristic Quality Assessment. Species listed with associated coefficient of conservatism (CC) values (ref Michigan database). Non-native species are indicated by an (*) and are not used in FQI calculations. Species indicated in **bold** are those resident that were identified within study plots prior to the start of the experiment.

	Species	CC Value
1.	***Acer rubrum* L.**	1
2.	*Ambrosia artemisiifolia* L.	0
3.	*Andropogon gerardii* Vitman	5
4.	***Asclepias syriaca* L.**	1
5.	***Bromus inermis** Leyss.**	-
6.	***Centaurea maculosa** Lam.**	-
7.	*Cichorium intybus** L.	-
8.	*Cirsium vulgare** (Savi) Ten.	-
9.	***Clinopodium vulgare* L.**	3
10.	*Comptonia peregrina* (L.) J.M. Coult.	6
11.	***Conyza canadensis* (L.) Cronquist**	0
12.	*Daucus carota** L.	-
13.	*Elaeagnus umbellata** Thunb.	-
14.	***Elytrigia repens* subsp. *repens****	-
15.	*Erigeron strigosus* Muhl. Ex Willd.	4
16.	***Fragaria virginiana* Mill.**	2
17.	*Holosteum umbellatum** L.	-
18.	***Hypericum perforatum** L.**	-
19.	*Juniperus virginiana* L.	3
20.	***Lepidium virginicum* L.**	0
21.	***Leucanthemum vulgare** Lam.**	-
22.	*Lupinus perennis* L.	7
23.	*Melilotus alba** (L.) Lam.	-
24.	*Melilotus officinalis** (L.) Lam.	-
25.	*Monarda fistulosa* L.	2
26.	*Monarda punctata* L.	4
27.	***Oenothera biennis* L.**	2
28.	***Panicum capillare* L.**	1
29.	*Pinus strobus* L.	3
30.	*Plantago rugelii* Decne.	0
31.	*Populus tremuloides* Michx.	1
32.	***Potentilla argentia* L.***	-
33.	***Potentilla recta** L.**	-
34.	***Pseudognaphalium obtusifolium* (L.) Hilliard & B.L. Burtt**	2
35.	*Pteridium aquilinum* (L.) Kuhn	0
36.	*Robinia viscosa** Vent.	-
37.	*Rudbeckia hirta* L.	1
38.	*Sassafras albidum* (Nutt.) Nees	5
39.	*Schizachyrium scoparium* (Michx.) Nash	5

40.	*Solidago canadensis* L.	1
41.	*Sorghastrum nutans* (L.) Nash	6
42.	*Symphyotrichum laeve* (L.) Á. Löve & D. Löve	5
43.	*Symphyotrichum ontarionis* (Wiegand) G.L. Nesom	6
44.	*Tragopogon pratensis** L.	-
45.	***Trifolium arvense** L.**	-
46.	*Triosteum perfoliatum* L.	5
47.	*Verbascum blattaria** L.	-
48.	***Verbascum thapsus** L.**	-
49.	*Verbena hastata* L.	4
50.	*Vitis aestivalis* Michx.	6

Table 5. Mean Bare-ground, Litter, Native, Non-Native, Resident, Planted, Grass, and Forb Cover (%) Values of All Treatment Groups in 2011. (↑) indicates a high seeding density (10,000 seeds/m^2) and (↓) indicates a low seeding density (1,000 seeds/m^2). No seeding of a group is indicated by a (0). Each subcategory of species richness variables was only tested against the treatments within its own subcategory. No similarities among any superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

Comparison	Bare-ground	Litter	Native	Non-Native	Resident	Planted	Grass	Forb
Early Season Flowering Forbs								
↑ Forbs, ↓ Grasses	36.80^{abe}(±1.61)	14.70^{a}(±1.18)	37.81^{bde}(±8.31)	62.19^{bef}(±8.31)	67.51^{bdi}(±8.25)	32.49^{ci}(±8.25)	18.10^{acehln}(±5.84)	81.90^{acdg}(±5.84)
↓ Forbs, ↑ Grasses	27.41^{bc}(±1.99)	18.18^{a}(±0.93)	46.60^{b}(±8.51)	53.40^{bd}(±8.51)	55.29^{df}(±8.31)	44.71^{c}(±8.31)	35.75^{bfh}(±7.98)	64.25^{beg}(±7.98)
↓ Forbs, ↓ Grasses	33.09^{abe}(±2.28)	18.98^{a}(±1.56)	25.84^{ab}(±4.73)	74.16^{abcd}(±4.73)	77.61^{bdh}(±4.39)	22.39^{bcgh}(±4.39)	12.28^{achg}(±3.81)	87.72^{acfg}(±3.81)
↓ Forbs, 0 Grasses	38.68^{ad}(±2.66)	19.12^{a}(±1.44)	26.15^{ab}(±7.45)	73.85^{abcdf}(±7.45)	84.23^{bhj}(±5.25)	15.77^{bghijk}(±5.25)	3.80^{giln}(±2.49)	96.20^{af}(±2.49)
Late Season Flowering Forbs								
↑ Forbs, ↓ Grasses	32.36^{abe}(±1.39)	19.52^{a}(±1.04)	22.85^{ab}(±5.55)	77.14^{abcd}(±5.55)	80.73^{bdgj}(±4.54)	19.26^{bcghij}(±4.54)	10.95^{achg}(±3.92)	89.05^{acf}(±3.92)
↓ Forbs, ↑ Grasses	27.61^{ce}(±2.61)	20.98^{a}(±1.05)	44.84^{b}(±7.92)	55.16^{bd}(±7.92)	58.24^{d}(±7.94)	41.76^{c}(±7.,94)	36.97^{be}(±8.27)	63.03^{bd}(±8.27)
↓ Forbs, ↓ Grasses	35.61^{abe}(±2.30)	15.48^{a}(±1.92)	28.40^{ab}(±6.01)	71.60^{abcd}(±6.01)	76.07^{bd}(±5.39)	23.93^{bcf}(±5.39)	10.32^{achij}(±2.59)	89.68^{acfg}(±2.59)
↓ Forbs, 0 Grasses	37.98^{ad}(±1.56)	17.36^{a}(±1.47)	12.66^{ace}(±2.82)	87.34^{acf}(±2.82)	90.79^{aceghi}(±1.88)	9.21^{bghijk}(±1.88)	6.50^{ajmn}(±5.10)	93.50^{af}(±5.10)
Legumes								
↑ Forbs, ↓ Grasses	37.20^{ae}(±1.42)	18.44^{a}(±1.46)	17.81^{acd}(±5.11)	82.19^{ace}(±5.11)	94.92^{aegh}(±1.34)	5.08^{adeg}(±1.34)	6.17^{agk}(±1.39)	93.83^{af}(±1.39)
↓ Forbs, ↑ Grasses	39.36^{a}(±3.26)	16.82^{a}(±1.11)	22.34^{ab}(±5.63)	77.66^{abcd}(±5.63)	79.73^{bde}(±4.71)	20.27^{bcd}(±4.71)	17.76^{acefk}(±4.11)	82.24^{def}(±4.11)
↓ Forbs, ↓ Grasses	36.82^{abe}(±1.68)	17.48^{a}(±1.49)	8.70^{a}(±1.30)	91.30^{a}(±1.30)	93.81^{aegh}(±1.03)	6.19^{adefh}(±1.03)	4.79^{ag}(±1.60)	95.21^{af}(±1.60)
↓ Forbs, 0 Grasses	38.46^{ad}(±1.31)	18.03^{a}(±2.27)	12.00^{a}(±5.31)	88.00^{a}(±5.31)	96.67^{aej}(±1.05)	3.33^{adek}(±1.05)	4.50^{gim}(±3.87)	95.50^{af}(±3.87)
Grasses Only								
High Grass Only	32.44^{ace}(±1.45)	18.63^{a}(±0.83)	31.73^{bc}(±4.48)	68.27^{bc}(±4.48)	74.01^{bcd}(±4.18)	25.99^{bc}(±4.18)	25.94^{bc}(±4.14)	74.06^{bce}(±4.14)
Low Grass Only	36.74^{ad}(±1.22)	18.34^{a}(±0.78)	21.25^{ab}(±3.88)	78.75^{acdf}(±3.88)	85.51^{bgj}(±3.78)	14.49^{behik}(±3.78)	13.27^{achmn}(±3.10)	86.73^{acf}(±3.10)
Background Species Only	37.04^{a}(±1.15)	16.93^{a}(±0.96)	13.73^{a}(±3.25)	86.27^{a}(±3.25)	91.12^{aegh}(±3.25)	8.88^{adejk}(±3.25)	3.88^{gj}(±1.67)	96.12^{a}(±1.67)
Control Plots	37.20^{ae}(±1.56)	18.45^{a}(±1.66)	8.01^{a}(±1.93)	91.99^{a}(±1.93)	99.83^{a}(±1.93)	0.17^{a}(±1.93)	3.32^{agm}(±1.22)	96.68^{af}(±1.22)

