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The Effects of Fire on the Vernal Herbs of an Eastern Mesic Forest

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THE EFFECTS OF FIRE ON THE VERNAL HERBS OF AN EASTERN MESIC FOREST

A Thesis
Presented to
The Faculty of the Department of Biology
Western Kentucky University
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In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

By
David Randolph Kem

May 2013

THE EFFECTS OF FIRE ON THE VERNAL HERBS OF AN EASTERN MESIC FOREST

Date Recommended 6 March 2013

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incredible knack for making difficult topics accessible to young students and can be credited for much of my knowledge of biology. His positive outlook, approachability, and willingness to give of his time and abilities go far beyond the duties of a college professor. Stepping in to make the completion of this research a reality stands as a testament to his kindness and support for the students of Western Kentucky University. Thank you, Dr. Philips.

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THE EFFECTS OF FIRE ON THE VERNAL HERBS OF AN EASTERN MESIC FOREST

David R. Kem May 2013 52 Pages

Directed by: Albert J. Meier, Lawrence A. Alice, and Keith Philips

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The effects of fire on vernal herbs of the mesic forests of eastern North America are poorly understood. I studied the influence of prescribed fire on species richness, abundance of rare and common species, and density of exotics in the vernal herbaceous layer. To determine these effects, three sites in central Kentucky were surveyed prior to and following one of three treatments: spring burn, winter burn, or negative control. I conducted low-intensity spring burns in April 2010 and winter burns in February 2011. I used chi square analyses to test for changes in species richness, abundance of rare species, abundance of common species, and abundance of *Glechoma hederacea,* an exotic herb. I used multiple logistic regressions to test for the effect of burn severity on the abundance of two of the most common herbs, *Erythronium americanum* and *Viola sororia* sensu lato. The abundance of rare species increased significantly after fire treatment, with a 2% greater increase on burned plots than control plots ($p < 0.05$), and showed a 40% greater increase in plots burned in winter than plots burned in spring. However, there was no significant difference in overall species richness due to fire or to the season in which the prescribed fire was conducted. There were no significant differences in the density of common species or *Glechoma hederacea* due to fire treatment or due to fire season. There were also no significant differences in the abundances of *Erythronium americanum* or *Viola sororia* sensu lato due to burn severity. Changes in the abundance of rare species due to fire might suggest that prescribed burns may slightly increase the diversity of vernal herbs in eastern mesic forests. Changes in the abundance of rare species due to fire season might suggest that prescribed fires conducted prior to emergence may further increase the diversity of vernal herbs in the eastern mesic forest.

INTRODUCTION

The temperate, continental climate of eastern North America has supported the dominance of broadleaf, deciduous trees. The tall, broadleaf trees of the eastern mesic forest provide a dense canopy in summer months which most species shed entirely in winter. Understory vegetation competes for light and nutrients, creating a layer of both woody and herbaceous plants. The herbaceous layer, composed of plants which lack secondary growth, represents the majority of species diversity in the eastern mesic forest (Roberts 2004), and can be subdivided by the season in which they flower. Vernal, or spring-flowering, herbs often create a dense layer of vegetation in the spring prior to canopy closure (Muller 1978; Bailey 1980; Bierzychudek 1982). The increased light availability and ample water available in spring give species with the ability to emerge and reproduce quickly a competitive advantage. Along with a strong response to microtophographic differences, this competitive advantage has led to the great diversity of vernal herbs found in a mature forest (Bratton 1976; Roberts 2004).

Vernal herbs play an extremely important role in nutrient cycling and energy flow in the forest ecosystem (Muller 1978, Roberts 2004). Herbaceous species are typically long-lived perennials (Bierzychudek 1982), and species diversity and cover tend to be higher in old growth forests (Duffy and Meier 1992, Bratton *et al.* 1994). However, there are several limiting factors which determine composition of the herbaceous understory. Competition for light, nutrients, and possibly soil moisture and temperature, drives the distribution of herbaceous species.

Vernal herbs emerge when the availabilities of light, moisture, and nutrients are all typically high. However, declines in vernal herb diversity and abundance after severe disturbance have been witnessed throughout the eastern forests (i.e., Duffy and Meier 1992; Bratton *et al.* 1994; Meier *et al.* 1995; Baskin 1997; Taverna *et al.* 2005). Although herbaceous plants have shown a resilience to extreme seasonal weather (Rogers 1983), the ground layer vegetation of the eastern mesic forest has responded negatively to change in forest structure and disturbance regime.

Pearson *et al.* (1998) found that forest herbs in the French Broad River Basin, North Carolina were more abundant in larger patches of mesic forests, suggesting that herbaceous plants in the eastern forest respond negatively to induced fragmentation. A possible mechanism explaining lack of recovery of herbaceous diversity and abundance after disturbance is that forest herbs are usually relatively long-lived perennials, which take several years to reach reproductive maturity (Meier *et al.* 1995). Repeated disturbance in plant communities with very few reproducing individuals could lead to a decline in both abundance and diversity of affected species. Many herbaceous understory plants have a low reproductive rate and produce very few, relatively heavy seeds (Bierzychudek 1982). Many forest herbs also have slow dispersal, often dropping seed no farther than the height of the stem (Bierzychudek 1982). Meier *et al.* (1995) suggest that slow vegetative spread may also slow recovery after disturbance. If a disturbance eliminates forest herbs from a large area, recovery for slow-dispersers could take a long time (Meier *et al.* 1995).

The herbaceous understory of the eastern mesic forest is a critical part of a mature, healthy forest ecosystem. This groundlayer vegetation provides much of the diversity of the forest and supports a wide variety of wildlife in eastern North America. Given the slow rates of recovery for many forest herbs, it is important to determine how management activities, including fire, influence them.

Soils

The soils of rich and semi-rich mesic forests are characterized by having high levels of moisture, mineral nutrients, and high-quality organic matter ("Rich and Semi-rich Mesic Forests" 2002). Much of the organic matter in the forest is contained within a thick layer of leaves and abundant humus (Bailey 1980). This is the source of the majority of available phosphorus and sulfur in the ecosystem, and virtually all of the available nitrogen (Debano 1990). Usually nutrients are made available to plants slowly via decomposition of organic matter, but fire can rapidly release these nutrients from organic matter.

Fire

Perhaps the most common form of disturbance in the eastern mesic forest, historically, has been fire. Characterized by an abundance of organic matter to provide fuel, eastern forests would have historically supported low-intensity fires every 0 – 35 years prior to anthropogenic influence (US Fish and Wildlife Service 2009). However, fire has influenced plant communities globally since at least the Mesozoic era (Mutch 1970; Bond and van Wilgen 1996) and has been utilized by hominids for more than a million years (Bond and van Wilgen 1996; Bond *et al.* 2005). During most of the last 4000 years, Native Americans used fire to systematically alter the landscape and vegetation of eastern North America (Baskin *et al.* 1997; Delcourt and Delcourt 1997).

This pattern of repeated burning was broken with European settlement in the east and policies of complete fire suppression were adopted in the 19^{th} and early 20^{th} centuries (Bond and van Wilgen 1996; Delcourt and Delcourt 1997; Abrams 2005; Bond *et al.* 2005). Lack of fire in the eastern mesic forest has led to compositional changes in forest structure and an increased effort by land managers to use prescribed fire as a management tool for a variety of purposes.

Fire in the eastern mesic forest can change many characteristics of forest soils. Soils can experience short-term, long-term, and even permanent changes following fire. The effects of fire on soil can be either beneficial or detrimental to plant life in the eastern forest. Fire severity and duration are particularly important in determining its effect on soil properties. High-intensity, long-duration fires tend to have longer lasting, even permanent effects on soils. Heating can result in increased soil pH due to organic acid denaturation (Certini 2005). Hotter fires volatize more of the available nutrients stored in the environment and may also create a long-lasting water-repellent layer of soil (DeBano 1990, 1998; Certini 2005), which can decrease soil permeability and lead to reduced moisture and nutrients in the soil.

Lower intensity, quicker-burning fires usually have shorter-lived effects on the soils of the eastern mesic forest. A substantial amount of soil organic nitrogen survives low-intensity fires (Certini 2005). Burning tends to increase the availability of most plant nutrients, and substantially increases the available phosphorus and mineralized nitrogen (Kozlowski 1974, Certini 2005). Changes to cycles of forest nutrients other than nitrogen and phosphorus are generally small (Certini 2005). Water repellent layers of soil following low-intensity, quicker-burning fires are either not present or tend to last less than a year following burning (DeBano 1998). Another effect of fire on soil properties is a change in temperature due to the black or ash-grey color of soil following fire (Certini 2005), which alters light reflection and absorption.

Plant communities are constantly undergoing the process of either primary or secondary succession (Odum 1985). Like other forms of disturbance, such as treefalls and even anthropogenic disturbances such as clearcutting, fire will force plant communities into an earlier stage of succession. The severity of the fire will determine the stage of succession; severe fires may kill all vegetation, returning a community to the beginning stages of succession, while a low-intensity fire might seemingly maintain the current stage. Abrams (1992, 2005) finds evidence that fire controls forest succession in oak dominated forests of eastern North America. He notes the dominance of oak in presettlement forests as evidence for regular fire, since oaks are a mid-successional species and largely fire-tolerant. Fire-controlled succession is further supported by Dey and Hartman's (2005) evidence that repeated burning increases oak regeneration, as well as the historical evidence of the decline in oak species following fire suppression in 19th and early 20th centuries (Abrams 2005).

Without regular fire, woody understory plants have increased in abundance, changing the vertical profile of the forest. Increased plant material in the understory increases combustible fuel, the likelihood of a wildfire, and the likelihood of one with greater intensity (Bond and van Wilgen 1996; Bond *et al.* 2005). Highly flammable properties of plant species which might have been beneficial to a community prior to fire exclusion might now be detrimental, as they can also lead to high-intensity fire (Mutch 1970). Reducing fire intensities in these areas may be critical for maintaining soils, water supplies, and biodiversity, as well as reducing impact to human communities (Dellasala *et al.* 2004). The threat of catastrophic wildfires following fire suppression led to the increased application of frequent, low-intensity prescribed fire as a means to reduce fuels and prevent uncontrollable, damaging fires.

Of course, some patches within a landscape will burn more frequently than others, due to differing climate, moisture, topography, soil characteristics, or other factors affecting flammability. During the late Archaic, Woodland, and Mississippian times, anthropogenic fires were concentrated within alluvial bottoms of rivers and upper slopes and ridgetops, and likely avoided more mesic areas (Delcourt and Delcourt 1997). Guyette *et al.* (2003) suggests that Native Americans likely burned under drier conditions because it would take less effort to modify the landscape using fire during drought. Some plants, particularly those in mesic areas, might be less adapted to fire than plant species in more frequently burned parts of the eastern forest. Implementing fire as a forest management tool might have beneficial effects for some plant communities while having a more detrimental effect on mesic forests.

Plant Response to Fire

To gain an understanding of fire's effects on ecosystems, one might begin by investigating the responses of plants and plant communities to different fire regimes. Not only do environmental factors such as topography and climate contribute to the fire regime of an ecosystem, but plant characteristics adapted in response to frequent or infrequent burning may also contribute to the flammability of a plant community and the frequency of fire (Whelan 1995). Plants adapted to frequent fire are referred to as 'fire-adapted,' and may benefit from, or even require, fire to be successful (Platt *et al.* 1988; Bond and van Wilgen 1996; Chang 1996). At the opposite end of the spectrum, plants in other communities may have adapted to fire-free conditions, lacking fire-adapted traits and less likely to survive the disturbance of fire. Individual plant survival depends upon the immediate effects of fire as well as the post-fire conditions imposed following a fire (Whelan 1995).

The likelihood of death for a plant depends upon the extent of damage to its parts (Whelan 1995; Roberts 2004). Plant cell mortality during fire is depends on the intensity and duration of the fire at the passage of the flames. Cell mortality results from the length of time cells are exposed to heat and whether the cells are hydrated and metabolically active (Whelan 1995). Plant cells which are dehydrated, and in a state of rest can tolerate higher temperatures than tissues that are hydrated and metabolically active (Whelan 1995). Secondary tissues, including bark, protects woody plants from low-intensity fires. Thick bark protects metabolically active plant tissues from flames. Assuming that bark thickness increases with tree size, the larger the tree, the more protected it is from one or more low frequency fires (Dey and Hartman 2005). In the eastern mesic forests of the United States, there are three guilds that typically exist in any community: the overstory of large trees, the woody understory, and the herbaceous layer. Each forest guild responds differently to both the fire itself and post fire conditions.

