The Effects of Prescribed Burning on Vegetation Community Composition: *A Case Study at Cedar Creek Ecosystem Science Reserve*

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ABSTRACT

While fire can be perceived as an unwanted event, it can be used as an ecological service for ecosystems that depend on fire cycles. Oak savannas would be considered one of these ecosystems as they thrive and benefit from burnings. The results of our study suggest that average biomass and species richness, respectively, are not influenced by burn frequency grouped by year of observation. However, average biomass and species richness are suggested to increase according to burn frequencies grouped with native species and decrease with burn frequencies and invasive status. An ideal burn frequency was not identified from the statistical analysis; however, the species status is an important variable to consider in conservation approaches. Our study partially supports the hypothesis that fire cycles promote biodiversity in terms of species biomass and richness. Our findings of the beneficial effects of prescribed burning have broad implications for the restoration of oak savannas.

INTRODUCTION

Bias in the media, when reporting natural disasters such as wildfires, has caused the general belief that fire is harmful to the environment and should be prevented at all costs. This is because fire is worthy of being on the front page of a news article. 88% of articles that report on fires discuss the negative aspects, but only 36% mention noteworthy information (Clegg et al., 2007). However, evidence from fire statistics over the past decade depicts that fire trends have actually decreased (Doerr & Santin, 2016). Fire severity has also decreased in western USA, with no clear trends in fatalities from fires within the past three decades (Doerr & Santin, 2016).

Yet, fire has been an important process that has been affecting ecosystems for over 350 million years (Pausas & Keeley, 2019). Although potentially harmful and can have large-scale environmental effects, fire plays an important role in plant ecology. When controlled, fires can allow for increases in diversity, regulation of biogeochemical cycles, and pest control (Pausas & Keeley, 2019). For humans, controlling fire came naturally as the need for cooking became a requirement for digestion of animal and plant products (Pausas & Keeley, 2019). Eventually, fire became common practice for agricultural use as well. Even now, farmers in many parts of the world burn fields in order to remove weeds and dead plant matter before a new planting season in a method called slash-and-burn (Pausas & Keeley, 2019).

Certain ecosystems have evolved to depend on fire to survive and reproduce. Oak savannas are an ecosystem that benefit from these services, because many species within are fire tolerant. They are considered an ecotone between a forest and grassland compared to a woodland (Apfelbaum & Haney, 1987). To differentiate oak savannas from the more commonly occurring oak woodlands, oak savannas are more open in stand structure (Ffolliott et al., 2008). Due to fire suppression over recent decades, oak savannas have now become rare and are considered an endangered ecosystem (White, 1986). Since there are only three major oaks savannas left in the world, species that are unique to oak savannas are becoming threatened and endangered, creating the need for conservation efforts (White, 1986). Fire cycles are important for the perseverance of oak savanna ecosystems because these communities thrive and benefit from frequent burning events (White, 1986). Thereby, prescribed burnings are an effective restoration technique for oak savannas due to the elimination of woody and fire intolerant species, suppression of trees and shrub growth, and the facilitating the establishment of forbes and grasses (Towne and Kemp, 2003; Grace et al., 2007; Pyke et al., 2010; Reich et al., 2001). Most fire intolerant species that are found within oak savannas are actually invasive species that became dominant after European settlers implemented fire suppression (Dey & Kabrick, 2015). Invasive species are classified as species that reduce the biodiversity of native species and change species composition because they compete for resources and win. Without prescribed burning, invasive species would proliferate and turn the oak savanna community into a closed canopy forest (White, 1986). Consequently, a prescribed burning regime is necessary for the survival and restoration of the oak savanna ecosystem.

While we know that prescribed burning will reduce woody and fire intolerant species, there are some variables that will need to be further examined, such as burn frequency. As plant species have set maturation and reproduction schedules, prescribed burns need to be planned accordingly. There are many studies that show the positive effects of prescribed burning and biodiversity; several of which demonstrate the relationship of burn frequency with stand structure or community composition rather than diversity specifically (Burton et al., 2011; Cavender-Bares & Reich, 2012; Izbicki et al., 2020; Peterson & Reich, 2001). However, there are few which have a main focus on both the relationship between burn frequency and diversity (in terms of biomass and species richness). Therefore, we propose the following question: how does burn frequency affect biodiversity?