Table 6. Mean Total, Native, Non-Native, Resident, Planted, Grass, and Forb Species Richness Values of All Treatment Groups in 2011. (↑) indicates a high seeding density (10,000 seeds/m^2) and (↓) indicates a low seeding density (1,000 seeds/m^2). No seeding of a group is indicated by a (0). Each subcategory of species richness variables was only tested against the treatments within its own subcategory. No similarities among any superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

Comparison	Total	Native	Non-Native	Resident	Planted	Grass	Forb
Early Season Flowering Forbs							
↑ Forbs, ↓ Grasses	12.00^{bde}(±0.67)	4.75^{a}(±0.66)	6.75^{a}(±0.23)	5.25^{hjl}(±0.36)	12.00^{bde}(±0.53)	2.50^{bg}(±0.35)	9.50^{bceh}(±0.56)
↓ Forbs, ↑ Grasses	13.00^{bd}(±0.64)	4.75^{a}(±0.51)	6.75^{a}(±0.44)	6.25^{efkl}(±0.48)	13.00^{bd}(±0.31)	3.50^{bf}(±0.19)	9.50^{bcde}(±0.60)
↓ Forbs, ↓ Grasses	13.50^{d}(±1.02)	5.25^{a}(±0.81)	7.00^{a}(±0.49)	6.50^{fhj}(±0.72)	13.50^{d}(±0.60)	3.25^{bg}(±0.47)	10.25^{bg}(±0.78)
↓ Forbs, 0 Grasses	12.75^{abcde}(±0.85)	5.25^{a}(±0.71)	7.75^{a}(±0.29)	5.00^{bdi}(±0.51)	12.75^{abcde}(±0.45)	1.50^{acd}(±0.36)	11.25^{bceh}(±0.64)
Late Season Flowering Forbs							
↑ Forbs, ↓ Grasses	12.75^{bcd}(±0.80)	5.75^{a}(±0.70)	8.00^{a}(±0.52)	4.75^{bdejkm}(±0.67)	12.75^{bcd}(±0.37)	3.00^{bcg}(±0.29)	9.75^{aefg}(±0.61)
↓ Forbs, ↑ Grasses	12.00^{bcd}(±0.41)	4.00^{a}(±0.45)	6.50^{a}(±0.43)	5.50^{bdefkl}(±0.31)	12.00^{bcd}(±0.19)	3.50^{be}(±0.19)	8.50^{acd}(±0.41)
↓ Forbs, ↓ Grasses	12.00^{bcd}(±0.71)	6.25^{a}(±0.52)	7.50^{a}(±0.39)	4.50^{bdehm}(±0.57)	12.00^{bcd}(±0.33)	2.25^{be}(±0.30)	9.75^{bceh}(±0.45)
↓ Forbs, 0 Grasses	9.50^{ace}(±0.66)	5.00^{a}(±0.45)	6.75^{a}(±0.45)	2.75^{cgim}(±0.50)	9.50^{ace}(±0.29)	1.50^{ad}(±0.31)	8.00^{adeg}(±0.50)
Legumes							
↑ Forbs, ↓ Grasses	11.25^{abcde}(±1.16)	5.50^{a}(±0.97)	7.25^{a}(±0.47)	4.00^{bdi}(±0.79)	11.25^{abcde}(±0.58)	2.00^{adeg}(±0.48)	9.25^{adeg}(±0.78)
↓ Forbs, ↑ Grasses	15.00^{bde}(±0.81)	6.20^{a}(±0.75)	7.80^{a}(±0.54)	7.20^{befkl}(±0.43)	15.00^{bde}(±0.61)	3.20^{be}(±0.18)	11.80^{bcdf}(±0.75)
↓ Forbs, ↓ Grasses	12.50^{bcd}(±0.80)	4.75^{a}(±0.66)	6.75^{a}(±0.36)	5.75^{bej}(±0.50)	12.50^{bcd}(±0.43)	2.50^{bde}(±0.37)	10.00^{adeg}(±0.74)
↓ Forbs, 0 Grasses	11.33^{abc}(±1.03)	5.67^{a}(±0.92)	8.00^{a}(±0.45)	3.33^{di}(±0.54)	11.33^{abc}(±0.70)	0.33^{ad}(±0.35)	11.00^{adeg}(±0.82)
Grasses Only							
High Grass Only	13.00^{bde}(±0.47)	6.25^{a}(±0.35)	7.25^{a}(±0.31)	5.75^{bdefkl}(±0.37)	13.00^{bde}(±0.21)	3.50^{b}(±0.17)	9.50^{ac}(±0.43)
Low Grass Only	13.75^{bcd}(±0.42)	6.50^{a}(±0.36)	8.75^{a}(±0.27)	5.00^{bdi}(±0.30)	13.75^{bcd}(±0.28)	3.50^{be}(±0.21)	10.25^{ade}(±0.31)
Background Species Only	9.75^{ac}(±0.43)	5.25^{a}(±0.43)	7.00^{a}(±0.29)	2.75^{cgi}(±0.42)	9.75^{ac}(±0.31)	0.75^{a}(±0.23)	9.00^{adh}(±0.35)
Control Plots	8.50^{a}(±0.54)	6.25^{a}(±0.28)	8.00^{a}(±0.49)	0.50^{a}(±0.47)	8.50^{a}(±0.13)	1.00^{ad}(±0.24)	7.50^{a}(±0.36)

Table 7. Mean Total, Litter, Native, Non-Native, Resident, Planted, Grass, and Forb Above-ground Biomass (g) Values of All Treatment Groups in 2011. (↑) indicates a high seeding density (10,000 seeds/m^2) and (↓) indicates a low seeding density (1,000 seeds/m^2). No seeding of a group is indicated by a (0). Each different measure was tested independently. No similarities among any superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by the Mann-Whitney U Test.

Comparison	Total	Litter	Native	Non-Native	Resident	Planted	Grass	Forb
Early Season Flowering Forbs								
↑ Forbs, ↓ Grasses	13.73(±2.92)		5.39(±3.48)	8.33(±2.45)	9.10(±2.00)	4.63(±3.41)	2.19(±1.84)	11.53(±1.45)
↓ Forbs, ↑ Grasses	17.69(±2.10)		7.22(±3.52)	10.47(±2.83)	10.65(±2.89)	7.04(±3.56)	5.78(±3.10)	11.92(±2.68)
↓ Forbs, ↓ Grasses	14.17(±2.41)		4.55(±2.04)	9.61(±3.29)	9.76(±3.22)	4.41(±2.03)	4.06(±3.23)	10.10(±3.34)
↓ Forbs, 0 Grasses	12.49(±2.27)		1.30(±0.70)	11.20(±2.21)	11.63(±1.92)	0.86(±0.72)	1.99(±0.08)	12.41(±2.22)
Late Season Flowering Forbs								
↑ Forbs, ↓ Grasses	19.37(±3.10)		3.33(±2.65)	16.05(±4.75)	16.09(±4.72)	3.28(±2.61)	1.88(±1.88)	17.50(±3.95)
↓ Forbs, ↑ Grasses	21.75(±4.42)		14.28(±7.87)	7.47(±3.94)	7.49(±3.93)	14.26(±7.87)	13.06[a](±7.14)	8.69(±3.26)
↓ Forbs, ↓ Grasses	13.33(±1.94)		5.34(±3.18)	7.96(±2.25)	8.25(±2.27)	5.08(±3.22)	1.50(±0.91)	11.83(±1.32)
↓ Forbs, 0 Grasses	14.23(±4.97)		0.93(±0.37)	13.29(±5.01)	13.50(±5.00)	0.73(±0.39)	4.44(±4.20)	9.78(±1.59)
Legumes								
↑ Forbs, ↓ Grasses	13.19(±2.63)		1.72(±1.25)	11.47(±2.00)	12.95(±2.65)	0.24(±0.06)	3.12(±2.97)	10.07(±2.40)
↓ Forbs, ↑ Grasses	13.90(±2.86)		1.19(±0.35)	12.72(±3.14)	12.73(±3.14)	1.18(±0.35)	1.22(±0.48)	12.69(±3.21)
↓ Forbs, ↓ Grasses	9.85(±2.05)		0.16(±0.14)	9.69(±1.92)	9.72(±1.95)	0.13(±0.11)	0.01(±0.01)	9.84(±2.05)
↓ Forbs, 0 Grasses	11.66(±4.75)		0.69(±0.63)	10.97(±5.34)	11.43(±4.91)	0.24(±0.18)	0.00(±0.00)	11.66(±4.75)
Grasses Only								
High Grass Only	14.51(±1.65)		4.46(±3.50)	10.05(±3.11)	10.07(±3.12)	4.44(±3.50)	3.94(±3.22)	10.56(±2.80)
Low Grass Only	12.58(±1.57)		2.60(±1.38)	9.98(±2.66)	10.00(±2.65)	2.58(±1.37)	1.18(±0.45)	11.40(±1.98)
Background Species Only	9.37(±2.13)		0.40(±0.08)	8.97(±2.06)	9.10(±2.01)	0.27(±0.14)	0.06(±0.06)	9.31(±2.12)
Control Plots	15.67(±2.10)		0.65(±0.41)	15.02(±2.06)	15.67(±2.10)	0.00(±0.00)	0.61(±0.32)	15.07(±2.33)