The overstory in the eastern mesic forest is the least affected of the three guilds by the passing of a low-intensity fire. The woody understory is more directly affected by lower intensity fires than the overstory. Elliot *et al.* (1999) found that high-intensity fires of the upper slopes of the southern Appalachians increased diversity of the understory and herbaceous layers, but decreased diversity in the overstory. Low-intensity fires tend to affect the structure of the forest, increase the availability of sunlight in the understory, and increase the diversity of r-selected, woody understory plants (Odum 1985). A decrease in sub-canopy cover due to fire will further shift competition from the shrub and sapling layer to the herbaceous ground layer (Bowles *et al.* 2007). The herbaceous layer is affected by both high- and low-intensity fires, the extent of which is determined by a number of pre- and post-fire conditions. Roberts (2004) describes a number of factors that influence the herbaceous response to disturbance: lesser competition with higher strata, increased competition within herb layer, changes in microclimate, increased woody substrate, changes in microtopography, changes in mineral soil substrates, damage to preexisting plants, and removal of propagules.

The season of fire may play a major role in determining both short- and long-term effects of fire on the herbaceous understory of the eastern mesic forest. Plant communities are constantly changing temporally and undergoing succession, and certainly some stages of development are more susceptible to damage and mortality by fire. While Hutchinson *et al.* (2005) report increases in the small-scale richness of native herbs following burns in fire-dependent oak forests, these burns are repeatedly conducted prior to emergence of vernal herbs. Most prescribed fires, however, are conducted during the spring, when vernal herbaceous species emerge and, if reproductively mature, flower and reproduce. Burns during spring may damage flowering buds, developing flowers, or fruits and in the process kill an entire year's worth of seeds (Whelan 1995). Vernal herbs often take years to reach reproductive maturity (Bierzychudek 1982; Duffy and Meier 1992), therefore repeated fires during flowering might be particularly damaging. As burn severity increases, the importance of seed and vegetative reproduction increases (Roberts 2004). Declines in herbaceous plant diversity and abundance following fire can be attributed to changes in community composition and competitive and reproductive disadvantages in a post-disturbance environment (Duffy and Meier 1992; Bratton *et al.* 1994), yet other factors such as increased deer densities also contribute to losses of vernal herb diversity (Taverna *et al.* 2005).

Purpose and a priori Hypotheses

The purpose of this study is to determine whether a single, low-intensity prescribed fire in an eastern mesic forest will influence the diversity of vernal herbs, abundance of rare and common species, and abundance of exotic herbaceous plants. Low-intensity fires and disturbances tend to increase competition in the herbaceous understory, therefore I hypothesize that there will be an increase in species richness of vernal herbs on plots that were burned compared to plots which did not receive fire treatment. I hypothesize that plots burned in the winter will have a greater increase in species richness than plots burned during the spring because plant mortality during the spring, when the few reproductively mature individuals in the population are flowering, should result in the loss of a year's worth of seed and should lead to a decrease in abundance of the most susceptible species after spring fire treatment.

As plant populations become more divided and isolated, an increasing number of species are becoming rare in mesic forests. I hypothesize that fire treatment will have a detrimental effect on the rare species present in plots. By disturbing the plant community, succession is set back to an earlier stage, which creates an advantage for r-selected species (Odum 1985). The resource-rich, post-fire environment should lead to a decline in rare herb species. I further hypothesize that spring burning will result in a greater decrease in the presence of rare species than winter burning, again due to the possible loss of annual reproduction.

Common species should be quick to take advantage of the post-fire environment. I hypothesize that there will be an increase in the abundance of common vernal herb species following fire treatment. I also hypothesize that there will be no significant difference in the changes in abundance of common species in plots burned in the spring and plots burned in winter, due to the increased likelihood of survival given low-intensity burning conditions.

Exotic species have invaded the eastern mesic forest, becoming established in many plant communities by out-competing native vegetation. If fire-tolerant, *Glechoma hederacea* (*Lamiaceae*), an invasive herb to Kentucky, should experience an increase in abundance following burn treatment. I also hypothesize that there will be a greater increase in abundance of *G. hederacea* on plots burned in the winter than plots burned in the spring, due to the possible loss of reproductively mature, slower-growing species.

Higher intensity fires do more damage to living plant tissue than low-intensity fires. Vernal herbs, which may be damaged by intense fires, should be at a greater disadvantage in plots that experience higher-intensity burns than in plots that are less intensely burned. Using burn severity as an indicator of fire intensity, I hypothesize that greater burn severity will decrease the abundances of two common vernal herbs, *Erythronium americanum* (*Liliaceae*) and *Viola sororia* sensu lato (*Violaceae*).

METHODS AND MATERIALS

Site Description

The Upper Green River Biological Preserve (UGRBP) in Hart County, Kentucky comprises around 485 hectares of protected land, about 3.2 kilometers north of Mammoth Cave National Park. The UGRBP is owned and managed by Western Kentucky University for the purposes of research and environmental education in a biologically diverse region. Sites at the WKU UGRBP were chosen for this study due to the abundance of vernal herbs and ease of use.

Three sites in an eastern mesic forest at the Upper Green River Biological Preserve were installed, each differing in elevation, slope, and distance from the edge of the tree line. Each site consisted of four replicates, each of which contained three plots. Plots were 2 X 4 m, and each plot was further subdivided into eight 1 m^2 subplots. Plots were separated by a one-meter strip to serve as a fire break, if necessary. Each replicate was separated by two meters. The total amount of land at the WKU Upper Green River Biological Preserve used for this study was 288 m^2.

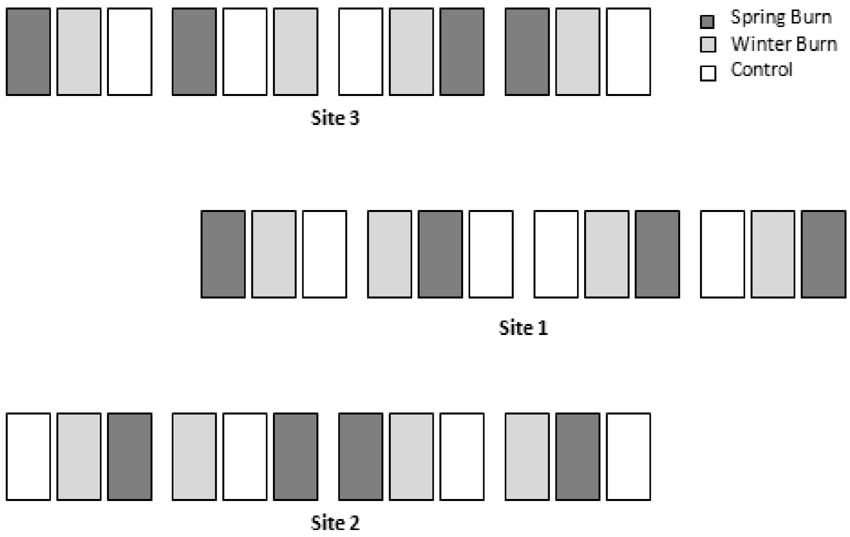

Figure 1. Site, repetition, and plot layout.

The map datum for Site 1 is NAD 83, and the coordinates are N37° 14’33.0” W085° 59’00.7”. This is a north facing slope with a 10% grade on Mississippian St. Genevieve limestone, at an elevation of 127 m above sea level and approximately 19.5 m from the edge of the alluvial floodplain. This site has experienced heavy grazing in the past (Vilma Jean Kinney, personal communication), and the dominant soil type described for the site in the soil map of Hart County is Caneyville silt loam, rocky, with a 6 – 20% slope. The map datum for Site 2 is NAD 83, and the coordinates are N37° 14’30.0” W85° 58’58.02”. This is a North-facing slope with a 12% grade on Mississippian St. Genevieve limestone, at an elevation of 127 m above sea level that straddled the mesic forest and the alluvial floodplain of the Green River. The dominant soil types on this site are a combination of rocky Caneyville complex and Nolin silt loam. The map datum for Site 3 is NAD 83, and the coordinates are N37° 14’28.7” W85° 58’58.5”. This is a north-facing slope with a 25% grade on upper Mississippian St. Genevieve limestone, at an elevation of 141 m and approximately 32.8 m from the edge of the alluvial floodplain. Soil is a rocky outcrop of Caneyville complex with some Caneyville rocky silt loam. Soil was sampled on 22 February 2011 and soil composition for all three sites was analyzed for essential nutrients (Table 1).

Table 1. Mehlich III analysis of soil reported as the average of plots in lbs/acre. * indicates that the variable was significant with respect to site.

Site	P*	K*	Ca*	Mg	Zn*	Soil pH*	Buffer pH*
1	16.875	177.5	3717.25	269.75	7.3875	6.175	6.8375
2	22.635	153.25	4783.875	273.5	7.7375	7.1625	7.1125
3	23.375	202.25	5054.125	293.75	5.675	6.375	6.875

I randomly applied one of three treatments to each of the plots in each replicate. The three treatments were spring burn, winter burn, and control (no burn). I conducted low-intensity spring burns on 10 April 2010 at 1120 hours Central Standard Time and winter burns on 22 February 2011 at 1500 hours. Prior to fire treatment, I placed two wooden dowel rods (1/4” X 48”) in each plot receiving treatment to measure scorch height and determine burn severity. I placed one dowel rod between subplots 1, 2, 3, and 4 and another between subplots 5, 6, 7, and 8. I ignited prescribed fires using a drip torch containing a fuel mixture of 70% diesel and 30% gasoline. I completed all spring burns within an hour of initial ignition and all winter burns within two hours of initial ignition.

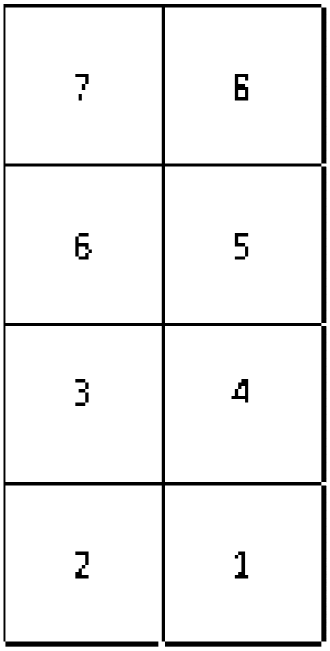

Figure 2. Sublot Layout.

Data Collection

I determined the density and frequency of herbaceous plants in all plots prior to any treatment by data collected on 9 April and 10 April 2010. Woody plants and vines were not included. I photographed and then identified unknown plants with the help of experts and plant identification books. I determined the density and frequency of herbaceous plants in all plots again following both spring and winter burn treatments on 8 April and 17 April 2011. I recorded the scorch height on each dowel rod as an indicator of fire intensity. A coded index was created to record the scorch height at each location, ranging from 1 (unscorched) to 5 (< 65.26 cm scorch height). I collected soil samples from each plot in two places using a soil corer. One sample was taken between subplots 1, 2, 3, and 4 and the other between subplots 5, 6, 7, and 8. All soil samples were taken

8-10 cm deep. Samples for site 1 were collected on 12 March 2011 and samples for sites 2 and 3 were collected on 19 March 2011.

Data Analysis

When the linear models were tested for normality and homoscedasticity several problems were found (Table 47). A logarithmic transformation was used to meet the assumptions of the repeated measures ANOVA test. However, data failed to fit a normal distribution after transformation (Table 48). Since data could not be transformed to meet the assumptions of the repeated measures ANOVA test, data were analyzed using the non-parametric chi-square goodness of fit analysis.

