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Prescribed Fire Effects on the Summer and Fall Herbs of Mesic Deciduous Forests

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PRESCRIBED FIRE EFFECTS ON THE SUMMER AND FALL HERBS OF MESIC DECIDUOUS FORESTS

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By

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ABSTRACT

After years of fire suppression, high intensity forest fires were destructive to surrounding areas. Historically, fire was common in the eastern United States, but was suppressed over the past century, and recently has become a major tool in forest management. But to date, there have been no studies on the influence of fire on mesic sites in the eastern United States. Because fire is being reintroduced as a management practice, it is critical to know the influence of fire in this region. This study seeks to understand the influences of fire on summer and fall herbs in the western mesophytic forest region. Data were collected from 24 plots in three sites at the WKU Upper Green River Biological Preserve, Hart County, Kentucky. Plot treatments were either spring burn or unburned. Two-way ANOVA tests compared species richness, presence of rare and common species, and the density of five individual species in burned and unburned plots. Overall, a spring prescribed fire had little to no effect on summer and fall herbs in study sites. However, two individual species in the fall were significantly influenced by fire, *Hydrophyllum canadense,* or bluntleaf waterleaf, a native herb to Kentucky, and *Glechoma hederacea,* or ground ivy an herb invasive to Kentucky*.* Each was negatively influenced by burning.

Keywords: Prescribed Fire, Forest Herbs, Western Mesophytic Forest, Species Richness, Mesic

Dedicated to my family and all those who love nature like I do.

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CHAPTER 1

INTRODUCTION

Herbaceous Layer

Temperate deciduous forests are one of the major biomes on earth and are found in regions of intermediate temperature, precipitation, and latitude. Deciduous forests are bordered by biomes which have more extreme climate characteristics, such as higher or lower temperatures and increased or decreased rainfall. These forests are found many places including eastern North America (Hutchinson et al., 2004). Throughout the temperate deciduous forests of eastern North America, herbaceous understory plants account for less than five percent of above-ground net primary productivity (Small and McCarthy, 2002a). However, herbaceous plants are an important part of mature, healthy forests playing roles in processes such as nutrient cycling and energy flow. The life histories and interaction of herbaceous plants with site and environment can influence nutrient cycling within the forest ecosystem. Forest ecosystems exhibit differences in growth in response to nutrient availability. The concentrations of nutrients change temporally and spatially throughout a forest. Herbaceous plants and woody plants show distinct differences in embodied nutrient concentrations, suggesting that position in canopy may be important in mineral nutrition and, therefore, ecosystem relations. The foliage of herbaceous plants contains higher nutrient concentrations, such as potassium and magnesium, than do woody plants. Also, summer green herbs show higher concentrations of calcium than vernal herbs and woody plants. Seasonal variation in nutrient concentrations suggests that plants absorb high levels of nutrients when availability is great, and then use re-translocation during times of lower availability (Muller, in Gilliam and Roberts, 2003). In addition to contributing greatly to nutrient cycling and energy flow, herbs constitute the majority of diversity of plants in the mature eastern deciduous forest (Hutchinson et al., 2004).

Three main limiting factors for many herbaceous plant communities are light, nutrients, and moisture. The light availability for herbaceous plants depends greatly on season and canopy phenology. Light penetration in the spring is high because the trees are leafless or budding. Conversely, during the summer light penetration is substantially reduced because trees are fully leafed out and therefore the canopy is mostly closed. In the fall, the canopy is mostly closed, but some areas are partially leafed because trees are starting to lose their leaves (Neufeld and Young, in Gilliam and Roberts, 2003). So, for summer and fall herbs, sunlight is usually considered to be the primary limiting resource as light has been shown to have significant effects on the species and growth of herbs. Light can largely affect germination (Small and McCarthy, 2002a). Because the summer and fall understory plants do not receive as much sunlight as the overstory and midstory plants, they have distinct adaptations that allow them to survive and thrive in such conditions. Because of the similar habitat characteristics and resource availability, there is evidence of convergence of physiologies and morphologies in herbaceous plants throughout the world. For example, herbaceous plants usually have underground storage organs which contain carbohydrates that can provide energy for extended periods of time. Herbs have to compete with other herbaceous plants, shrubs and woody plants for resources. Unlike these woody plants and trees, herbs have no above-ground secondary growth, and need carbon and nutrients to regenerate their stems and leaves each year in the spring and summer (Muller, in Gilliam & Roberts, 2003).