Table 8. Mean Floristic Quality Index (FQI) and Shannon Diversity (H') Values of All Treatment Groups in 2011. (↑) indicates a high seeding density (10,000 seeds/m^2) and (↓) indicates a low seeding density (1,000 seeds/m^2). No seeding of a group is indicated by a (0). Each different measure was tested independently. No similarities among any superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

Comparison	FQI	H'
Early Season Flowering Forbs		
↑ Forbs, ↓ Grasses	10.15^{fi}(±0.50)	1.71^{ab}(±0.12)
↓ Forbs, ↑ Grasses	11.24^{ef}(±0.20)	1.73^{ab}(±0.08)
↓ Forbs, ↓ Grasses	10.59^{bdef}(±0.46)	1.61^{ac}(±0.13)
↓ Forbs, 0 Grasses	8.53^{cgh}(±0.52)	1.41^{ac}(±0.08)
Late Season Flowering Forbs		
↑ Forbs, ↓ Grasses	9.30^{bdgi}(±0.41)	1.53^{ac}(±0.10)
↓ Forbs, ↑ Grasses	9.57^{bdef}(±0.17)	1.60^{ac}(±0.08)
↓ Forbs, ↓ Grasses	9.12^{bdefh}(±0.21)	1.60^{ac}(±0.10)
↓ Forbs, 0 Grasses	5.78^{c}(±0.40)	1.30^{ac}(±0.09)
Legumes		
↑ Forbs, ↓ Grasses	8.04^{bc}(±0.73)	1.35^{ac}(±0.10)
↓ Forbs, ↑ Grasses	11.39^{def}(±0.58)	1.49^{ac}(±0.12)
↓ Forbs, ↓ Grasses	9.89^{bdef}(±0.38)	1.16^{c}(±0.12)
↓ Forbs, 0 Grasses	5.78^{cg}(±0.96)	1.32^{ac}(±0.12)
Grasses Only		
High Grass Only	10.77^{bdef}(±0.21)	1.61^{ab}(±0.08)
Low Grass Only	9.67^{bdg}(±0.31)	1.49^{ac}(±0.08)
Background Species Only	6.61^{c}(±0.32)	1.40^{ac}(±0.06)
Control Plots	1.56^{a}(±0.56)	1.26^{ac}(±0.09)

Table 9. Mean Bare-ground, Litter, Native, Non-Native, Resident, Planted, Grass, and Forb Cover (%) Values of Grass Treatment Groups in 2011. Each subcategory of species richness variables was only tested against the treatments within its own subcategory. No similarities between any superscript letters indicate significant ($p \leq 0.05$) differences between the groups as determined by Tukey post-hoc analysis.

Comparison	Bare-ground	Litter	Native	Non-Native	Resident	Planted	Grass	Forb
Control Plots	37.20^{ab}(±1.56)	18.45(±1.66)	8.01^{a}(±1.93)	91.99^{a}(±1.93)	99.83(±0.17)	0.17(±0.17)	3.32(±1.22)	96.68(±1.22)
Background Only, No Grass	37.04^{b}(±1.62)	16.93(±1.35)	13.73^{ab}(±4.59)	86.27^{ab}(±4.59)	91.12^{b}(±4.25)	8.88^{b}(±4.25)	3.88(±2.35)	96.12(±2.35)
Forb Treatment, No Grass	38.38^{b}(±1.09)	18.17(±1.00)	16.94^{ab}(±3.29)	83.06^{ab}(±3.29)	90.57^{ab}(±2.03)	9.43^{ab}(±2.03)	4.93(±2.23)	95.07(±2.23)
High Grass	31.85^{a}(±1.20)	18.65(±0.51)	35.02(±3.28)	64.38(±3.28)	68.00^{c}(±3.17)	31.40^{c}(±3.17)	28.47^{b}(±3.01)	71.53^{a}(±3.01)
Low Grass	35.67^{b}(±0.64)	17.66(±0.50)	22.99^{b}(±2.06)	77.01^{b}(±2.06)	82.71^{a}(±1.92)	17.29^{a}(±1.92)	11.14^{a}(±1.40)	88.86^{b}(±1.40)

Table 10. Mean Total, Native, Non-Native, Resident, Planted, Grass, and Forb Species Richness Values of Grass Treatment Groups in 2011. Each subcategory of species richness variables was only tested against the treatments within its own subcategory. No similarities between any superscript letters indicate significant ($p \leq 0.05$) differences between the groups as determined by Tukey post-hoc analysis.

Comparison	Total	Native	Non-Native	Resident	Planted	Grass	Forb
Control Plots	7.75^{b}(±0.54)	2.33(±0.28)	5.25(±0.49)	7.33(±0.47)	0.25(±0.13)	0.83(±0.24)	6.92(±0.36)
Background Only, No Grass	9.92^{bc}(±0.60)	4.63^{b}(±0.61)	5.25(±0.41)	7.08(±0.60)	2.79^{b}(±0.44)	0.75(±0.32)	9.17^{a}(±0.50)
Forb Treatment, No Grass	10.61^{c}(±0.49)	5.33^{b}(±0.42)	5.28(±0.23)	7.25(±0.29)	3.36^{b}(±0.29)	0.94(±0.19)	9.69^{a}(±0.38)
High Grass	12.88^{a}(±0.31)	7.48^{a}(±0.26)	5.37(±0.21)	7.25(±0.21)	5.60^{a}(±0.19)	3.50^{b}(±0.09)	9.40^{a}(±0.28)
Low Grass	12.49^{a}(±0.29)	6.96^{a}(±0.25)	5.50(±0.15)	7.43(±0.20)	5.03^{a}(±0.19)	2.63^{a}(±0.13)	9.86^{a}(±0.23)

Table 11. Mean Total, Litter, Native, Non-Native, Resident, Planted, Grass, and Forb Biomass (g) Values of Grass Treatment Groups in 2011. Each subcategory of species richness variables was only tested against the treatments within its own subcategory. No similarities between any superscript letters indicate significant ($p \leq 0.05$) differences between the groups as determined by Tukey post-hoc analysis.

Comparison	Total	Litter	Native	Non-Native	Resident	Planted	Grass	Forb
Control Plots	15.67(±2.10)	6.82(±1.59)	0.57(±0.41)	13.02(±2.05)	13.60(±2.10)	0.00(±0.00)	0.81(±0.32)	12.79(±2.33)
Background Only, No Grass	9.37(±2.13)	2.21(±0.96)	0.40(±0.08)	8.97(±2.06)	9.10(±2.01)	0.27(±0.14)	0.06(±0.06)	9.31(±2.12)
Forb Treatment, No Grass	12.90(±2.14)	6.15(±1.03)	1.00(±0.31)	11.90(±2.22)	12.25(±2.13)	0.64(±0.29)	1.64(±1.54)	11.25(±1.48)
High Grass	16.78(±1.54)	7.69(±1.09)	6.46(±2.30)	10.33(±1.55)	10.38(±1.56)	6.40[a](±2.30)	5.72[a](±2.09)	11.06(±1.43)
Low Grass	13.75(±0.96)	7.01(±0.63)	3.30(±0.84)	10.44(±1.08)	10.84(±1.09)	2.91(±0.83)	1.99(±0.70)	11.75(±0.96)

Table 12. Mean Floristic Quality Index (FQI) and Shannon Diversity (H') Values of Grass Treatment Groups in 2011. Each different measure was tested independently. No similarities between any superscript letters indicate significant ($p \leq 0.05$) differences between the groups as determined by Tukey post-hoc analysis.