Modifying methods from Knops (2018), which recorded biomass and species richness after burn treatments in Cedar Creek Ecosystem Science Reserve, we used statistical analysis to determine the relationship between burn frequency and biodiversity. Cedar Creek is an important conservation area in the United States, as it is one of the few oak savannas in North America. There are many scientific test plots and LTER sites at this location. Based on previous knowledge for prescribed burning, and the effects on vegetation composition, we predict that the communities that undergo frequent burnings will have increased diversity in terms of biomass and species richness. Specifically, we predict that native species will be more abundant, while invasive species will become less abundant. We hypothesis that fire cycles promote biodiversity and greater species richness, along with biomass, as burning allows community composition to regenerate and prevents strong competitors from dominating.

METHODS

Our study area was the Cedar Creek Ecosystem Science Reserve, which is a biological field station run by the University of Minnesota, USA. Cedar Creek hosts multiple different ecosystems found throughout North America, and is an important conservation area since it hosts one of the few oak savanna ecosystems left in North America (Li et al., 2013). The majority of experiments that take place at Cedar Creek focus on studying the long-term effects of human-driven environmental changes, by evaluating different disturbance patterns used for conservation management (Li et al., 2013). Without frequent fire disturbances, Cedar Creek is susceptible to invasive species which can result in the loss of native species due to competition. Studies have shown that oak savanna communities benefit from fire cycles (Izbicki et al, 2020; Li et al., 2013; White, 1986).

Observational data used in this study was from experiment #012: “Effect of Fire Frequency on Grassland Vegetation and Soils – Plant aboveground biomass data” (Knops, 2018). This experiment was conducted by Johannes Knops from 1983-2010 to assess the impacts of different fire frequency treatments on vegetation structure and composition in a fertile grassland ecosystem at Cedar Creek. Experiment 12 data was used in research conducted by Li, Zuo and Knops (2013), which looked at the impacts of prescribed burning treatments on vegetation succession. As outlined in Li et al. (2013), experimental design involved: four prescribed burning treatments that were implemented in Field B at Cedar Creek early in the spring, between march-april. The burning treatments were: burning every year, burning every other year, burning every four years and an unburned control. These treatments took place on 24 individual plots, where each burn frequency treatment was randomly assigned to 6 plots to replicate. Plot dimensions were 8x8 meters and placed on a 3x8 meter grid with 2 meter walkways. A total of 1264 observations were taken over a period of 27 years, with data collection occurring on 5 different years: 1983, 1987, 1991, 2000, and 2010 (Li et al. 2013). Plant aboveground biomass sorted by species, percent vegetation cover, and light penetration were sampled over the course of this experiment. 56 different plant species were sampled in this experiment, along with several miscellaneous plant categories (ex. leaf litter).

Data used in our study was retrieved through the Long Term Ecological Research Network (LTER) data portal and was extracted as a CSV file. Our data analysis and statistical tests were done using RStudio programming. Our tidied dataset variables consisted of: year of data collection [1983, 1987, 1991, 2000, 2010], plot number [1:24], the burn frequency treatments [1, 0.5, 0.25, 0], species name, and biomass with units g/m^{-2}. Data tidying procedures involved changing the format of the 'Year' variable from [YYMMDD] to [YYYY] and correcting syntax errors in plant species names. Biomass corresponding to individual plots was grouped by year and burn frequency treatment, then averaged over the six replicate plots to give average biomass value for each species, according to a specific burn frequency for each of the five data collection years. Species corresponding to individual plots were also grouped by year and burn frequency treatment, then unique species names were counted to give a species richness value, according to a specific burn frequency for each of the five data collection years.

For our statistical analysis, we performed an ANOVA test to compare both average biomass and species richness with various burn frequencies within and between plot sites. In this case, each plot was considered an independent sample. An ANOVA table was generated using Satterthwaite's method, which was fit with a linear mixed-effect model. We also wanted to see if the effects of burn frequency would differ between invasive and native species, so we created a new variable which represented species status as invasive or native. We then ran another regression model to determine if biomass and richness varied with burning frequency and species status. For our post-hoc analysis, we performed pairwise contrasts with Tukey adjustments.