Chi-square goodness of fit tests used burning and burn season as treatments. Tests of *a priori* hypotheses were performed on the changes in species richness for vernal herbs. Rare species, the nine herbs found in the least number of plots prior to any treatment, and common species, the eleven herbs found in the most plots prior to treatment, were analyzed with a chi-square goodness of fit analysis. The changes in abundance of *Glechoma hederacea,* an invasive herb, were analyzed using a chi-square goodness of fit analysis. A Spearman's correlation coefficient was used to relate density of two species to burn severity. Following testing of *a priori* hypotheses, chi-square goodness of fit tests were used for exploratory analyses of changes in abundance of individual species present in twenty or more plots prior to treatment. Soil samples were sent to the University of Kentucky Cooperative Extension Service to be analyzed. A Mehlich III test was used to evaluate the soil for essential nutrients including phosphorus, potassium, calcium, magnesium, zinc, and soil and buffer pH. All results for essential nutrients and pH were reported in lbs/acre. To analyze the relationship between sites and the soil, a general linear model one-way ANOVA was used in the SPSS statistical program.

RESULTS

There were 20 different species of vernal herb found in the plots between 2010 and 2011. The fewest non-woody species in a plot was 4 in 2010. The most species found in a plot was 11 in 2011.

The results for the chi-square goodness of fit analysis of species richness showed an equal distribution in overall species richness from spring 2010 to spring 2011 ($X^{2(1, N = 40)} = 0.15$, $p = 0.93$). There was an equal distribution in species richness due to fire treatment ($X^{2(3, N = 40)} = 0.24$, $p = 0.97$) or due to burn season ($X^{2(5, N = 40)} = 0.22$, $p = 1.00$). Descriptive statistics are listed in Appendix 1. The results for species richness are shown in Table 2.

There was an unequal distribution in the abundance of rare species from year one to year two of this study ($X^{2(1, N = 18)} = 9.62$, $p = 0.00$), which corresponds to a 51% increase in the presence of rare species. The chi-square goodness of fit analyses also show an unequal distribtion in abundance by burning ($X^{2(3, N = 18)} = 9.48$, $p = 0.02$) and abundance by burn season ($X^{2(5, N = 18)} = 12.56$, $p = 0.03$). There was a 2% greater increase in rare herb species abundance in plots receiving burn treatment to control plots. There was also a 93% increase in rare species on plots receiving winter burn treatment, a 53% percent increase on plots receiving spring burn treatment, and a 40% increase on control plots. Descriptive statistics are listed in Appendix 1. The results for changes in abundance of rare herb species are shown in Table 6.

The results for the chi-square goodness of fit analysis show an equal distribution in the abundance of common herb species from year one to year two of the study ($X^{2(1, N =}$

$^{22)} = 0.98$, $p = 0.32$). Also, there were equal distributions in the presence of common herb species in respect to burning ($X^{2(3,\ N = 22)} = 0.98$, $p = 0.81$) and burn season ($X^{2(5,\ N = 22)} = 1.12$, $p = 0.95$). Descriptive statistics are listed in Appendix 1. The results for common species are shown in Table 10.

There was an equal distribution in the abundance of *Glechoma hederacea* from year one to year two of this study ($X^{2(1,\ N = 2)} = 0.59$, $p = 0.44$). The chi-square goodness of fit analysis results showed an equal distribution in abundance by burning ($X^{2(3,\ N = 2)} = 0.61$, $p = 0.89$) or by burn season ($X^{2(5,\ N = 2)} = 0.89$, $p = 0.97$). Descriptive statistics are listed in Appendix 1. The results for changes in abundance of *Glechoma hederacea* are shown in Table 14.

Results for the Spearman's correlation coefficient between burn severity and density of two of the most common individual species are not significant at the 95% confidence level for either *Erythronium americanum* ($r[52] = -0.07$, $p = 0.795$) or *Viola sororia* sensu lato ($r[67] = -0.04$, $p = 0.85$). Results for the Spearman's correlation coefficient between burn severity and density of *Erythronium americanum* are shown in Table 15, while Table 16 shows the results for the Spearman's correlation coefficient between burn severity and *Viola sororia* sensu lato.

Exploratory Analyses

The results of the exploratory chi-square goodness of fit analyses that were conducted on the most common species (species present on 20 or more plots prior to treatment) showed no effect of burning or burn season on any vernal herb species tested. Chi-square goodness of fit analyses on individual species indicated that there were also no significant changes in composition of any of the most common individual species from 2010 to 2011. Descriptive statistics are listed in Appendix 1. Table 17 shows the significance values for results of analyses for individual species. Tables 18 – 23 show the results for chi-square goodness of fit analyses of individual species.

DISCUSSION

Contrary to my *a priori* hypotheses, plots receiving burn treatment did not experience an increase in vernal herb richness. This study fails to support the results of Elliot *et al.* (1999), who found that high-intensity fires in the southern Appalachians led to an increase in diversity in the herbaceous understory. Similarly, Royo *et al.* (2010) stated that the combined effects of prescribed fire and canopy gaps result in more diverse understory plant assemblages. However, I accepted the null hypotheses that fire or fire season will not cause a significant change in vernal herb richness.

There were no significant differences in the species richness of vernal herbs between plots burned in the winter, plots burned in the spring, and negative control plots. This fails to support the findings of Green *et al.* (2010), who suggested that fires later in the growing season had a greater impact on more competitive species in the understory due to the additional stress caused by burning after seedlings were physiologically active. My findings indicate that burn season may not cause a significant difference in the increase in species richness.

I reject the null hypothesis that there would not be a significant change in rare herb species abundance due to fire. I anticipated a decrease in abundance due to fire and fire season, however, there was a 51% increase in the number of rare species on plots from year one to year two and a 2% greater increase on plots receiving burn treatment than control plots. Furthermore, there was a 40% greater increase on plots receiving winter burn treatment than plots receiving spring burn treatment. The results of this study might indicate that a relationship between fire and species richness exists, even in the eastern mesic forest. Since winter burns were conducted prior to emergence, these results may support the findings of Hutchinson *et al.* (2005), who reported an increase in small-scale native herb richness following burns in fire-dependent oak communities.

I accepted the null hypothesis that fire season will not impact the abundance of common herbs. There were no significant differences in the abundances of common herb species by year, fire treatment, or burn season.

I accepted the null hypothesis that fire will not cause a change in the abundance of the exotic herb *Glechoma hederacea*. I also accepted the null hypothesis that there will be no difference in the abundance of *Glechoma hederacea* on plots burned in the winter than on plots burned in the spring.

I accepted the null hypothesis that burn severity has no relationship with the abundances of *Erythronium americanum* and *Viola sororia* sensu lato. The lack of a significant relationship between burn severity and the abundances of these two abundant herbs may be due to all burns being conducted at relatively low severity.

While statistically significant, the difference in abundance of rare herbs is very likely biologically insignificant. The results of this study do suggest, however, that vernal herbs of the eastern mesic forest have a tolerance to mild fires. Less severe than clear-cutting or many other forms of disturbance, low-intensity prescribed fire may not reduce the diversity of vernal herbs. This provides insight and direction for both future research and land managers seeking to understand fire's impact on the communities exposed to burning in the eastern mesic forest.

Exploratory Analyses

Exploratory analyses of individual species did not produce any significant changes in the abundance of any individual species in regards to fire treatment or in regards to burn season.

Possible Confounding Factors

Record-breaking rainfall amounts, and the associated flooding of the Green River, may have altered the plant community during this study. On 1 May 2010 and 2 May 2010, southern Kentucky experienced rainfall amounts which broke prior records for single- and two-day rainfall totals (NOAA 2010). Bowling Green, Kentucky (~40 miles southwest of the study site) recorded 4.75 inches (120 mm) of rain on 1 May, followed by 4.92 inches (125 mm) of rain on 2 May, for a total of 9.67 inches (245 mm) over a two-day period (NOAA 2010). River levels in southern Kentucky responded with historic crests in the days following the downpour of rain. The Green River at Munfordville (upstream of study site) recorded a crest of 51.88 ft (15.8 m), which is 23.88 ft (7.28 m) above flood stage, two days later, on 4 May 2010 (National Weather Service 2012). The sites in this study were affected differently by the rising Green River. Site 3, which was higher in elevation than sites 1 and 2, was not affected by flooding. Site 2, the lowest in elevation and within the floodplain of the Green River, was completely submerged. Site 1 had both plots that were affected by flooding and plots that remained dry during high water. Exploratory analyses were conducted on all data excluding site 2, however results returned no significance and were excluded from this thesis.

Another possible means of disturbance which may have affected the data collected in this study is herbivore browsing. Taverna *et al.* (2005) suggest that increased deer densities may contribute to a loss in vernal herb diversity. Herbivory would create a greater advantage for non-herbaceous plants in all plots, but may have a stronger impact on some treatment plots than on others. However, this study does not factor for the effect of herbivory on vernal herbs and this might be a possible subject of future research.

The difference in fire intensity between spring burns and winter burns might also have had an impact on the results of this study in regards to burn season. Spring burn treatments were conducted with ease, using very little drip torch fuel to ignite fires on assigned plots. However, winter burns were much more difficult. Fire weather conditions thwarted all attempts to conduct winter burns prior to 22 February 2011. More drip torch fuel was needed to ignite plots during winter burns than spring burns and plots burned less evenly, which may have affected the results of this study. Due to wetter conditions, winter burn plots also had a much lower mean burn severity value (mean = 1.17) than plots burned in the spring (mean = 2.50). Lower-severity fires, as used in this study, may lack the intensity to alter available light, moisture, or nutrients to an extent that would cause a change in community structure. Soil properties, such as pH or water permeability, were also unlikely to have been significantly altered due to the low intensity of fire.

Future Research

Future research on the effect of fire on the vernal herbs of the eastern mesic forest should focus on methods which will factor in repeated burning of different frequencies over a longer period of study. A single year of study may prove to be inadequate to tease out the effects of weak disturbances on species such as vernal herbs. Vernal herbs are usually long-lived and take several years to reach reproductive maturity (Bierzychudek 1982), which might indicate that only long-term studies could expect to determine the true effects of any treatment on herbaceous plant communities.

Burning historically occurred under a variety of climactic conditions, which may be a factor in current loss of understory diversity (McEwan *et al.* 2007). The current management practice in Kentucky is the use of fire almost exclusively in the spring, when conditions exist that result in low-intensity fires which are easy to control. However, previous research indicates that single low- to moderate-intensity prescribed fires, conducted in late winter to early spring, do very little to alter future wildfire risks in Appalachian hardwood forests (Loucks *et al.* 2008). Prior to European settlement, fire in the eastern mesic forest might have been much more common in the summer season, when dry conditions would have allowed for easy ignition and farther-reaching fires (Guyette *et al.* 2003).

Research on the effect of fire on the vernal herbs should seek to understand the effects of fires of differing intensities on herbaceous understories. Studies show that fires which fail to alter the canopy or the midstory may act as a selection agent for more competitive species in the understory (Alexander *et al.* 2008; Green *et al.* 2010). Higher-intensity burns result in greater gaps in the canopy, which result in increased light in the understory over a longer timeframe (Green *et al.* 2010) and may result in increases in the understory and herbaceous layers (Elliot *et al.* 1999). Studies which seek to learn more about vernal herbs should also seek to gain an understanding of higher-intensity fire's role in the eastern mesic forest.

Management Implications

Fire's ability to increase the abundance of rare vernal herbs in the eastern mesic forest offers land managers affirmation for what has become a common practice in managing forests in eastern North America. The results of this study indicate that a single burning of a forest patch rich in vernal herbs, regardless of whether emergence of spring herbs has yet occurred, will increase the abundance of rare species. This study also indicates that prescribed fires conducted during the winter may benefit rare herb species greater than prescribed fires conducted in the spring. The increased presence of rare herb species should lead to an increase in overall species richness over time. Current land management practice is to prescribe fire to forests occasionally, depending on local factors, to reduce fuel loads in an effort to prevent wildfire. Continuing the current practice of infrequent burning of forests in the eastern US, including at nearby Mammoth Cave National Park, may allow land managers not only continue to accomplish current objectives, but may also lead to an increase in the diversity of vernal herbs in eastern mesic forests

APPENDIX I

Table 2. Chi-square goodness of fit results for species richness.

Source	df	X^2	Sig.
ΔRichness	1	0.154574132	0.9256
ΔRichness*Fire	3	0.236272457	0.9715
ΔRichness*Season	5	0.217970048	0.9989

ΔAbundance = Change in Abundance

Table 3. Plot occurrence count by species.