Comparison	FQI	H'
Control Plots	1.37(±0.56)	1.26^{b}(±0.09)
Background Only, No Grass	6.56^{a}(±0.45)	1.40^{ab}(±0.06)
Forb Treatment, No Grass	6.71^{a}(±0.39)	1.34^{b}(±0.06)
High Grass	10.37^{c}(±0.17)	1.61^{a}(±0.04)
Low Grass	9.35^{b}(±0.18)	1.49^{ab}(±0.04)

Table 13. Mean Bare-ground, Litter, Native, Non-Native, Resident, Planted, Grass, and Forb Cover (%) Values of Forb Treatment Groups in 2011. Each subcategory of species richness variables was only tested against the treatments within its own subcategory. No similarities between any superscript letters indicate significant ($p \leq 0.05$) differences between the groups as determined by Tukey post-hoc analysis.

Comparison	Bare-ground	Litter	Native	Non-Native	Resident	Planted	Grass	Forb
Control Plots	37.20^{ab}(±1.56)	18.45(±1.66)	8.01^{a}(±1.93)	91.99^{a}(±1.93)	99.83(±0.17)	0.17(±0.17)	3.32(±1.22)	96.68(±1.22)
Background Only	35.41^{ab}(±0.77)	17.97(±0.50)	22.24^{ab}(±2.39)	77.76^{ab}(±2.39)	83.55^{a}(±2.26)	16.45^{a}(±2.26)	14.36^{ab}(±2.08)	85.64^{ab}(±2.08)
Legumes	37.96^{a}(±1.01)	17.69(±0.80)	14.68^{a}(±2.39)	84.57^{a}(±2.39)	90.96^{a}(±1.58)	8.29^{a}(±1.58)	8.30^{a}(±1.80)	91.70^{a}(±1.80)
Early Season	33.99^{ab}(±1.22)	17.74(±0.68)	34.10^{c}(±3.80)	65.90^{c}(±3.80)	71.16^{b}(±3.65)	28.84^{b}(±3.65)	17.48^{bc}(±3.14)	82.52^{bc}(±3.14)
Late Season	33.40^{b}(±1.13)	18.33(±0.75)	27.19^{bc}(±3.31)	72.81^{bc}(±3.31)	76.46^{b}(±3.12)	23.54^{b}(±3.12)	16.18^{bc}(±3.15)	83.82^{bc}(±3.15)

Table 14. Mean Total, Native, Non-Native, Resident, Planted, Grass, and Forb Species Richness Values of Forb Treatment Groups in 2011. Each subcategory of species richness variables was only tested against the treatments within its own subcategory. No similarities between any superscript letters indicate significant ($p \leq 0.05$) differences between the groups as determined by Tukey post-hoc analysis.

Comparison	Total	Native	Non-Native	Resident	Planted	Grass	Forb
Control Plots	7.75(±0.54)	2.33(±0.28)	5.25(±0.49)	7.33(±0.47)	0.25(±0.13)	0.83^{a}(±0.24)	6.92(±0.36)
Background Only	11.53^{a}(±0.29)	5.93^{a}(±0.25)	5.58(±0.17)	7.51(±0.21)	4.00^{a}(±0.19)	2.46^{b}(±0.19)	9.08^{b}(±0.21)
Legumes	11.83^{ab}(±0.49)	6.46^{a}(±0.43)	5.35(±0.23)	7.21(±0.29)	4.60^{a}(±0.32)	2.06^{ab}(±0.22)	9.77^{ab}(±0.38)
Early Season	13.25^{b}(±0.44)	8.06^{b}(±0.37)	5.15(±0.19)	7.29(±0.27)	5.92^{b}(±0.29)	2.56^{b}(±0.22)	10.71^{a}(±0.33)
Late Season	11.63^{a}(±0.35)	6.17^{a}(±0.30)	5.42(±0.23)	7.13(±0.26)	4.46^{a}(±0.20)	2.40^{b}(±0.19)	9.23^{b}(±0.26)

Table 15. Mean Total, Litter, Native, Non-Native, Resident, Planted, Grass, and Forb Biomass (g) Values of Forb Treatment Groups in 2011. Each subcategory of species richness variables was only tested against the treatments within its own subcategory. No similarities between any superscript letters indicate significant ($p \leq 0.05$) differences between the groups as determined by a Mann-Whitney U test.

Comparison	Total	Litter	Native	Non-Native	Resident	Planted	Grass	Forb
Control Plots	15.67(±2.10)	6.82(±1.59)	0.57(±0.41)	13.02(±2.05)	13.60(±2.10)	0.00[a](±0.00)	0.81(±0.32)	12.79(±2.33)
Background Only	12.15(±1.14)	6.55(±1.21)	2.49(±1.24)	9.67(±1.39)	9.72(±1.38)	2.43(±1.25)	1.73(±1.10)	10.43(±1.24)
Legumes	12.29(±1.40)	5.57(±0.69)	0.97(±0.35)	11.32(±1.42)	11.79(±1.44)	0.51[a](±0.16)	1.17(±0.75)	11.13(±1.42)
Early Season	14.52(±1.20)	7.58(±0.86)	4.62(±1.33)	9.90(±1.25)	10.28(±1.17)	4.23(±1.33)	3.03(±1.21)	11.49(±1.15)
Late Season	17.17(±1.92)	7.16(±1.17)	5.97(±2.38)	11.20(±2.07)	11.33(±2.06)	5.84(±2.39)	5.22(±2.26)	11.95(±1.51)

Table 16. Mean Floristic Quality Index (FQI) and Shannon Diversity (H') Values of Forb Treatment Groups in 2011. Each different measure was tested independently. No similarities between any superscript letters indicate significant ($p \leq 0.05$) differences between the groups as determined by Tukey post-hoc analysis.

Comparison	FQI	H'
Control Plots	1.37(±0.56)	1.26^{a}(±0.09)
Background Only	8.39^{b}(±0.23)	1.50^{ab}(±0.04)
Legumes	8.89^{ab}(±0.40)	1.33^{a}(±0.06)
Early Season	9.99^{a}(±0.31)	1.62^{b}(±0.05)
Late Season	8.51^{b}(±0.27)	1.50^{ab}(±0.05)

Appendix B – Figures

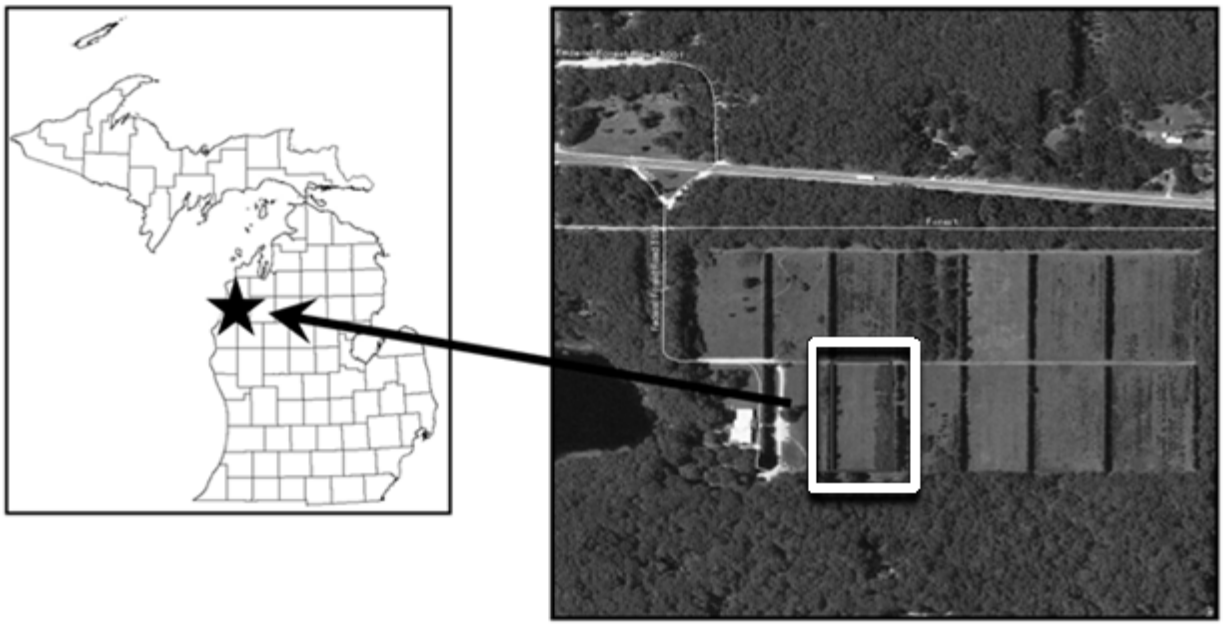

Figure 1. Chittenden Nursery, Manistee County, Michigan. Location of approximately 1.35 hectare project site is outlined.