RESULTS

The dataset from the Cedar Creek Ecosystem Science Reserve provided observational data from 24 plots with four treatments, starting in 1983 (Li et al., 2013). Spanning the five independent years of data collection, there were 1264 observations over the 24 plots (Li et al., 2013). 56 species were recorded in the experimental field, along with several additional genus families and miscellaneous categories (Li et al., 2013). Biomass was calculated for each of the 24 plots, treated as individual samples, then averaged according to the burning treatment, with each of the four frequencies having six replicates. The average biomass data was visualized in bar plots according to burn frequency replicates throughout the years of observation (Fig. 1). The affected variable, average biomass, for each burn frequency treatment, was presented along the vertical axis, to represent the accumulation in plant matter from zero (Fig. 1). The years of observation are presented as discrete units, due to the data collection only taking place in specific years and not continuously. No obvious trends over time were detected in terms of changes in average biomass when grouped by burn frequency (Fig. 1). The ANOVA table fit with the linear mixed-effects model suggested that average biomass was influenced by burn treatment and time (p-value = 0.030, N = 24). The plots burned every four years were only observed to differ significantly in average biomass from 1991 to 2000, and from 1991 to 2010 (p-value = 0.008; p-value = 0.006; Table 1). The average biomass of the plots that were not burned, burned every year, and burned every other year did not show statistically significant differences according to year of observation (Table 1).

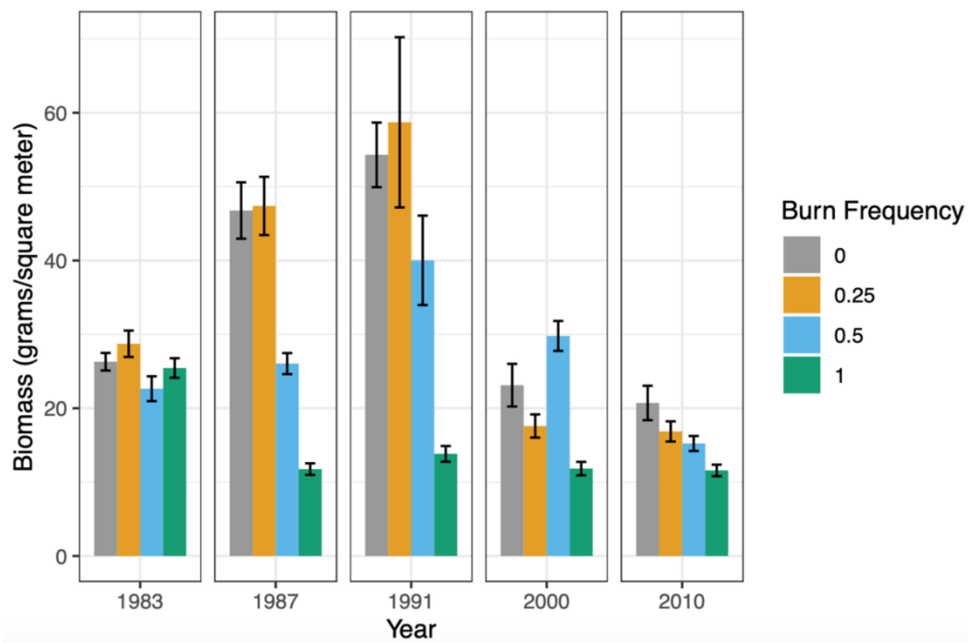

Figure 1. Average biomass, in grams per square meter, for the various burn frequency treatments for each year of observation. The colour fill is based on burn frequency treatment, with "0" representing no burning, "0.25" representing a 4-year burn cycle, "0.5" representing a 2-year burn cycle, and "1" representing a 1-year burn cycle. The error bars represent one standard error above and below the average biomass.

Table 1. Statistically significant average biomass pairwise contrasts of burn frequency for years of observation with the respective standard error, t ratio, and p-value. Burn frequencies are represented as "0" for no burning, "0.25" for a 4-year burn cycle, "0.5" for a 2-year burn cycle, and "1" for a 1-year burn cycle.