Species	# Plots 2010	# Plots 2011
Viola sororia sensu lato	34	35
Dentaria laciniata	36	35
Claytonia virginica	33	31
Glechoma hederacea	27	23
Asarum canadense	10	7
Erythronium americanum	30	24
Stellaria pubera	20	19
Ranunculus abortivus	15	11
Dicentra canadensis	13	15
Podophyllum peltatum	7	7
Allium canadense	7	9
Dentaria diphylla	11	8
Galium aparine	19	27
Enemion biternatum	17	11
Corydalis flavula	8	9
Trillium sessile	3	14
Stylophorum digitatum	18	15
Stellaria media	4	12
Urtica dioica	0	12
Erigenea bulbosa	5	0
TOTALS	317	324

Table 4. Plot occurrence count by burn treatment.

Species	# Control 2010	#Burn 2010	#Control 2011	#Burn 2011
V. sororia s. lat.	11	23	12	23
D. laciniata	12	24	11	24
C. virginica	11	22	11	20
G. hederacea	9	18	8	15
A. canadense	3	7	3	4
E. americanum	12	18	9	15
S. pubera	6	14	5	14
R. abortivus	5	10	3	8
D. canadensis	4	9	4	11
P. peltatum	4	3	4	3
A. canadense	2	5	2	7
D. diphylla	3	8	2	6
G. aparine	6	13	11	16
E. biternatum	6	11	4	7
C. flavula	4	4	4	5
T. sessile	1	2	5	9
S. digitatum	5	13	4	11
S. media	1	3	4	8
U. dioica	0	0	4	8
E. bulbosa	2	3	0	0
TOTALS	107	210	110	214

Table 5. Plot occurrence count by burn season.

Species	#Control 2010	#Spring 2010	# Winter 2010	#Control 2011	#Spring 2011	#Winter 2011
V. sororia s. lat.	11	12	11	12	11	12
D. laciniata	12	12	12	11	12	12
C. virginica	11	11	11	11	10	10
G. hederacea	9	8	10	8	7	8
A. canadense	3	5	2	3	2	2
E. americanum	12	9	9	9	8	7
S. pubera	6	6	8	5	7	7
R. abortivus	5	4	6	3	5	3
D. canadensis	4	6	3	4	5	6
P. peltatum	4	1	2	4	1	2
A. canadense	2	3	2	2	3	4
D. diphylla	3	4	2	2	4	2
G. aparine	6	7	6	11	7	9
E. biternatum	6	4	7	4	3	4
C. flavula	4	2	2	4	3	2
T. sessile	1	1	1	5	4	5
S. digitatum	5	7	6	4	5	6
S. media	1	1	2	4	4	4
U. dioica	0	0	0	4	4	4
E. bulbosa	2	2	1	0	0	0
TOTALS	107	105	103	110	105	109

Table 6. Chi-square goodness of fit results for change in presence of rare species.

Source	df	X^2	Sig.
ΔAbundance	1	9.618181818	0.0019
ΔAbundance*Season	3	9.478616886	0.0235
ΔAbundance*Fire	5	12.55501364	0.0279

ΔAbundance = Change in Abundance

Table 7. Plot occurrence count of rare species.

Species	# Plots 2010	# Plots 2011
E. bulbosa	5	0
P. peltatum	7	7
A. canadense	7	9
D. diphylla	11	8
C. flavula	8	9
S. media	4	12
U. dioica	0	12
A. canadense	10	10
T. sessile	3	14
TOTALS	55	81

Table 8. Plot occurrence count of rare species by burn treatment.

Species	# Control 2010	#Burn 2010	#Control 2011	#Burn 2011
E. bulbosa	2	3	0	0
P. peltatum	4	3	4	3
A. canadense	2	5	2	7
D. diphylla	3	8	2	6
C. flavula	4	4	4	5
S. media	1	3	4	8
U. dioica	0	0	4	8
A. canadense	3	7	3	7
T. sessile	1	2	5	9
TOTALS	20	35	28	53

Table 9. Plot occurrence count of rare species by burn season.

Species	#Control 2010	#Spring 2010	# Winter 2010	#Control 2011	#Spring 2011	#Winter 2011
E. bulbosa	2	2	1	0	0	0
P. peltatum	4	1	2	4	1	2
A. canadense	2	3	2	2	3	4
D. diphylla	3	4	4	2	4	2
C. flavula	4	2	2	4	3	2
S. media	1	1	2	4	4	4
U. dioica	0	0	0	4	4	4
A. canadense	3	4	3	3	3	4
T. sessile	1	1	1	5	4	5
TOTALS	20	18	17	28	26	27

Table 10. Chi-square goodness of fit results for change in presence of common species.

Source	df	X²	Sig.
ΔAbundance	1	0.977099237	0.3229
ΔAbundance*Fire	3	0.97896986	0.8063
ΔAbundance *Season	5	1.120959579	0.9522

ΔAbundance = Change in Abundance

Table 11. Plot occurrence count of common species.

Species	# Plots 2010	# Plots 2011
Viola sororia sensu lato	34	35
Claytonia virginica	33	31
Dentaria laciniata	36	35
Galium aparine	19	27
Erythronium americanum	30	24
Glechoma hederacea	27	23
Stellaria pubera	20	19
Enemion biternatum	17	11
Stylophorum digitatum	18	15
Dicentra canadensis	13	15
Ranunculus abortivus	15	11
TOTALS	262	246

Table 12. Plot occurrence count of common species by burn treatment.

Species	# Control 2010	#Burn 2010	#Control 2011	#Burn 2011
V. sororia s. lat.	11	23	12	23
C. virginica	11	22	11	20
D. laciniata	12	24	11	24
G.aparine	6	13	11	16
E. americanum	12	18	9	15
G.hederacea	9	18	8	15
S.pubera	6	14	5	14
E.biternatum	6	11	4	7
S. digitatum	5	13	4	11
D.canadensis	4	9	4	11
R.abortivus	5	10	3	8
TOTALS	87	175	82	164

Table 13. Plot occurrence count of common species by burn season.

Species	#Control 2010	#Spring 2010	# Winter 2010	#Control 2011	#Spring 2011	#Winter 2011
V. sororia s. lat.	11	12	11	12	11	12
C. virginica	11	11	11	11	10	10
D. laciniata	12	12	12	11	12	12
G.aparine	6	7	6	11	7	9
E. americanum	12	9	9	9	8	7
G.hederacea	9	8	10	8	7	8
S.pubera	6	6	8	5	7	7
E.biternatum	6	4	7	4	3	4
S. digitatum	5	7	6	4	5	6
D.canadensis	4	6	3	4	5	6
R.abortivus	5	4	6	3	5	3
TOTALS	87	86	89	82	80	84

Table 14. Chi-square goodness of fit results for change in abundance of *G. hederacea*.

Source	df	X²	Sig.
ΔAbundance	1	0.592592593	0.4414
ΔAbundance*Fire	3	0.611111111	0.8938
ΔAbundance*Season	5	0.888888889	0.9710

ΔAbundance = Change in Abundance

Table 15. Results of Spearman's correlation coefficient for burn severity and abundance of *E. americanum.*

Source	Correlation Coefficient	Sig
Severity	-0.066	0.795

Table 16. Results for Spearman's correlation coefficient for burn severity for *V. sororia* sensu lato.

Source	Correlation Coefficient	Sig
Mean Severity	-0.040	0.854

Table 17. Significance values for chi-square goodness of fit tests for changes in abundance of individual species.

Species	ΔAbundance	ΔAbund/ Burn	ΔAbund/ Season
Claytonia virginica	0.7277	0.9804	0.9992
Dentaria laciniata	0.8676	0.9937	0.9998
E. americanum	0.2733	0.5828	0.8491
Galium aparine	0.0664	0.2264	0.4474
Glechoma hederacea	0.4414	0.8938	0.971
Stellaria pubera	0.8230	0.9071	0.9736
Viola sororia s. lat.	0.8638	0.9962	0.9995

ΔAbundance = Change in Abundance

Table 18. Chi-square goodness of fit results for change in abundance of *Claytonia virginica*.

Source	df	X²	Sig.
ΔAbundance	1	0.121212121	0.7277
ΔAbundance*Fire	3	0.181818182	0.9804
ΔAbundance*Season	5	0.181818182	0.9992

ΔAbundance = Change in Abundance

Table 19. Chi-square goodness of fit results for change in abundance of *Dentaria laciniata.*

Source	df	X²	Sig.
ΔAbundance	1	0.027777778	0.8676
ΔAbundance*Fire	3	0.083333333	0.9937
ΔAbundance*Season	5	0.083333333	0.9998

ΔAbundance = Change in Abundance

Table 20. Chi-square goodness of fit results for change in abundance of *Erythronium americanum.*

Source	df	X²	Sig.
ΔAbundance	1	1.2	0.2733
ΔAbundance*Fire	3	1.95	0.5828
ΔAbundance*Season	5	2	0.8491

ΔAbundance = Change in Abundance

Table 21. Chi-square goodness of fit results for change in abundance of *Galium aparine.*

Source	df	X²	Sig.
ΔAbundance	1	3.368421053	0.0664
ΔAbundance*Fire	3	4.346331908	0.2264
ΔAbundance*Season	5	4.747772512	0.4474

ΔAbundance = Change in Abundance

Table 22. Chi-square goodness of fit results for change in abundance of *Stellaria pubera.*

Source	df	X²	Sig.
ΔAbundance	1	0.05	0.8230
ΔAbundance*Fire	3	0.552779124	0.9071
ΔAbundance*Season	5	0.850584708	0.9736

ΔAbundance = Change in Abundance

Table 23. Chi-square goodness of fit results for change in abundance of *Viola sororia* sensu lato.

Source	df	X²	Sig.
ΔAbundance	1	0.029411765	0.8638
ΔAbundance*Fire	1	0.058839538	0.9962
ΔAbundance *Season	2	0.147696381	0.9995

ΔAbundance = Change in Abundance

Table 24. Burn severity data (control plots excluded).

Plot Number	Site	Rep	Plot	Scorch Height	Coded
209-U	1	1	1	UB	1
209-D	1	1	1	UB	1
210-U	1	1	2	UB	1
210-D	1	1	2	7.50 cm	2
212-U	1	2	1	11.20 cm	2
212-D	1	2	1	9.00 cm	2
213-U	1	2	2	41.00 cm	3
213-D	1	2	2	8.00 cm	2
216-U	1	3	2	UB	1
216-D	1	3	2	18.00 cm	2
217-U	1	3	3	UB	1
217-D	1	3	3	UB	1
219-U	1	4	2	13.00 cm	2
219-D	1	4	2	UB	1
220-U	1	4	3	87.00 cm	5
220-D	1	4	3	X	5
222-U	2	1	2	UB	1
222-D	2	1	2	6.00 cm	2
223-U	2	1	3	UB	1
223-D	2	1	3	UB	1
225-U	2	2	2	UB	1
225-D	2	2	2	UB	1
226-U	2	2	3	UB	1
226-D	2	2	3	7.50 cm	2
227-U	2	3	1	UB	1
227-D	2	3	1	12.00 cm	2
229-U	2	3	3	UB	1
229-D	2	3	3	8.80 cm	2
230-U	2	4	1	X	5
230-D	2	4	1	UB	1
231-U	2	4	2	UB	1
231-D	2	4	2	UB	1
234-U	3	1	2	UB	1
234-D	3	1	2	UB	1
235-U	3	1	3	UB	1
235-D	3	1	3	UB	1
236-U	3	2	1	X	5
236-D	3	2	1	X	5
237-U	3	2	2	UB	1
237-D	3	2	2	UB	1
239-U	3	3	1	UB	1
239-D	3	3	1	UB	1
241-U	3	3	3	UB	1
241-D	3	3	3	UB	1
243-U	3	4	2	UB	1
243-D	3	4	2	UB	1
244-U	3	4	3	87.00 cm	5
244-D	3	4	3	67.00 cm	5

Table 25. Results for Lilliefors test for normality

	Statistic	df	Sig.
Species 2010	.121	36	.200
Species 2011	.164	36	.016

Table 26. Results for Lilliefors test for normality on transformed data

	Statistic	df	Sig.
Trans_Species 2010	.106	36	.200
Trans_Species 2011	.173	36	.008