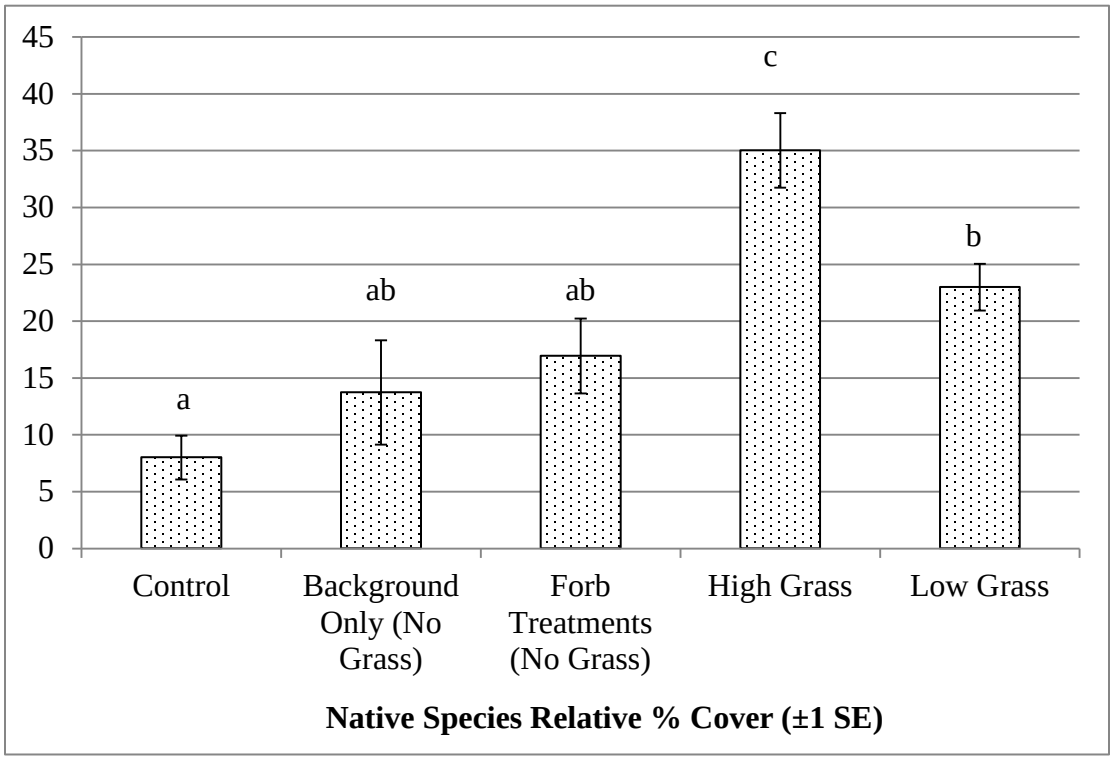

Figure 2. Grass Treatment mean Native Species Relative Cover (%) in 2011. High = 10,000 seeds/m^2 and Low = 1,000 seeds/m^2. No similarities among superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

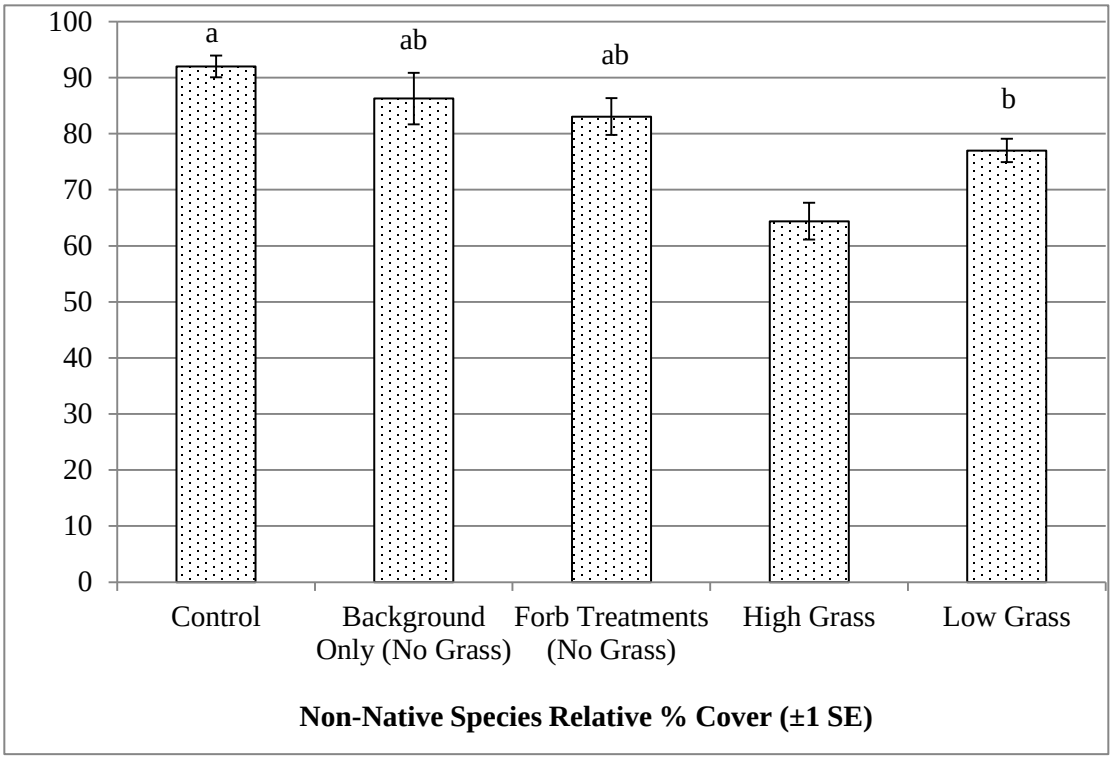

Figure 3. Grass Treatment mean Non-Native Species Relative Cover (%) in 2011. High = 10,000 seeds/m^2 and Low = 1,000 seeds/m^2. No similarities among superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

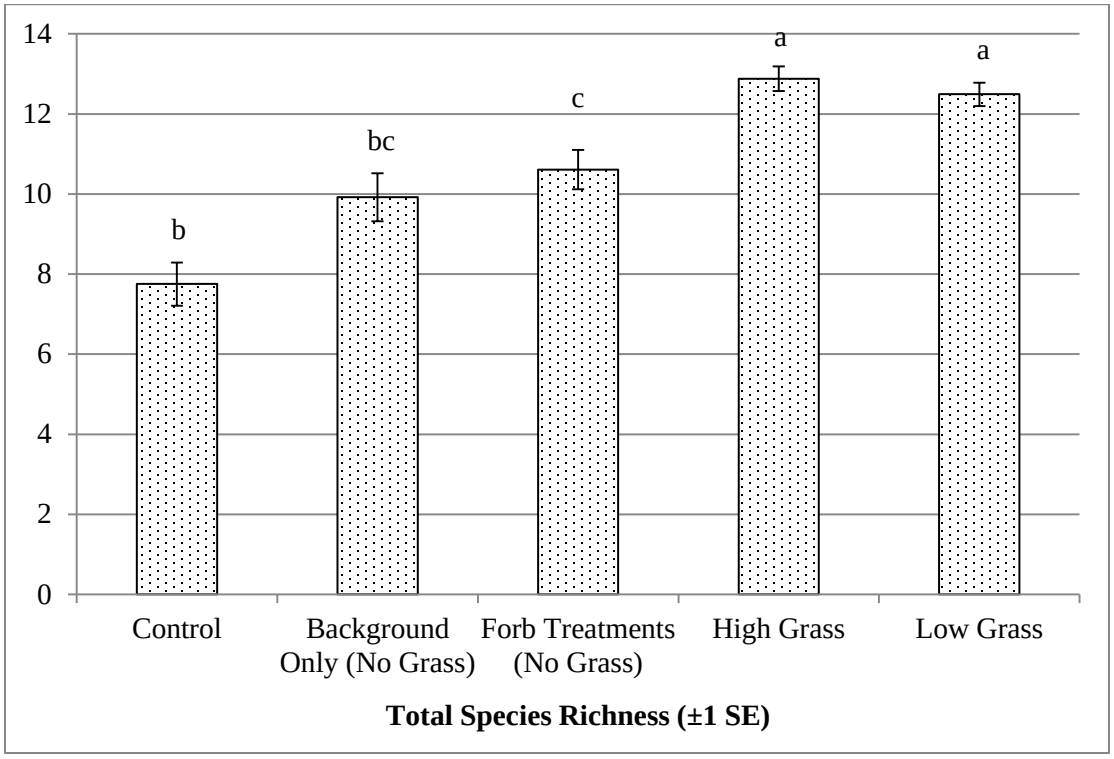

Figure 4. Grass Treatment mean Total Species Richness in 2011. High = 10,000 seeds/m^2 and Low = 1,000 seeds/m^2. No similarities among superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