Contrast	Standard Error	t ratio	p-value
0.25 1991 - 1 2010	10.1754555	4.63233254	0.0018058
1 1987 - 0.25 1991	10.1754555	-4.614673	0.00192934
0.25 1991 - 1 2000	10.1754555	4.60733422	0.00198301
0.25 1991 - 1 1991	10.1754555	4.41161963	0.00406579
0.25 1991 - 0.25 2010	9.65878831	4.33341762	0.00615523

0.25 1991 - 0.5 2010	10.1754555	4.27361599	0.00663283
0.25 1991 - 0.25 2000	9.65878831	4.25740897	0.0079583
0 1991 - 1 2010	10.1754555	4.19916807	0.00858377
1 1987 - 0 1991	10.1754555	-4.1815085	0.00911913
0 1991 - 1 2000	10.1754555	4.17416975	0.0093506
0 1991 - 1 1991	10.1754555	3.97845516	0.01793757
0 1991 - 0.5 2010	10.1754555	3.84045152	0.02780837
0.25 1991 - 0 2010	10.1754555	3.73440185	0.03845884
0 1991 - 0.25 2010	10.1754555	3.68022028	0.04518557

Species richness was calculated for each of the 24 plots, treated as individual samples, then averaged according to the burning treatment, with each of the four frequencies having six replicates. The species richness, or count of unique species, was visualized in bar plots according to burn frequency and year of observation (Fig. 2). The affected variable, species richness for each burn frequency treatment, was presented along the vertical axis, to represent the count of unique species (Fig. 2). The horizontal axis represents years of observation as discrete units, due to non-continuous data collection. The bar plot did not display any obvious trends over time in terms of changes in species richness when grouped by burn frequency (Fig. 2). The statistical analysis did not reveal a statistically significant association between species richness and burning frequency, grouped by year of observation (p-value = 0.430, N = 24).

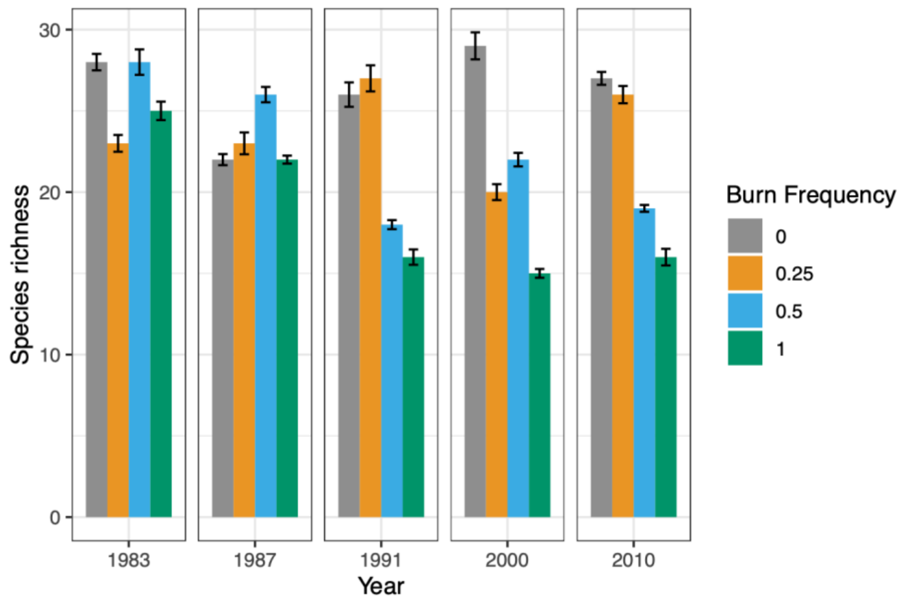

Figure 2. Average species richness for the various burn frequency treatment per year of observation. Species richness represents the count of unique species. The colour fill is based on burn frequency treatment, with “0” representing no burning, “0.25” representing a 4-year burn cycle, “0.5” representing a 2-year burn cycle, and “1” representing a 1-year burn cycle. The error bars represent one standard error above and below average species richness.