Soil

The soils of mesic forests have relatively high levels of moisture, mineral nutrients, and organic matter. Because of this, these forests tend to grow at faster rates and have higher plant diversity than other forests ("Rich and Semi-rich Mesic Forests, 2002). This community can occur in several different soil types, but loam is predominant. Other soil types include sandy loam, loamy sand, silt loam, clay loam, and silty clay loam. Important characteristics of soil include the pH, nitrification, phosphorus concentration, and organic matter. Essential nutrients in these forests are maintained by the decomposition of deciduous leaves and coarse woody debris (Kost et al., 2007). Low soil pH can decrease plant diversity, especially when aluminum reaches toxic levels (Viltinat, Brunn, & Burnet, 2008). However, other nutrients, such as manganese, show a positive correlation with diversity and abundance (Muller, in Gilliam and Roberts, 2003). Many factors can affect these characteristics of soil. A study by Ehrenfeld and Kourtev (2001) on deciduous forests showed that invasive species can change the soil composition and begin a positive feedback system in their favor. Findings showed significant differences in the pH and nitrogen cycling of the soil underneath exotics and native plants, with the soil under exotics being higher in pH and having higher net nitrification rates (Ehrenfeld, Kourtev, and Huang, 2011). In addition, many disturbances such as fire, clearcutting, and grazing can negatively affect the soil. For example, grazing commonly leads to higher pH, increased levels of nitrification, and elevated phosphorus concentrations, as well as a decrease in organic material, increasing conditions favorable for exotic species (Viltinat et al., 2008). Fire blackens the soil surface, which then warms more quickly, allowing for stimulation of soil microbial activity and nutrient cycling. Increased nutrient cycling and the small amount of materials that are volatilized as a result of fire may also result in increased soil exchangeable base cations and increased availability of nitrogen, phosphorus and micronutrients (Bidwell, Masters, Weir, and Engle, n.d.).

Knoepp et al. (2009) carried out a study that focused on the effects of prescribed burns on nutrient cycling in soil of sub-mesic forests of the Southern Appalachians. Study sites consisted of a 5-10 ha areas within a sub-watershed region. The three sites were located at Alarka Laurel Branch and Robin Branch in the Nantahala National Forest, and Roach Mill Branch in Chattahoochee-Oconee National Forest. In this study a Before-After/Control Impact design was used. In the Alarka Laurel Branch, 12 burned plots and 5 unburned plots were established. Robin Branch contained 12 burned and 6 unburned plots, and Roach Mill Branch contained 10 burned and 4 unburned pots. The burns were all of low to moderate intensity. Knoepp et al. (2009) sampled the forest floor mass, carbon and nitrogen. The forest floor sampling was broken up into several components including small wood and litter (Oi) and fermentation and humus (Oe + Oa). Results showed that low intensity fire removes the upper levels of the Oi layer while keeping a large amount of the Oe + Oa layer. This protects the surface soil from erosion and retains a large proportion of plants' nutrients that are important for post-burn recovery. Soil nitrogen availability increased while small amounts of nutrients like inorganic nitrogen were lost. High intensity fires were shown to have many negative effects on the soil. These included large losses of site nutrients through leaching, altered nitrogen availability, and increased erosion (Knoepp, Elliot, Clinton, and Vose, 2009).

Fire

All forests are subject to disturbances that vary in size, intensity, frequency, and type. Larger disturbances include fire, clearcutting, and grazing while smaller disturbances like treefalls and water saturation have a more localized effect (Thompson, 1980). In a forest, the understory appears to be most sensitive to larger disturbances like fire and clearcuts (Small and McCarthy, 2002a). Herbaceous plants respond differently to each type of disturbance. Although most disturbances are thought to have only negative effects, some can have positive effects. Treefalls can open up the canopy allowing for more sunlight as well as sites for new colonization of plants, helping maintain the local diversity of herbaceous plants (Thompson, 1980; Meier et al., 1995).