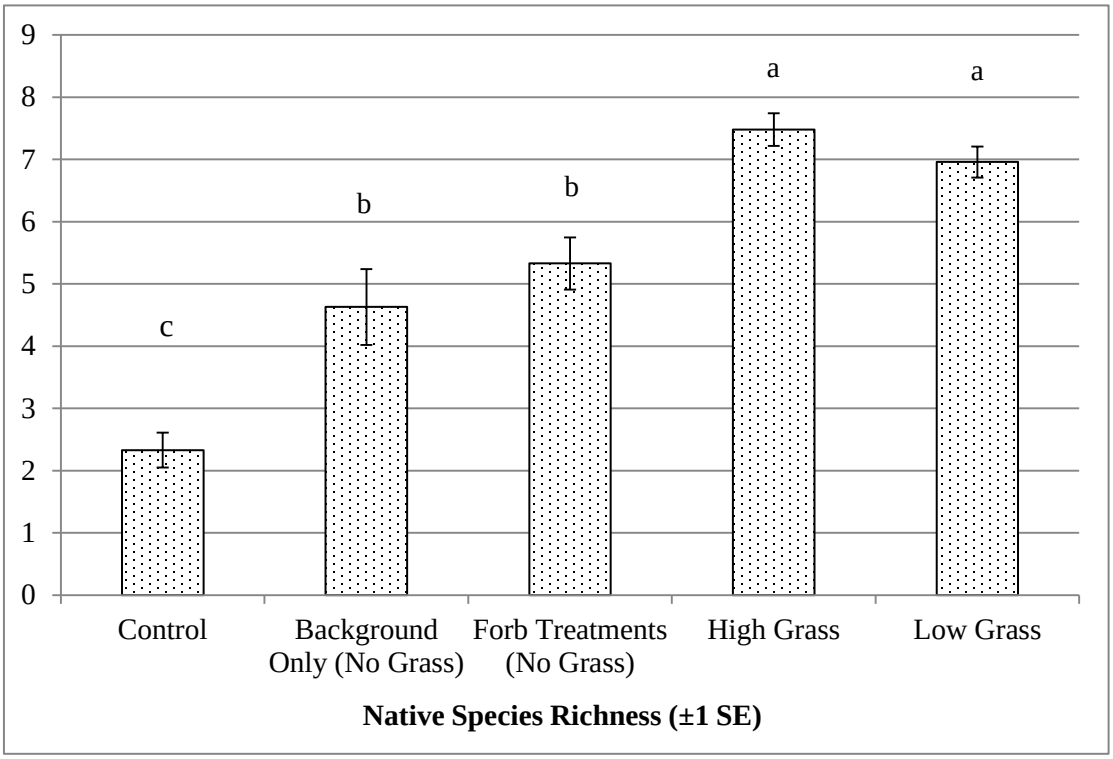

Figure 5. Grass Treatment mean Native Species Richness in 2011. High = 10,000 seeds/m^2 and Low = 1,000 seeds/m^2. No similarities among superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

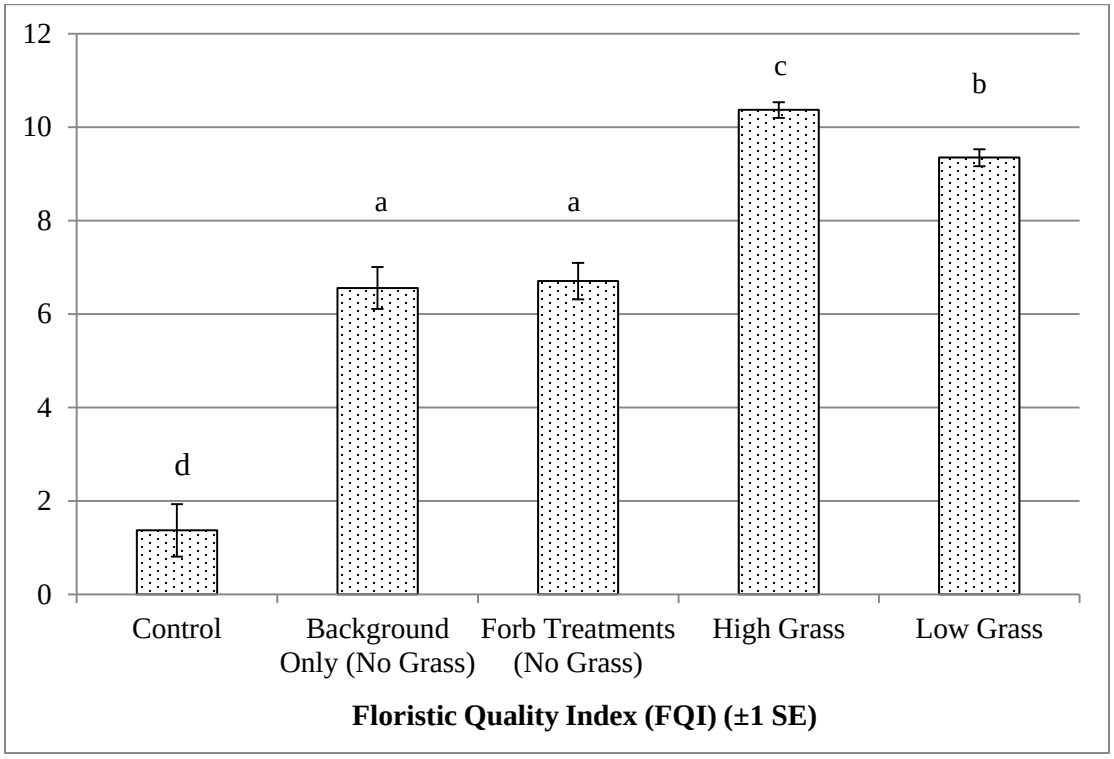

Figure 6. Grass Treatment mean FQI in 2011. High = 10,000 seeds/m^2 and Low = 1,000 seeds/m^2. No similarities among superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

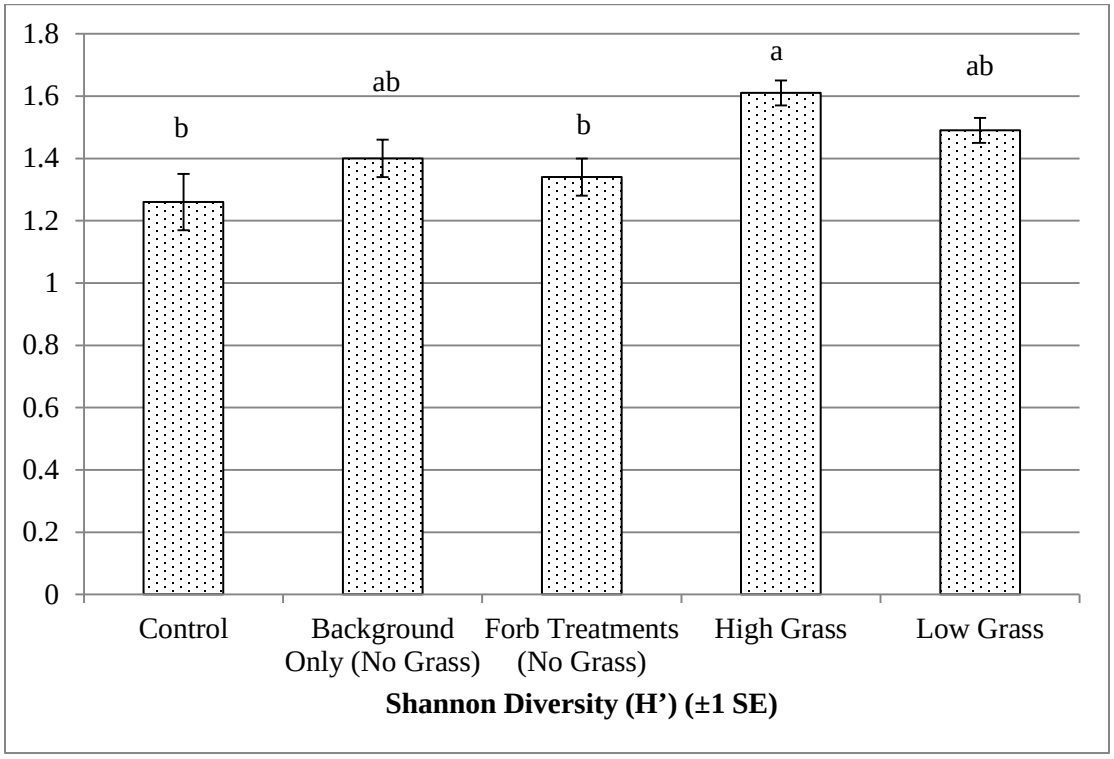

Figure 7. Grass Treatment mean H' in 2011. High = 10,000 seeds/m^2 and Low = 1,000 seeds/m^2. No similarities among superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