The data was further separated according to plant species status - as native or invasive in the oak savanna - and visualized as bar graphs. Average biomass was plotted along the vertical axis, as the response variable, according to year of data collection (Fig. 3). The bar plot showed an obvious difference between the average biomass of invasive and native species when grouped by burn frequency (Fig. 3). From the ANOVA table, the burning treatments grouped by year of observation and species status did not display statistically significant differences in average biomass (p-value = 0.101, N = 24). However, the difference between the average biomass for native and invasive species when grouped by burn frequency was found to be statistically significant (p-value = 0.022, N = 24). The pairwise contrasts revealed statistically significant differences between the invasive and native species average biomass for all of the burn treatments, including the control (Table 2). Other statistically significant contrasts were detected; however, they were not considered to be relevant to the testable predictions. There was no statistically significant difference in average biomass for the various burn treatments of invasive or native species, respectively

(Table 2). Therefore, the results suggest that the increased average biomass of native species, when grouped with burn frequency, is statistically significant compared to invasive species (Table 2). Thus, average biomass increases according to the burn frequencies with native species and decreases with burn frequencies grouped with invasive species.

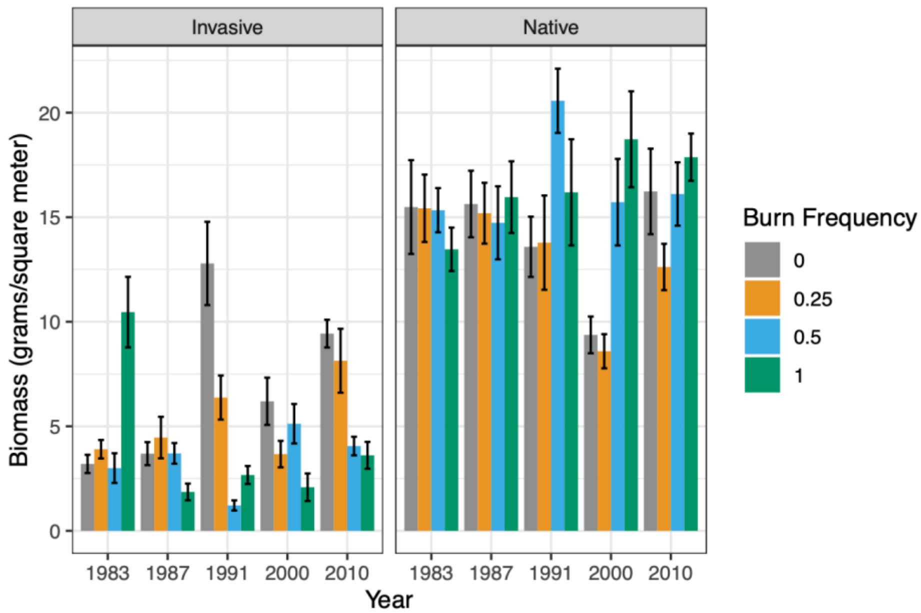

Figure 3. Average biomass, in grams per square meter, for each burn frequency per year of observation, according to the species status as native or invasive. The colour fill is based on burn frequency treatment, with “0” representing no burning, “0.25” representing a 4-year burn cycle, “0.5” representing a 2-year burn cycle, and “1” representing a 1-year burn cycle. The error bars represent one standard error above and below the average biomass.

Table 2. Statistically significant average biomass pairwise contrasts of burn frequency for species status as native or invasive with the respective standard error, t ratio, and p-value. Burn frequencies are represented as “0” for no burning, “0.25” for a 4-year burn cycle, “0.5” for a 2-year burn cycle, and “1” for a 1-year burn cycle.