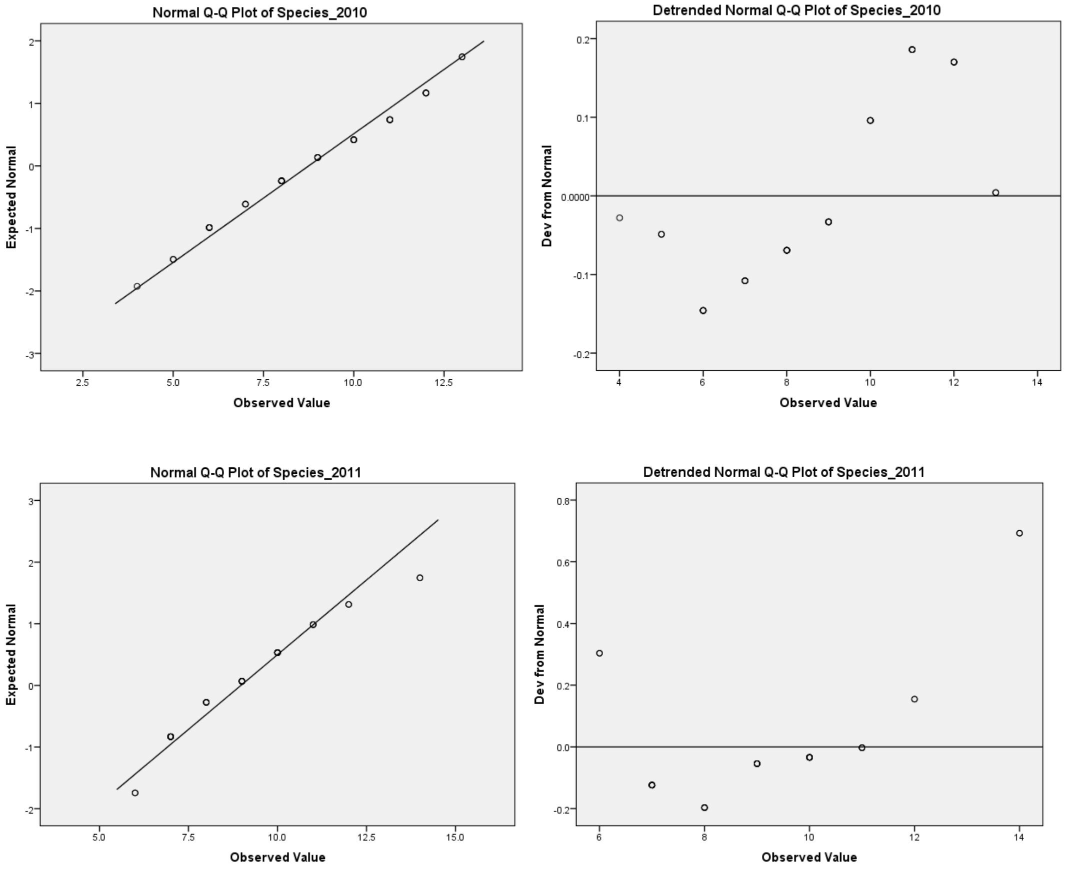

Figure 3. Diagnostic plots to check the validity of the assumptions made by repeated measures ANOVA testing for the dependent variable species richness when compared to the variables sites, burn, and burn season.

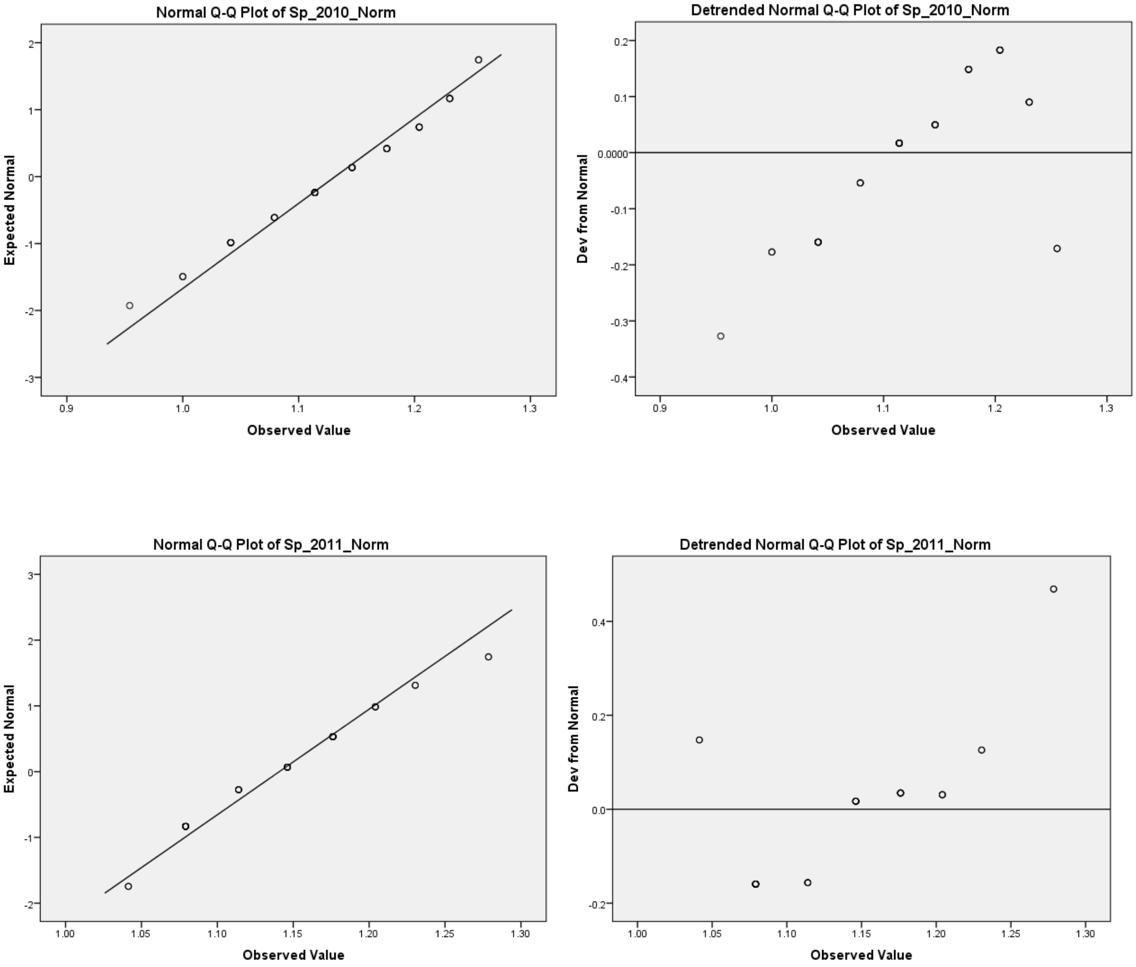

Figure 4. Diagnostic plots to check the validity of the assumptions made by repeated measures ANOVA testing for the dependent variable species richness (log transformed) when compared to the variables sites, burn, and burn season.

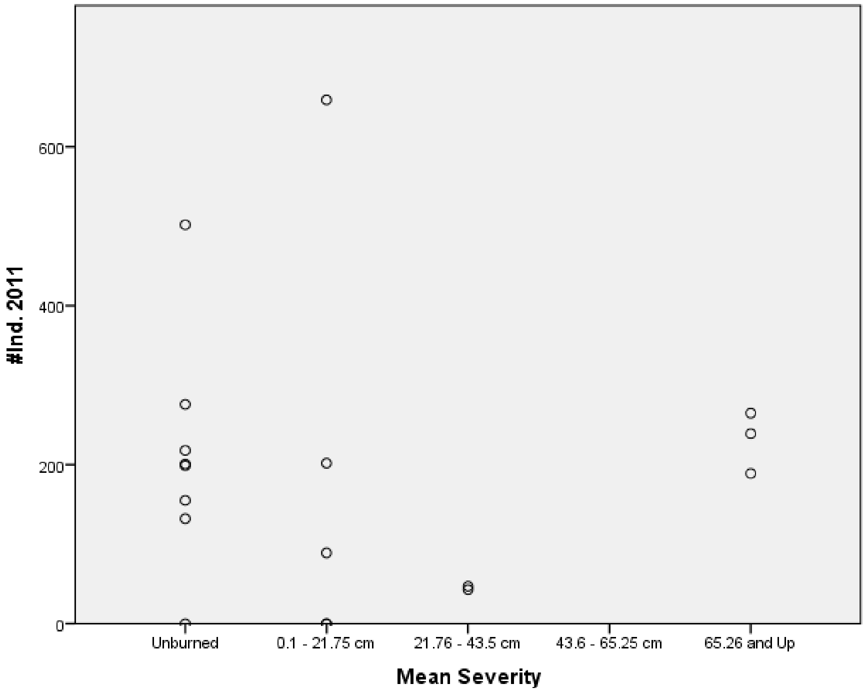

Figure 5. Scatter plot for burn severity and abundance of *Erythronium americanum*.

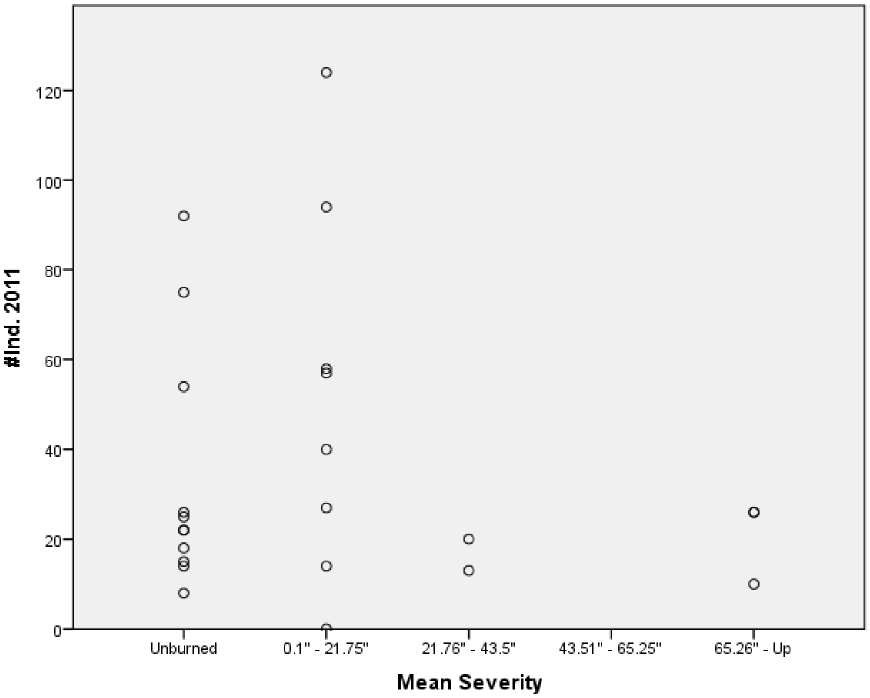

Figure 6. Scatter plot for burn severity and abundance of *Viola sororia* sensu lato.

APPENDIX II

Table 27. Mean number of species per plot by burn season, with standard errors.

Source	Winter Yr1	SE Winter – Yr1	Spring – Yr1	SE Spring - Yr1	Control – Yr1	SE Control – Yr1	Total – Yr1	SE Total – Yr1	Winter – Yr2	SE Winter – Yr2	Spring – Yr2	SE Spring – Yr2	Control – Yr2	SE Control – Yr2	Total – Yr2	SE Total – Yr2
Species/ Site1	8.2	0.3	7.5	0.6	8.3	1.4	8.0	0.5	8.8	0.8	7.0	0.7	7.8	0.5	7.8	0.4
Species/ Site2	10.7	0.6	11.5	0.9	11.5	0.6	11.3	0.4	10.3	0.3	11.3	0.9	11.6	1.3	11.0	0.5
Species/ Site3	7.0	1.3	7.0	0.6	7.0	1.1	7.0	0.5	8.3	0.9	8.0	0.6	8.0	0.6	8.1	0.4
Overall Species	8.6	0.6	8.7	0.7	8.9	0.8	8.8	0.4	9.1	0.5	8.8	0.7	9.1	0.7	9.0	0.3

Table 28. Mean number of species per plot by burn treatment, with standard errors.