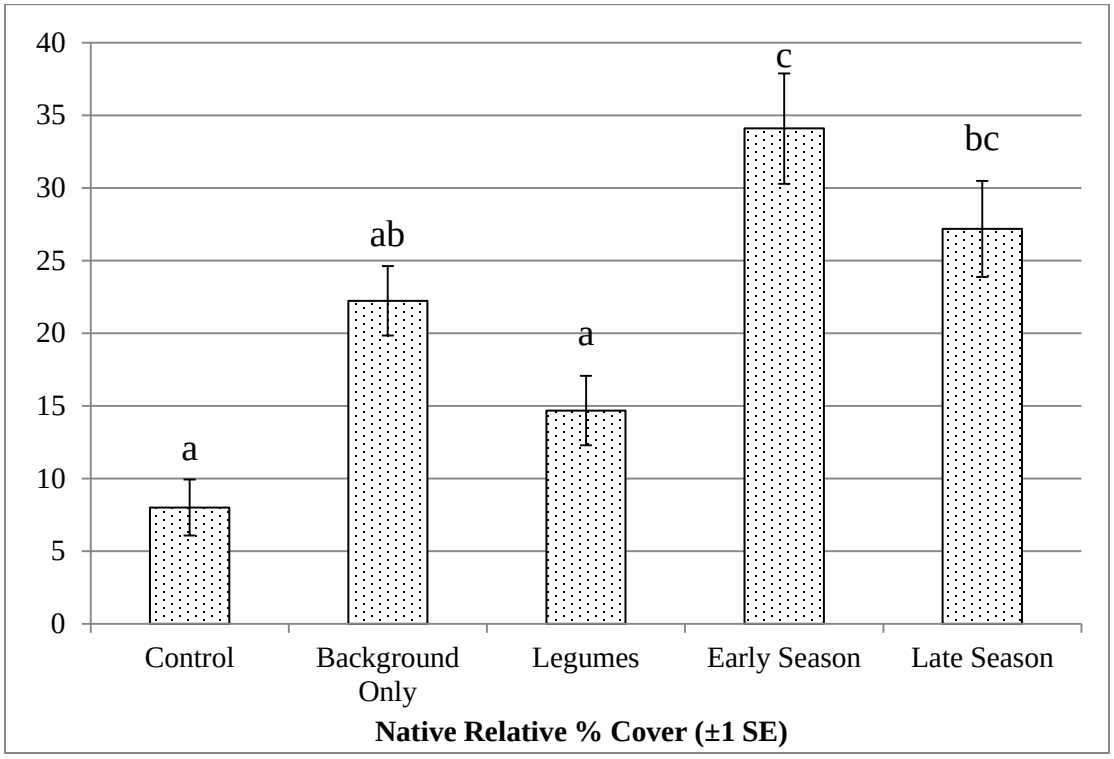

Figure 8. Forb Treatment mean Native Relative Cover (%) in 2011. No similarities among superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

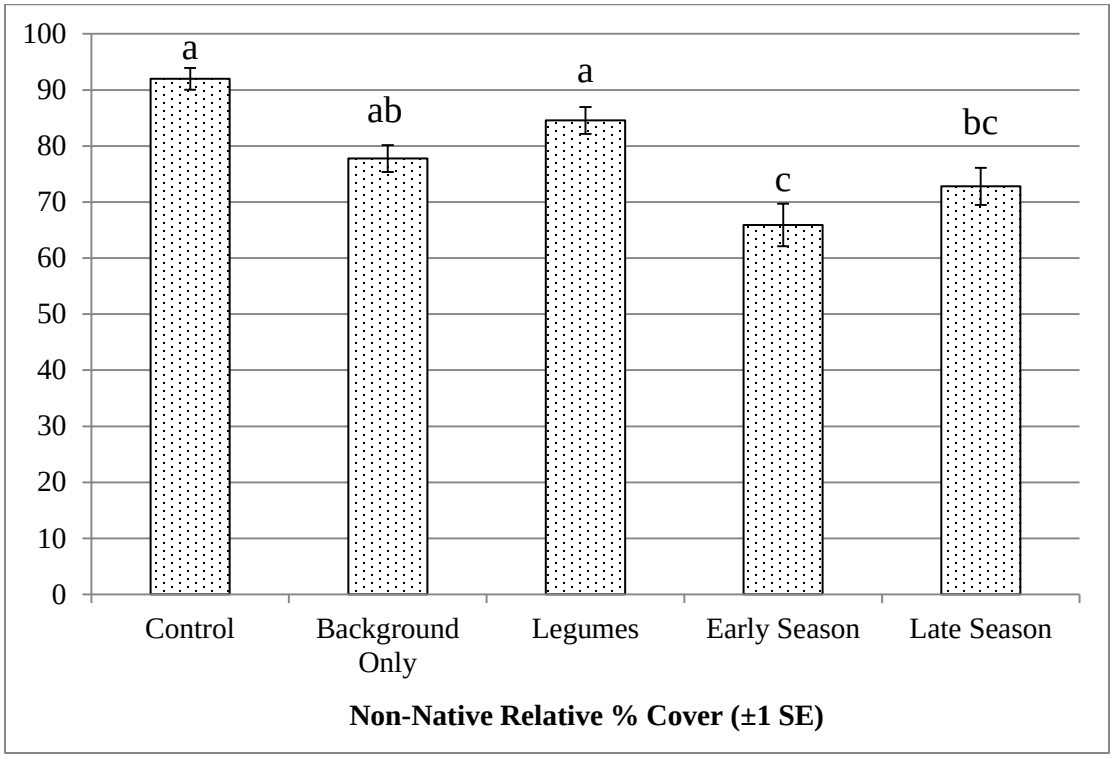

Figure 9. Forb Treatment mean Non-Native Relative Cover (%) in 2011. No similarities among superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

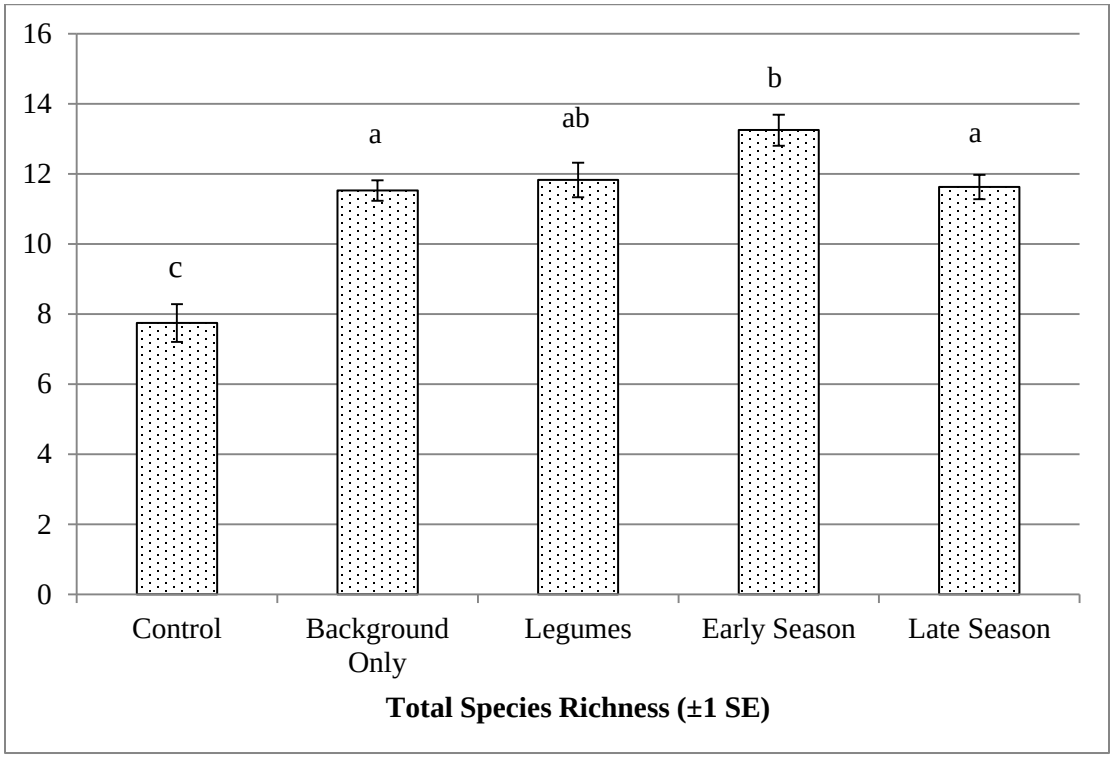

Figure 10. Forb Treatment mean Total Species Richness in 2011. No similarities among superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