Larger disturbances, however, can be very harmful to mesic plant communities. Recovery not only depends on the characteristics of each event, but also the life-history of plants such as the pre-disturbance community composition, survival of pre-established individuals, recruitment of new individuals through different dispersal mechanisms, and required germination conditions (Roberts, 2004, McIntyre et al., 1995). Previous studies show that it may take a century or more for the understory herbaceous community to recover from major disturbances such as clearcuts and agricultural uses (Meier et al. 1995, Wyatt and Silman, 2010). Indeed, a disturbed forest may never return to the baseline of species richness and composition characteristic of undisturbed forests (Wyatt and Silman, 2010). Meier et al. (1995) found, in a study of vernal herb recovery in clearcut areas, that succession causes the environment to go from no canopy to a completely closed canopy, and it is difficult for herbaceous plants to survive in either of these conditions. In addition, recovery of herbs may be slow because of inherent limitations of clonal growth and ant or gravity seed dispersal (Beattie & Culver, 1981). This study will uniquely focus on the effects of prescribed burns on the summer and fall herbaceous plant of eastern mesic forests.

Fire has been a natural and anthropogenic disturbance throughout the world, including in the western mesophytic forest region, for much of human history. Reconstruction of the pre-settlement fire regime of the eastern United States deciduous forests relied heavily on first-hand accounts of composition descriptions. Early settlers described the forests as being dominated by pine, oak, chestnut, and hickory. The presence of these fire-prevalent species suggests a regular, low-intensity fire regime. To more accurately recreate the fire history of eastern deciduous forests, many studies have used different techniques. One study by Fesenmyer and Christensen (2010) used radiocarbon-dated soil charcoal from across a topographic gradient in the southern Appalachian Mountains. Soil samples were collected immediately upslope or downslope of rock outcrops in pine forests, xeric oak-dominated hardwood forests, and mesic cove forests where charcoal content tended to be higher. They did not find a strong relationship between soil depth and age of charcoal deposits, but did find that fire had occurred regularly in all tested communities over the past 4000 years (Fesenmyer & Christensen, 2010). The dominance of oak throughout eastern deciduous forests is associated with the occurrence of regular fires throughout the Holocene. In one investigation, the change of pine dominance to oak dominance in study stands coincided with an increased abundance of soil charcoal. The burning practices of Native Americans also contributed to the regular fire regime, and promoted oak-dominated forests (Abrams, 1992). This conclusion is also supported by a study conducted by Delcourt and Delcourt (1997) on the fossil pollen and charcoal particles in the peat of Horse Cove Bog in North Carolina. These results suggest that Native Americans' use of fire promoted the dominance of oak and chestnut throughout the southern Appalachians.

Additionally, fire has a major impact on the composition and age structure of a community, such as regulating a balance between late successional species such as sugar maple and beech and early successional species like oak (Reich and Frelich, 2002). Forest composition will also see changes in the absence of fire. Shade-tolerant species like *Acer rubrum* will begin to establish and recruit in the overstory. These species were formerly confined to the understory because oak is more fire-tolerant (Elliot et al., 1999). In addition, Bratton and Meier (1998) found a decrease in fire tolerant species and an increase in fire intolerant species following fire suppression in the mesophytic Chattooga River watershed.