Source	Burn - Yr1	SE Burn - Yr1	Control - Yr1	SE Control – Yr1	Total - Yr1	SE Total – Yr1	Burn - Yr2	SE Burn – Yr2	Control - Yr2	SE Control – Yr2	Total - Yr2	SE total – Yr2
Species/Site1	7.9	0.4	8.3	1.0	8.0	0.5	7.9	0.6	7.8	0.5	7.8	0.4
Species/Site2	11.1	0.5	11.5	0.5	11.3	0.4	10.8	0.5	11.5	1.3	11.0	0.5
Species/Site3	7.0	0.7	7.0	0.8	7.0	0.5	8.1	0.5	8.0	0.6	8.1	0.4
Overall Species	8.7	0.5	8.9	0.8	8.8	0.4	8.9	0.4	9.1	0.7	9.0	0.3

Table 29. Mean number of individuals per plot by burn season, with standard errors.

Source	Winter Yr1	SE Winter – Yr1	Spring – Yr1	SE Spring - Yr1	Control – Yr1	SE Control – Yr1	Total – Yr1	SE Total – Yr1	Winter – Yr2	SE Winter – Yr2	Spring – Yr2	SE Spring – Yr2	Control – Yr2	SE Control – Yr2	Total – Yr2	SE Total – Yr2
Individuals/ Site1	57.2	11.2	52.4	12.5	48.5	11.4	52.8	6.5	124.8	25.8	86.3	20.3	110.5	23.7	107.9	13.6
Individuals/ Site2	100.4	28.1	58.3	12.8	80.5	18.3	78.7	11.5	60.6	14.8	47.2	11.7	69.9	14.7	59.0	7.9
Individuals/ Site3	52.6	14.1	56.7	14.3	50.3	13.7	53.2	8.0	71.4	16.6	59.2	12.2	54.4	13.7	61.8	8.2
Total Abundance	73.6	12.7	56.4	7.8	63.3	9.5	64.3	5.9	82.9	11.1	60.6	8.4	77.0	10.2	73.5	5.7

Table 30. Mean number of individuals per plot by burn treatment, with standard errors.

Source	Burn - Yr1	SE Burn - Yr1	Control - Yr1	SE Control – Yr1	Total - Yr1	SE Total – Yr1	Burn - Yr2	SE Burn – Yr2	Control - Yr2	SE Control – Yr2	Total - Yr2	SE total – Yr2
Individuals/Site1	55.0	8.3	48.5	10.2	52.8	6.5	106.6	16.7	110.5	23.7	107.9	13.6
Individuals/Site2	77.7	14.7	80.5	18.3	78.7	11.5	53.3	9.3	69.9	14.7	59.0	7.9
Individuals/Site3	54.6	10.0	50.3	13.7	53.2	8.0	65.4	10.4	54.4	13.7	61.8	8.2
Total Abundance	64.9	7.4	63.3	9.5	64.3	5.9	71.7	7.0	77.0	10.2	73.5	5.7

Table 31. Mean number of rare individuals per plot by burn season, with standard errors.

Source	Winter Yr1	SE Winter – Yr1	Spring – Yr1	SE Spring - Yr1	Control – Yr1	SE Control – Yr1	Total – Yr1	SE Total – Yr1	Winter – Yr2	SE Winter – Yr2	Spring – Yr2	SE Spring – Yr2	Control – Yr2	SE Control – Yr2	Total – Yr2	SE Total – Yr2
Individuals/Site1	7.5	4.5	10.8	6.0	5.3	1.6	7.3	2.0	6.3	5.0	0.3	0.3	1.1	0.7	2.3	1.4
Individuals/Site2	20.7	8.6	13.6	5.4	25.4	12.1	19.8	5.4	50.3	17.0	44.8	18.2	50.3	14.5	45.7	9.5
Individuals/Site3	4.0	3.6	5.8	5.6	2.6	2.2	3.9	2.0	8.2	2.4	11.8	4.5	8.8	3.2	9.4	1.9
Total Abundance	13.7	5.0	11.7	3.8	15.6	6.8	13.8	3.3	30.8	10.2	32.1	12.6	26.0	8.5	29.3	6.0

Table 32. Mean number of rare individuals per plot by burn treatment, with standard errors.

Source	Burn - Yr1	SE Burn - Yr1	Control - Yr1	SE Control – Yr1	Total - Yr1	SE Total – Yr1	Burn - Yr2	SE Burn – Yr2	Control - Yr2	SE Control – Yr2	Total - Yr2	SE total – Yr2
Individuals/Site1	9.1	3.5	5.3	1.6	7.3	2.0	3.3	2.6	1.1	0.7	2.3	1.4
Individuals/Site2	16.4	4.7	25.4	12.1	19.8	5.4	47.0	12.7	43.3	14.5	45.7	9.5
Individuals/Site3	4.8	3.0	2.6	2.2	3.9	2.0	9.8	2.4	8.8	3.2	9.4	1.9
Total Abundance	12.6	3.0	15.6	6.8	13.8	3.3	31.5	8.2	26.0	8.5	29.3	6.0

Table 33. Mean number of common individuals per plot by burn season, with standard errors.

Source	Winter Yr1	SE Winter – Yr1	Spring – Yr1	SE Spring - Yr1	Control – Yr1	SE Control – Yr1	Total – Yr1	SE Total – Yr1	Winter – Yr2	SE Winter – Yr2	Spring – Yr2	SE Spring – Yr2	Control – Yr2	SE Control – Yr2	Total – Yr2	SE Total – Yr2
Individuals/Site1	63.1	12.2	58.0	13.9	58.6	11.9	60.0	7.2	138.7	27.9	97.7	22.2	136.0	27.3	124.8	15.1
Individuals/Site2	124.4	35.7	77.1	17.4	104.7	24.9	101.5	15.4	63.7	18.6	48.1	14.9	81.5	20.0	64.2	10.3
Individuals/Site3	62.0	16.3	65.2	16.2	63.9	16.8	63.7	9.4	83.6	19.1	67.1	13.7	67.5	16.8	73.0	9.6
Total Abundance	86.1	15.1	68.1	9.5	79.2	12.0	77.8	7.2	93.9	13.1	68.1	9.9	94.0	12.8	85.3	7.0

Table 34. Mean number of common individuals per plot by burn treatment, with standard errors.

Source	Burn - Yr1	SE Burn - Yr1	Control - Yr1	SE Control – Yr1	Total - Yr1	SE Total – Yr1	Burn - Yr2	SE Burn – Yr2	Control - Yr2	SE Control – Yr2	Total - Yr2	SE total – Yr2
Individuals/Site1	60.7	9.1	58.6	11.9	60.0	7.2	119.5	18.2	136.0	23.3	124.8	15.1
Individuals/Site2	99.9	19.4	104.7	24.9	101.5	15.4	55.6	11.8	81.5	20.0	64.2	10.3
Individuals/Site3	63.6	11.4	63.9	16.8	63.7	9.4	75.5	11.8	67.5	16.8	73.0	9.6
Total Abundance	77.2	9.0	79.2	12.0	77.8	7.2	81.1	8.3	94.0	12.8	85.3	7.0

Table 35. Mean number of *Glechoma hederacea* individuals per plot by burn season, with standard errors.

Source	Winter Yr1	SE Winter – Yr1	Spring – Yr1	SE Spring - Yr1	Control – Yr1	SE Control – Yr1	Total – Yr1	SE Total – Yr1	Winter – Yr2	SE Winter – Yr2	Spring – Yr2	SE Spring – Yr2	Control – Yr2	SE Control – Yr2	Total – Yr2	SE Total – Yr2
Abundance/Site1	62.0	27.7	34.8	18.8	29.3	14.6	42.0	11.8	38.0	30.2	24.3	17.3	20.3	10.3	27.5	11.2
Abundance/Site2	40.0	15.5	65.8	18.8	125.0	54.9	76.9	21.1	71.3	22.5	100.5	69.9	71.3	49.7	117.1	30.1
Abundance/Site3	7.5	5.5	0.0	0.0	4.0	0.0	6.3	3.4	16.0	16.0	0.0	0.0	15.0	0.0	15.7	9.3
Total Abundance	42.3	13.4	50.3	13.6	69.0	29.3	53.6	29.3	46.9	15.7	62.4	36.3	90.4	35.0	66.0	16.6

Table 36. Mean number of *Glechoma hederacea* individuals per plot by burn treatment, with standard errors.

Source	Burn - Yr1	SE Burn - Yr1	Control - Yr1	SE Control – Yr1	Total - Yr1	SE Total – Yr1	Burn - Yr2	SE Burn – Yr2	Control - Yr2	SE Control – Yr2	Total - Yr2	SE total – Yr2
Individuals/Site1	48.4	16.3	29.3	14.6	42.0	11.8	31.1	16.3	20.3	10.3	27.5	11.2
Individuals/Site2	52.9	12.3	125.0	54.9	76.9	21.1	85.9	34.5	179.5	49.7	117.1	30.1
Individuals/Site3	7.5	5.5	4.0	0.0	6.3	3.4	16.0	16.0	15.0	0.0	15.7	9.2
Total Abundance	45.8	9.4	69.0	29.3	53.6	11.4	53.8	17.8	90.4	35.0	66.0	16.6

Table 37. Mean number of *Viola sororia* sensu lato individuals per plot by burn season, with standard errors.

Source	Winter Yr1	SE Winter – Yr1	Spring – Yr1	SE Spring - Yr1	Control – Yr1	SE Control – Yr1	Total – Yr1	SE Total – Yr1	Winter – Yr2	SE Winter – Yr2	Spring – Yr2	SE Spring – Yr2	Control – Yr2	SE Control – Yr2	Total – Yr2	SE Total – Yr2
Abundance/Site1	27.2	6.0	32.5	10.1	37.8	10.8	32.1	4.8	52.2	10.2	34.3	9.6	65.8	17.8	50.9	7.6
Abundance/Site2	81.5	24.4	80.3	32.2	86.3	17.6	82.7	13.3	59.3	19.5	42.8	27.7	73.5	20.4	58.5	12.5
Abundance/Site3	8.8	6.8	21.0	13.2	3.0	1.5	10.9	5.0	16.8	3.4	17.0	3.4	7.5	2.2	13.8	2.1
Total Abundance	38.2	11.3	44.6	13.4	42.3	12.0	41.6	6.9	43.5	8.4	31.3	9.5	48.9	12.1	41.3	5.7

Table 38. Mean number of *Viola sororia* sensu lato individuals per plot by burn treatment, with standard errors.

Source	Burn - Yr1	SE Burn - Yr1	Control - Yr1	SE Control – Yr1	Total - Yr1	SE Total – Yr1	Burn - Yr2	SE Burn – Yr2	Control - Yr2	SE Control – Yr2	Total - Yr2	SE total – Yr2
Individuals/Site1	29.6	5.3	37.8	10.8	32.1	4.8	44.2	7.4	65.8	17.8	50.9	7.6
Individuals/Site2	80.9	18.7	86.3	17.6	82.7	13.3	51.0	16.0	73.5	20.4	58.5	12.5
Individuals/Site3	14.9	7.3	3.0	1.5	10.9	5.0	16.9	2.2	7.5	2.2	13.8	2.1
Total Abundance	41.3	8.6	42.3	12.0	41.6	6.9	37.6	6.3	48.9	12.1	41.3	5.7

Table 39. Mean number of *Claytonia virginica* individuals per plot by burn season, with standard errors.

Source	Winter Yr1	SE Winter – Yr1	Spring – Yr1	SE Spring - Yr1	Control – Yr1	SE Control – Yr1	Total – Yr1	SE Total – Yr1	Winter – Yr2	SE Winter – Yr2	Spring – Yr2	SE Spring – Yr2	Control – Yr2	SE Control – Yr2	Total – Yr2	SE Total – Yr2
Abundance/Site1	66.0	15.1	64.8	12.2	62.0	13.6	64.3	8.0	206.5	15.0	169.0	11.1	199.8	15.9	191.8	8.9
Abundance/Site2	192.5	48.0	166.3	31.3	167.8	21.3	175.5	18.8	6.5	3.8	20.5	15.4	15.8	8.3	14.3	5.7
Abundance/Site3	18.8	11.1	29.8	16.0	12.5	4.2	20.3	6.4	66.0	2.5	112.8	22.0	47.5	15.3	75.4	11.6
Total Abundance	92.4	27.0	86.9	20.8	80.8	21.0	86.7	13.0	93.0	25.7	100.8	20.4	87.7	25.2	93.8	13.4

Table 40. Mean number of *Claytonia virginica* individuals per plot by burn treatment, with standard errors.