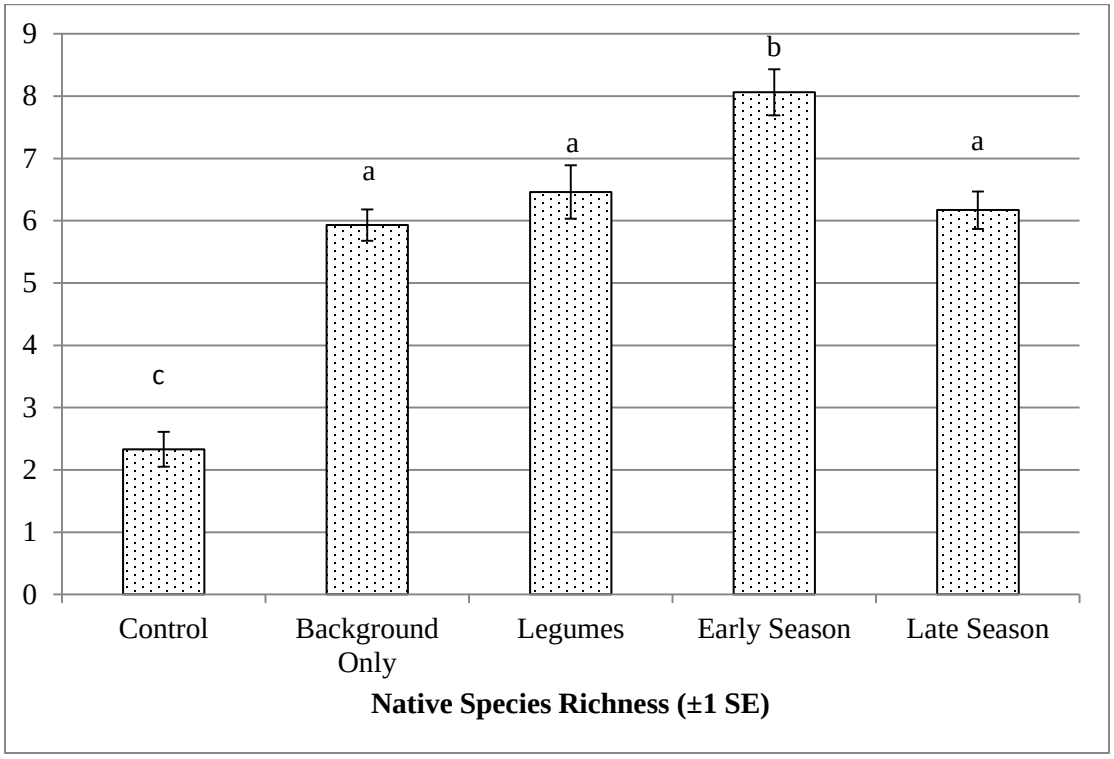

Figure 11. Forb Treatment mean Native Species Richness in 2011. No similarities among superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

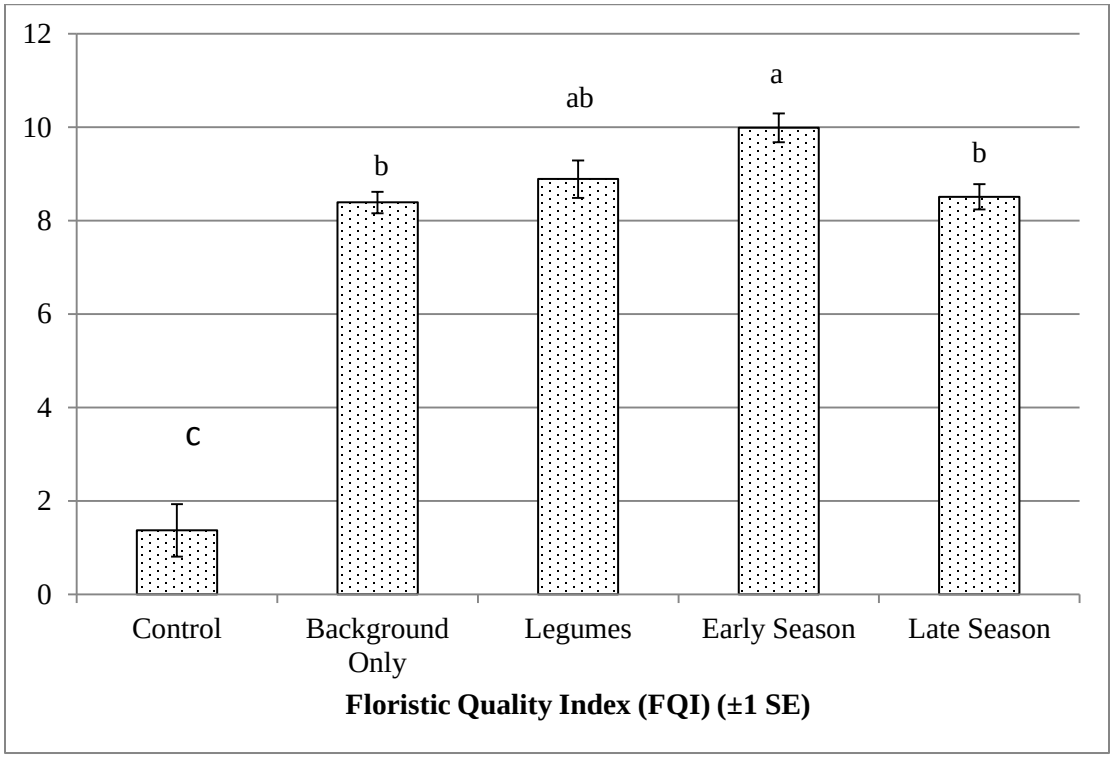

Figure 12. Forb Treatment mean FQI in 2011. No similarities among superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.

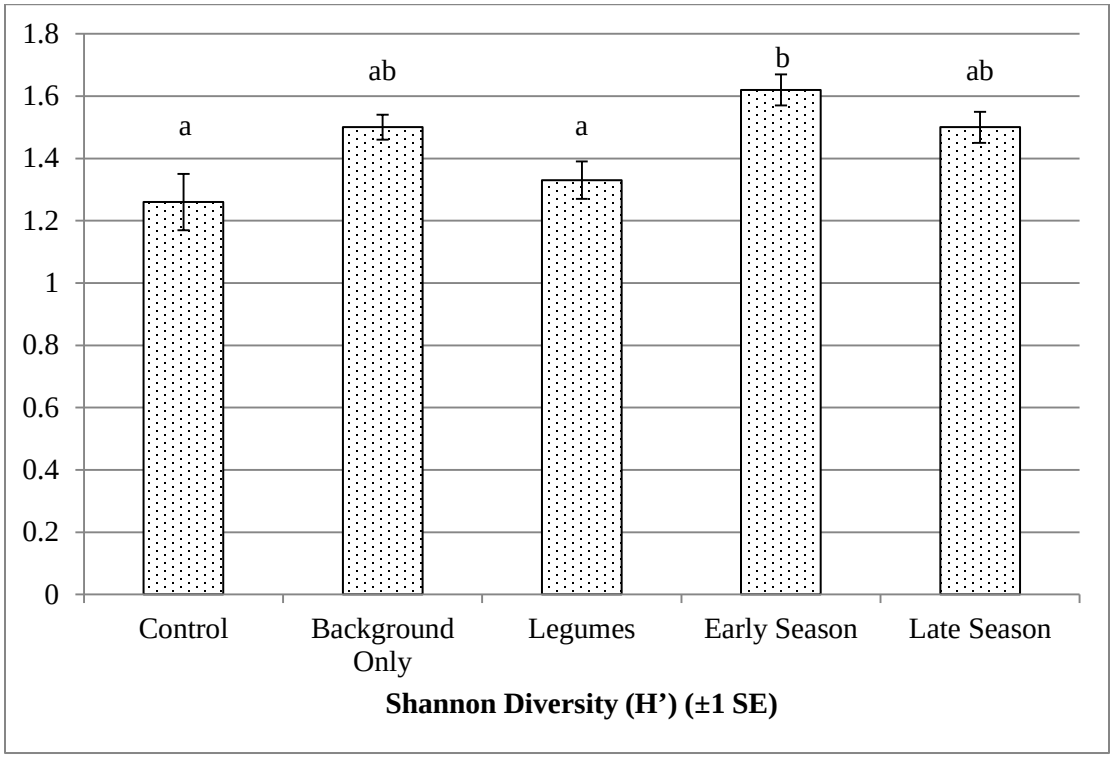

Figure 13. Forb Treatment mean H' in 2011. No similarities among superscript letters indicate significant ($p \leq .05$) differences among the groups as determined by Tukey post-hoc analysis.