Contrast	Standard Error	t ratio	p-value
0.5 Invasive - 0.5 Native	1.5677627	-9.052888	2.45E-14

1 Invasive - 1 Native	1.58461521	-8.9092631	3.57E-14
0.25 Invasive - 0.25 Native	1.5677627	-5.8735993	5.69E-07
0 Invasive - 0 Native	1.58461521	-5.7991512	8.25E-07
1 Invasive - 0.5 Native	2.25725258	-6.3929343	6.13E-06
0.5 Invasive - 1 Native	2.24545401	-6.1814076	1.24E-05
0.25 Invasive - 0.5 Native	2.24545401	-5.6735972	5.59E-05
0.25 Invasive - 1 Native	2.24545401	-5.534332	8.45E-05
0 Invasive - 0.5 Native	2.25725258	-5.3457184	0.00014027
0 Invasive - 1 Native	2.25725258	-5.2071811	0.00021169
1 Invasive - 0 Native	2.25725258	-5.1182815	0.00027543
0.5 Invasive - 0 Native	2.24545401	-5.0393224	0.00036276
1 Invasive - 0.25 Native	2.25725258	-4.8284697	0.00064579
0.5 Invasive - 0.25 Native	2.24545401	-4.7479879	0.00084592
0.25 Invasive - 0 Native	2.24545401	-4.3922468	0.0023352
0 Invasive - 0.25 Native	2.25725258	-3.7812538	0.01220154

Further dividing the data in terms of species richness according to species status in the oak savanna revealed a notable difference between native and invasive species (Fig. 4). Species richness, the count of unique species, was plotted along the vertical axis as the affected variable by year of observation (Fig. 4). The notable difference in species richness between the native and invasive groups was observed for every burn frequency, including the control with no burning (Fig. 4). From the ANOVA test, the difference in species richness was not statistically significant, in terms of its association with burn frequency grouped by species status and year of observation (p-value = 0.997, N = 24). However, statistical analysis confirmed the visual difference, suggesting the influence of burn frequency and status on species richness is statistically significant (p-value = 0.011, N = 24). The post-hoc analysis found statistically significant pairwise contrasts between the invasive and native species richness for all of the burning treatments (Table 3). There was no statistically significant difference in species richness for the various burn treatments of invasive species (Table 3). Pairwise contrasts for species richness of native species grouped by burn frequency only suggested a statistically significant difference between the 4-year and 1-year cycles (Table 3). Other statistically significant contrasts were detected; however, they were not considered to be relevant to the testable predictions. Thus, the results suggest species richness is significantly influenced by burn frequency and species status as native or invasive in the oak savanna.

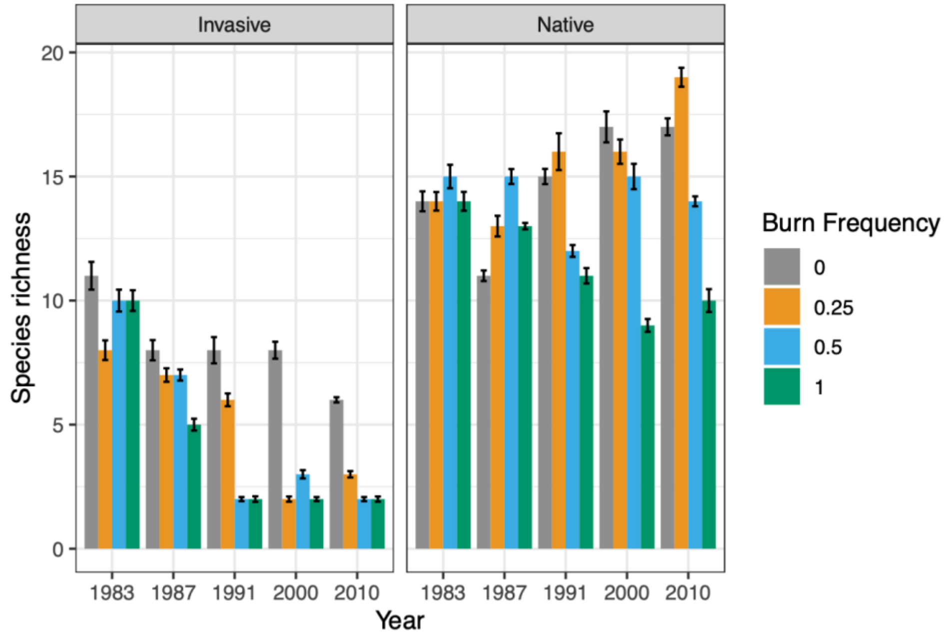

Figure 4. Average species richness for each burn frequency per year of observation, according to the species status as native or invasive. The colour fill is based on burn frequency treatment, with “0” representing no burning, “0.25” representing a 4-year burn cycle, “0.5” representing a 2-year burn cycle, and “1” representing a 1-year burn cycle. The error bars represent one standard error above and below the mean species richness.