Source	Burn - Yr1	SE Burn - Yr1	Control - Yr1	SE Control – Yr1	Total - Yr1	SE Total – Yr1	Burn - Yr2	SE Burn – Yr2	Control - Yr2	SE Control – Yr2	Total - Yr2	SE total – Yr2
Individuals/Site1	65.4	9.0	62.0	13.6	64.3	7.1	187.8	11.2	199.8	15.9	191.8	8.9
Individuals/Site2	179.4	27.0	167.8	21.3	175.5	18.8	13.5	7.8	15.8	8.3	14.3	5.7
Individuals/Site3	24.3	9.3	12.5	4.2	20.3	6.4	89.4	13.5	47.5	15.3	75.4	11.6
Total Abundance	89.7	16.7	80.8	21.0	86.7	13.0	96.9	16.1	87.7	25.2	93.8	13.4

Table 41. Mean number of *Dentaria laciniata* individuals per plot by burn season, with standard errors.

Source	Winter Yr1	SE Winter – Yr1	Spring – Yr1	SE Spring - Yr1	Control – Yr1	SE Control – Yr1	Total – Yr1	SE Total – Yr1	Winter – Yr2	SE Winter – Yr2	Spring – Yr2	SE Spring – Yr2	Control – Yr2	SE Control – Yr2	Total – Yr2	SE Total – Yr2
Abundance/Site1	143.5	34.0	196.3	35.6	153.5	31.7	164.4	18.9	291.3	40.0	333.5	54.7	302.8	34.7	309.2	23.6
Abundance/Site2	50.5	18.3	70.3	16.9	61.5	28.6	60.8	11.7	8.3	2.9	30.5	10.0	31.5	19.2	23.4	7.3
Abundance/Site3	122.0	31.8	179.5	50.0	194.8	34.4	165.4	22.7	109.0	42.2	119.8	27.7	134.0	39.6	120.9	19.6
Total Abundance	105.3	19.3	148.7	25.5	136.6	23.6	130.2	13.2	136.2	39.4	161.3	42.7	156.1	37.7	151.2	22.5

Table 42. Mean number of *Dentaria laciniata* individuals per plot by burn treatment, with standard errors.

Source	Burn - Yr1	SE Burn - Yr1	Control - Yr1	SE Control – Yr1	Total - Yr1	SE Total – Yr1	Burn - Yr2	SE Burn – Yr2	Control - Yr2	SE Control – Yr2	Total - Yr2	SE total – Yr2
Individuals/Site1	169.9	24.9	153.5	31.7	164.4	18.9	312.4	32.4	302.8	34.7	309.2	23.6
Individuals/Site2	60.4	12.1	61.5	28.6	60.8	11.7	19.4	6.4	31.5	19.2	23.4	7.3
Individuals/Site3	150.8	29.5	194.8	34.4	165.4	22.7	114.4	23.4	134.0	39.6	120.9	19.6
Total Abundance	127.0	16.3	136.6	23.6	130.2	13.2	148.7	28.5	156.1	37.7	151.2	22.5

Table 43. Mean number of *Galium aparine* individuals per plot by burn season, with standard errors.

Source	Winter Yr1	SE Winter – Yr1	Spring – Yr1	SE Spring - Yr1	Control – Yr1	SE Control – Yr1	Total – Yr1	SE Total – Yr1	Winter – Yr2	SE Winter – Yr2	Spring – Yr2	SE Spring – Yr2	Control – Yr2	SE Control – Yr2	Total – Yr2	SE Total – Yr2
Abundance/Site1	2.5	2.5	0.0	0.0	0.0	0.0	0.7	0.7	1.0	0.0	2.0	0.0	3.0	1.0	2.1	0.5
Abundance/Site2	29.8	8.1	31.5	10.7	16.3	6.3	25.8	4.9	7.3	3.2	2.3	1.7	1.3	0.9	3.6	1.4
Abundance/Site3	0.3	0.3	1.0	0.4	2.5	2.2	1.3	0.7	3.3	1.6	3.3	2.0	5.0	2.1	3.8	1.0
Total Abundance	12.5	5.6	13.0	6.4	6.8	3.2	10.7	2.9	4.4	1.5	2.6	1.0	3.1	0.9	3.4	0.7

Table 44. Mean number of *Galium aparine* individuals per plot by burn treatment, with standard errors.

Source	Burn - Yr1	SE Burn - Yr1	Control - Yr1	SE Control – Yr1	Total - Yr1	SE Total – Yr1	Burn - Yr2	SE Burn – Yr2	Control - Yr2	SE Control – Yr2	Total - Yr2	SE total – Yr2
Individuals/Site1	1.3	1.3	0.0	0.0	0.7	0.7	1.5	0.3	3.0	1.0	2.1	0.5
Individuals/Site2	30.6	6.2	16.3	6.3	25.8	4.9	4.8	1.9	1.3	0.9	3.6	1.4
Individuals/Site3	0.6	0.3	2.5	2.2	1.3	0.7	3.3	1.2	5.0	2.1	3.8	1.0
Total Abundance	12.8	4.1	6.8	3.2	10.7	2.9	3.5	0.9	3.1	0.9	3.4	0.7

Table 45. Mean number of *Erythronium americanum* individuals per plot by burn season, with standard errors.

Source	Winter Yr1	SE Winter – Yr1	Spring – Yr1	SE Spring - Yr1	Control – Yr1	SE Control – Yr1	Total – Yr1	SE Total – Yr1	Winter – Yr2	SE Winter – Yr2	Spring – Yr2	SE Spring – Yr2	Control – Yr2	SE Control – Yr2	Total – Yr2	SE Total – Yr2
Abundance/Site1	144.0	36.6	34.7	19.2	52.5	28.3	74.6	21.4	454.3	134.0	133.7	66.8	205.5	130.7	258.6	75.5
Abundance/Site2	24.0	3.9	28.0	25.0	8.3	2.9	17.1	6.0	0.0	0.0	21.5	21.5	1.5	1.5	6.1	5.3
Abundance/Site3	116.5	27.0	209.0	14.9	92.8	18.8	139.4	18.6	206.3	29.7	196.0	17.3	138.8	60.4	180.3	22.8
Total Abundance	105.1	22.1	110.7	32.4	51.2	14.7	85.2	13.7	243.1	72.3	136.4	31.6	115.3	50.4	160.0	31.7

Table 46. Mean number of *Erythronium americanum* individuals per plot by burn treatment, with standard errors.

Source	Burn - Yr1	SE Burn - Yr1	Control - Yr1	SE Control – Yr1	Total - Yr1	SE Total – Yr1	Burn - Yr2	SE Burn – Yr2	Control - Yr2	SE Control – Yr2	Total - Yr2	SE total – Yr2
Individuals/Site1	89.3	30.7	52.5	28.3	74.6	21.4	294.0	98.1	205.5	130.8	258.6	75.5
Individuals/Site2	8.3	10.4	26.0	2.9	17.1	6.0	10.8	10.8	1.5	1.5	6.1	5.3
Individuals/Site3	92.8	22.6	162.8	18.8	139.4	18.9	201.1	16.0	138.8	60.4	180.3	22.8
Total Abundance	51.2	19.0	107.9	14.6	85.2	13.7	189.8	40.4	115.3	50.4	160.0	31.7

Table 47. Mean number of *Stellaria pubera* individuals per plot by burn season, with standard errors.

Source	Winter Yr1	SE Winter – Yr1	Spring – Yr1	SE Spring - Yr1	Control – Yr1	SE Control – Yr1	Total – Yr1	SE Total – Yr1	Winter – Yr2	SE Winter – Yr2	Spring – Yr2	SE Spring – Yr2	Control – Yr2	SE Control – Yr2	Total – Yr2	SE Total – Yr2
Abundance/Site1	146.0	59.8	86.3	77.0	182.0	30.0	132.6	35.5	246.7	83.3	16.3	6.3	332.5	109.5	181.8	60.7
Abundance/Site2	67.0	38.6	44.5	21.2	97.5	29.3	69.7	17.2	17.8	5.5	17.8	7.4	79.5	40.2	38.3	15.2
Abundance/Site3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0
Total Abundance	100.9	34.5	54.6	29.1	125.7	26.8	90.3	18.1	163.8	56.0	15.6	4.3	115.9	65.5	91.4	28.6

Table 48. Mean number of *Stellaria pubera* individuals per plot by burn treatment, with standard errors.

Source	Burn - Yr1	SE Burn - Yr1	Control - Yr1	SE Control – Yr1	Total - Yr1	SE Total – Yr1	Burn - Yr2	SE Burn – Yr2	Control - Yr2	SE Control – Yr2	Total - Yr2	SE total – Yr2
Individuals/Site1	116.2	45.6	182.0	30.0	132.6	35.5	131.5	63.6	332.5	109.5	181.8	60.7
Individuals/Site2	55.8	20.8	97.5	29.3	69.7	17.2	17.8	4.3	79.5	40.2	38.3	15.2
Individuals/Site3	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	5.0	0.0
Total Abundance	76.2	22.4	125.7	26.8	90.3	18.1	62.4	28.5	163.8	65.5	91.4	28.6

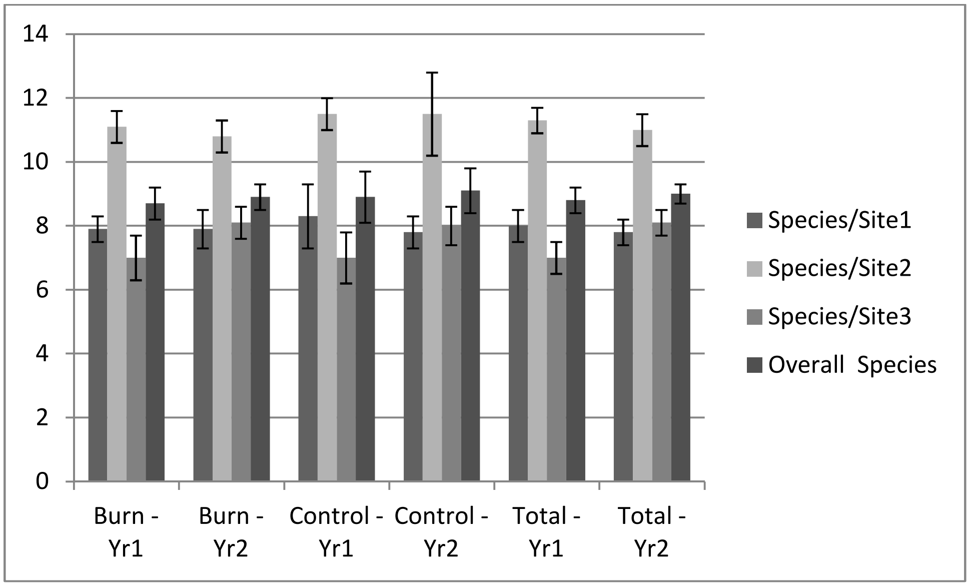

Figure 7. Mean number of species per plot by burn treatment.

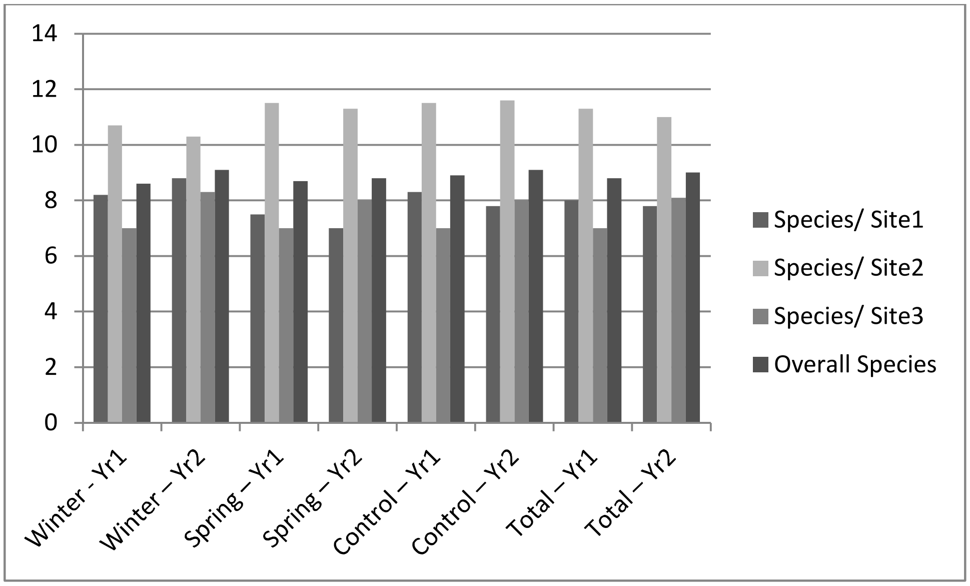

Figure 8. Mean number of species per plot by burn season.