Table 3. Statistically significant species richness pairwise contrasts between burn frequency for species status as native or invasive, respectively, with the standard error, t ratio, and p-value. Burn frequencies are represented as “0” for no burning, “0.25” for a 4-year burn cycle, “0.5” for a 2-year burn cycle, and “1” for a 1-year burn cycle.

Contrasts	Standard Error	t ratio	p-value
0.25 Invasive - 0.25 Native	0.43372601	-9.8372395	0
0.5 Invasive - 0.5 Native	0.43372601	-7.5316365	6.78E-11
1 Invasive - 0.25 Native	0.50353565	-8.9348397	1.61E-10
0.5 Invasive - 0.25 Native	0.49957875	-8.2736371	2.03E-09

1 Invasive - 0 Native	0.50353565	-7.6108686	1.80E-08
1 Invasive - 0.5 Native	0.50353565	-7.2136772	7.47E-08
0.25 Invasive - 0 Native	0.49957875	-7.2060711	8.76E-08
0.5 Invasive - 0 Native	0.49957875	-6.9391795	2.26E-07
0.25 Invasive - 0.5 Native	0.49957875	-6.8057338	3.63E-07
1 Invasive - 1 Native	0.43827785	-5.701886	1.34E-06
0 Invasive - 0 Native	0.43827785	-5.568932	2.56E-06
0 Invasive - 0.25 Native	0.50353565	-6.1711741	3.14E-06
0.25 Invasive - 1 Native	0.49957875	-4.5371558	0.00090957
0 Invasive - 0.5 Native	0.50353565	-4.4500117	0.001166
0.5 Invasive - 1 Native	0.49957875	-4.2702643	0.00212805
0.25 Native - 1 Native	0.49957875	4.00337281	0.0048409

DISCUSSION

Using biomass and species richness as proxies for biodiversity, the aim of this study was to investigate whether prescribed burning influences biodiversity within the Cedar Creek oak savanna. Research has denoted that fire operates as an environmental filter, and selects for species that have evolved to tolerate and depend on fire (Cavender-Bares & Reich, 2012). Prescribed burning has the capacity to eliminate woody species and herbaceous fire intolerant species, as well as regulate competitive interactions between species (Li et al., 2013). Moreover, prescribed burning can be used as a restoration management tool, as it has the ability to reduce oak overstory density, reduce shrub and sapling density and encourage the growth of grasses and forbs (White, 1986).

Based on the aforementioned information, this led to the hypothesis that fire cycles promote biodiversity in terms of biomass and greater species richness, as burning allows community composition to regenerate and prevents strong competitors from dominating. We predicted that the communities that undergo more frequent burnings will have increased diversity in terms of biomass and species richness, meaning we expect both biomass and species richness to increase following the prescribed burns. Furthermore, we also predicted that with more frequent burnings, native species will be more abundant, and invasive species will be less abundant. We predicted the latter based on knowledge of community composition within this oak savanna. Knowing that the native species tend to be fire tolerant, we figured that prescribed burning would give these species the opportunity to regenerate without the competing effects of the dominant, fire intolerant, invasive species.

Results specify that our predictions and hypothesis are for the most part, largely supported. Statistical analysis indicates that average biomass was influenced when grouped by burn frequency and time. However, this result was only upheld for the plots burned every four years and not for the plots that were not burned, burned every year, and burned every other. This holds true with aspects of our prediction, as well as various studies investigating such. One study investigating the effects of timing on prescribed burning found that when burned in spring, much like the timing of our study, grass biomass significantly increases following the burns (Towne & Kemp, 2003). This is an important finding, as native grasses are crucial to the restoration of oak savannas. Furthermore, it has been found that both C_3 and C_4 grasses see biomass significantly increase with an increase in fire frequency, benefiting most from 5 fires per decade (Burton, Hallgren, Fuhlendorf & Leslie Jr., 2011). Our finding of significant differences in average biomass may arise due to the reduction in below ground competition for moisture and nutrients (Burton, Hallgren, Fuhlendorf & Leslie Jr., 2011).