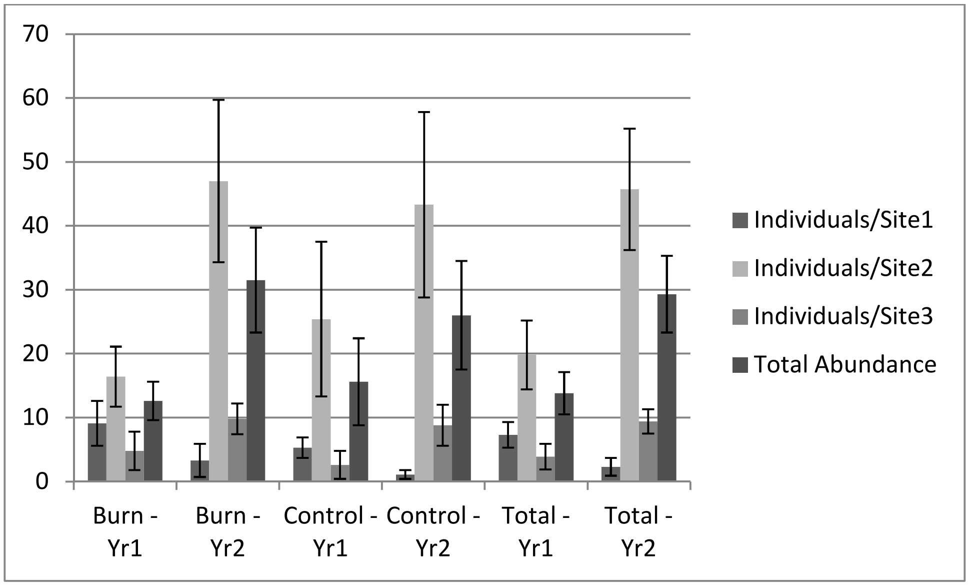

Figure 9. Mean number of rare individuals per plot by burn treatment.

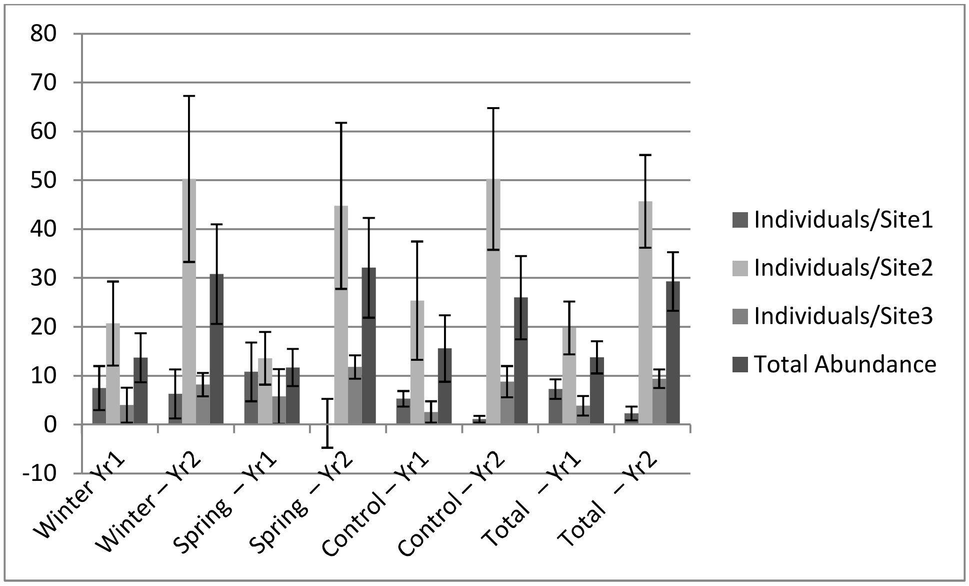

Figure 10. Mean number of rare individuals per plot by burn season.

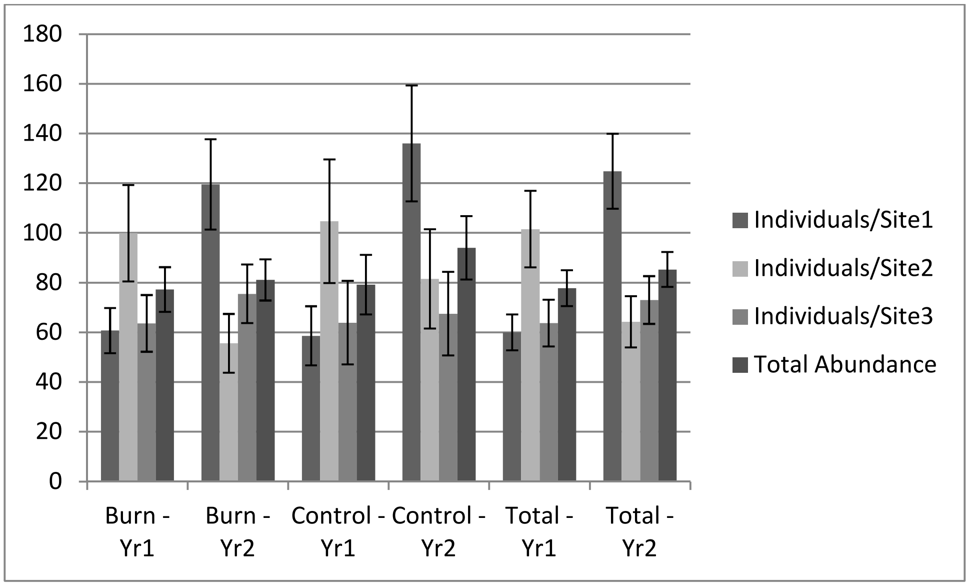

Figure 11. Mean number of common individuals per plot by burn treatment.

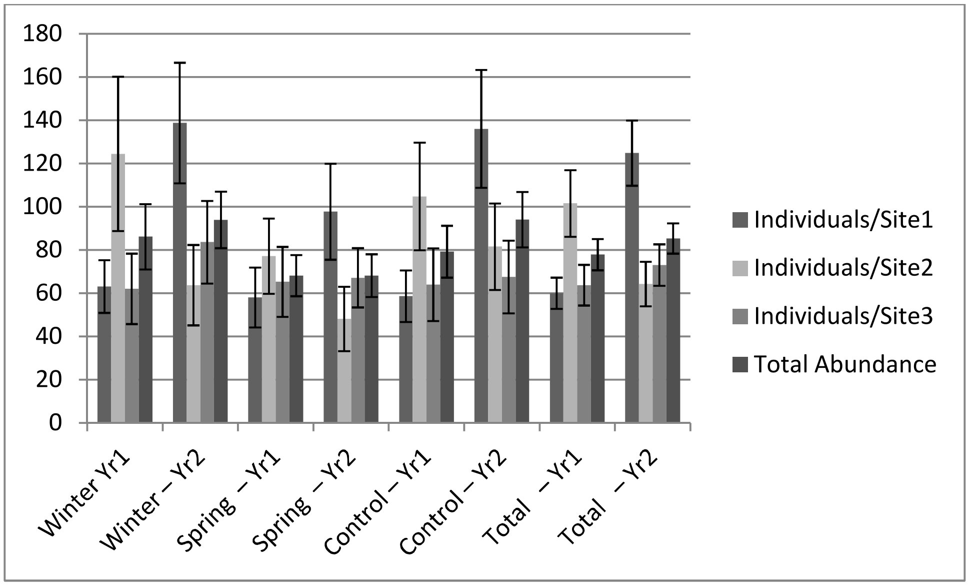

Figure 12. Mean number of common individuals per plot by burn season.

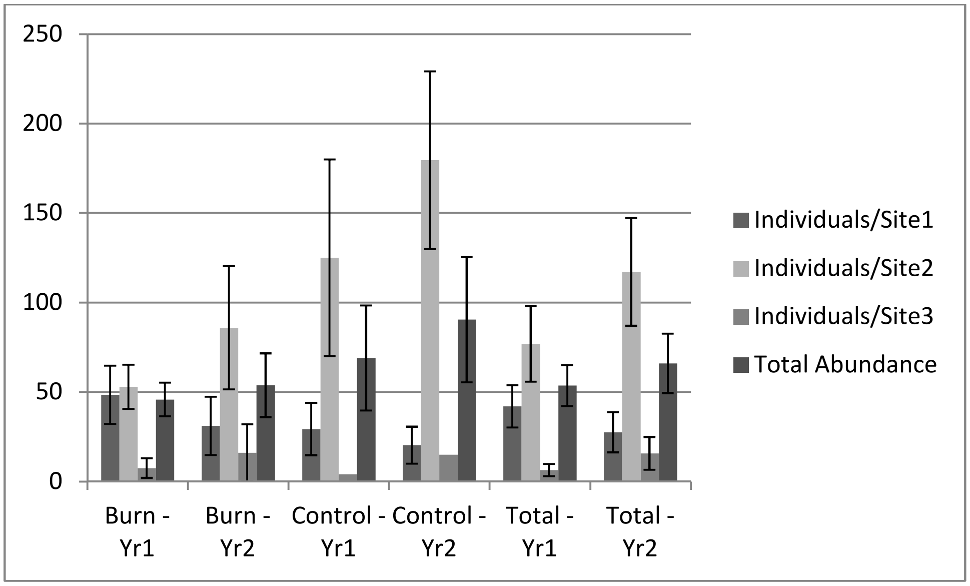

Figure 13. Mean number of *G. hederacea* individuals per plot by burn treatment.

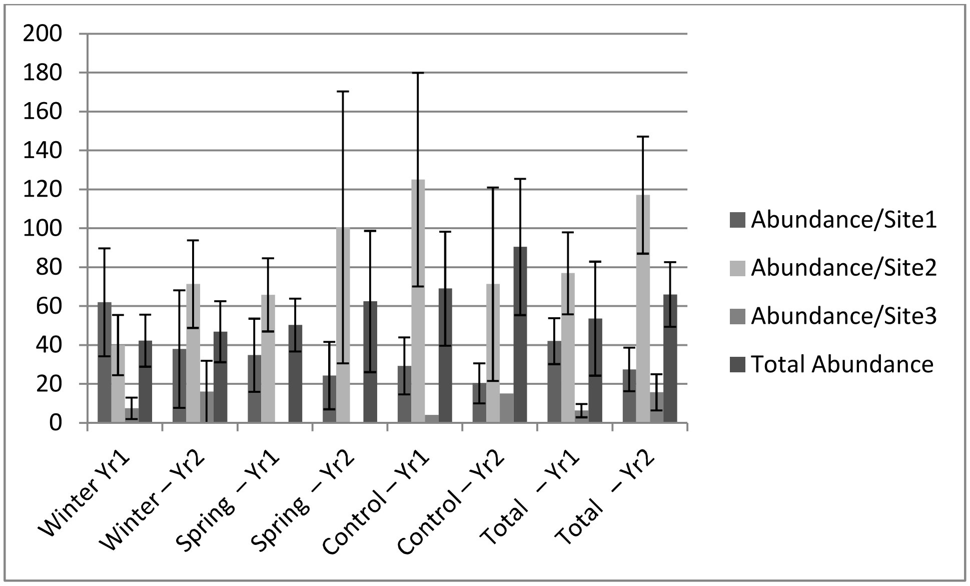

Figure 14. Mean number of *G. hederacea* individuals per plot by burn season.

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