Contrary to our prediction of increased species richness, results indicated that there were no significant differences in species richness when grouped by burn frequency and time. The literature shows mixed results when it comes to the effect of prescribed burning on species richness. One study noted that forbs and C_3 grasses showed an increase in species richness as fire frequency increased, yet woody plant understory, as well as C_4 grasses and legumes did not show any response to fire frequency (Burton, Hallgren, Fuhlendorf & Leslie Jr., 2011). On the contrary, another study found that species richness decreased with increased fire frequency (Li et al., 2013). These mixed findings can be attributed to the notion that fire's impact on species composition strongly depends on the sites fertility and productivity (Li et al., 2013). In terms of our study, perhaps the fertility and productivity at the Cedar Creek site is playing a mediating role in the effect on species richness, causing there to be no change following burns over time.

In terms of average biomass grouped by burn frequencies and species status, results supported our prediction that native species will be more abundant than invasive species, as significant differences between invasive and native species were found. Results indicated that average biomass increased according to burn frequencies with native species, and average biomass decreased according to burn frequencies with invasive species. It has been previously found that frequent fire favours grasses capable of rapid seedling establishment and vegetative growth, over shrubs and trees that are slower to regenerate after the burnings. (Burton, Hallgren, Fuhlendorf & Leslie Jr., 2011). These characteristics of rapid seedling establishment are common to native grasses found at Cedar Creek, and furthermore, slow regenerative growth of shrubs and trees is more common with invasive species, as they are typically fire intolerant. Our findings can perhaps be attributed to the reduction in below ground competition for moisture and nutrients that occurs when invasive species are less present following the prescribed burn. Research has delineated that most invasive shrub and tree species at Cedar Creek do resprout after fire (Peterson, Reich & Wrage, 2007). However, in the two to four years it takes to recover the lost biomass, native species are able to regenerate without the competing effects of invasive species (Peterson, Reich & Wrage, 2007). This perhaps is the reason that our findings show that native species biomass increased, while invasive species biomass decreased.

Lastly, in terms of species richness grouped by burn frequencies and species status, our predictions were again supported. Results indicated that species richness is significantly influenced by burn frequency and species status as native or invasive. This result is rather interesting, as earlier it was noted that when grouped by burn frequency and time, there was no chance in species richness. Perhaps there is no change in species richness overall, and the change is dependent on further variables, such as species status. Previous research done at Cedar Creek with respect to prescribed burning supports our findings in that the majority of species found in the understory, shrub, and overstory layers had significantly different occurrences with respect to burn versus control plots (White, 1986). It has been noted that the response of various groups of species differed (White, 1986). Typically occurring native grass and forb species had their lowest occurrence in the control plot, and had their maximum occurrence recorded in burn plots (White, 1986). This goes to show the influential effect of further grouping species based on status.

Our statistical analysis provided support for aspects of our predictions and hypothesis. However, changes in vegetation composition in grasslands and savannas may take longer time periods to show the effects of prescribed burnings. Therefore, a limitation to keep in mind is the rather short study period, and the fact that species may have not had time to fully show the effects of prescribed burnings. Moreover, our study did not take into account fire's interactions with abiotic factors such as climate, that work together to impose environmental filters on the establishment and population dynamics of species (Cavender- Bares & Reich, 2012). Future studies should keep this facet in mind, and further investigate the relationship between fire and abiotic influences. The influential effect of being grouped by species status and burn frequency should be further investigated in future research. Future research should allow for longer study time periods, to allow full effects of prescribed burning to show. Lastly, this experiment should be repeated on other oak savannas to see if results generalize.

Our study partially supports the hypothesis that fire cycles promote biodiversity in terms of species biomass and richness. Our findings of the beneficial effects of prescribed burning has broad implications for the restoration of oak savannas, as this ecosystem is becoming endangered. Our results are supported by many previous studies, as aforementioned. Our findings can help tailor the species status specific fire regimes needed to obtain optimal results, and can be beneficial in the management of oak savanna restoration. With the right approach to prescribed burning, this practice has the capability to bring this unique ecosystem back to much of its original glory.

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