Major temporal changes in fire regimes occurred when European settlers arrived and displaced Native American populations (Guyette et al., 2002). Before European settlers in America, the Native Americans used fire to modify the forests. These were usually periodic and low-intensity fires that were used for a variety of reasons, including to encourage fruit and berry production, expose chestnuts and acorns for collecting, fire-proof villages, control pests, maintain open woodlands and savannahs for desired early-successional plants and wildlife, concentrate game in convenient areas, and facilitate travel over long areas (Brose, Schuler, Van Leer, & Desrt, 2001). Early American settlers adopted the Native American burning practices; however, with the emergence of logging and its excessive debris, the forests became prone to large, high-intensity fires that had much different effects than the Native American fires. These fires were very harmful to soils, waterways, and adjacent uncut forests. Widespread wildfires occurred in the late 1800s, spurring new efforts to prevent wildfires and identifying it as a destructive and unnecessary disturbance (Brose et al., 2001). Prevention of forest fires became a top priority of the newly-formed US Forest Service, and in 1911, federal funding was assigned to cooperative fire prevention programs. In 1915, a fire warden program was established and fire suppression truly began. Prior to the fire prevention and warden programs there were a number of state and local laws for fire prevention. There were several educational fire prevention campaigns, and during World War II on August 9, 1944, Smokey the Bear was born. The Smokey the Bear campaign continued to have great success throughout the late 1900s, and the famous slogan "Remember, Only You Can Prevent Forest Fires" was known around America. Focus on the Smokey the Bear campaign continued until the end of the century when the fire exclusion policy started to be questioned (Carle, 2002).

Over the past century of fire suppression, unforeseen consequences have cropped up, such as increasing amounts of flammable fuels like woody debris and leaf litter that have resulted in an increased number of wildfires with higher intensity than in past, severely damaging plant life, wildlife, and neighboring towns (Brose et al., 2001). Now that more is known about the negative consequences of fire suppression, prescribed burns are starting to be reintroduced in many areas of the United States as land management practices, both private and public (Knapp, Schwilk, Kane, & Keeley, 2007). This transition has moved slowly with the ingrained negative attitude of North Americans toward fire slowly changing (Carle, 2002).

Herbaceous Plant Response to Fire

No research has been conducted on herbaceous plant response to fire in mesic forests including the western mesophytic forest region, which is located in the eastern United States. Consequently, nothing is known about the plant response to fire in region. However, recently many studies across the country have focused on the benefits of fire on plant communities and ecosystems. Prescribed fires can help reduce fuel loads by reducing woody understory plants, increase light, water and nutrient resources, promote plant diversity, and improve community health (Bond and van Wilgen, 1996). Forests destroyed by fire may take centuries to recover, while grasslands may recover within a few months. The response of plants to fire is variable and depends on the capacity as an individual to survive as well as the recruitment of the species. The duration and intensity of a fire will also affect the plant response (Bond and van Wilgen, 1996). High-intensity fires in particular can negatively influence herbaceous plants, and may result in direct mortality of plants because they lack adaptations, such as thick bark and the ability to resprout, that enable woody plants to survive. Frequent low-intensity burns may lessen the threat of higher-intensity burns by reducing the growth of woody understory plants.

Distinctive communities throughout the country respond differently to fire. Some communities, such as the pine savannahs of southeastern United States, have several pyrophilic plants that need fire to maintain a healthy ecosystem. These plants have morphologically adapted to fire and require it for processes such as seed germination (Barbour & Billings, 2000). In addition, other studies show positive effects of fire on herbaceous understory in additional communities. Historically, mixed conifer forests of the western United States depended upon a periodic regime low to medium-intensity fires. One study by Knapp et al. (2007) focused on the role of prescribed burns in understory vegetation in mixed-conifer forests. Results showed that species richness of native herbs increased in burned areas while the presence of exotics was not significantly affected by fire. In addition, two species with fire-germinated seeds showed increase density (Knapp et al., 2007).

Another study on the effects of fire on vegetation was done on the barrens of Illinois in the Western Forest-Prairie Natural Division. Through collected data and historical data of past vegetation types, researchers drew the conclusions that high-intensity and high frequency fire promoted prairie and savanna; less intense and less frequent fires promoted barrens and woodlands; and, finally, low-intensity and infrequent fires allowed closed canopy forests to dominate (McClain & Ebinger, 2007). These results are supported by the theories for the origin of The Big Barrens in Kentucky. The Big Barrens of Kentucky form a crescent corresponding to the karst landscape with soil derived from soluble limestone that extends slightly into the north part of Tennessee (McInteer, 1946). The Big Barrens is located very close to the Upper Green River Biological Preserve and contains deciduous forests. This area was originally thought to be barren in the sense of low productivity; however, it is now believed that the burning regime of Native Americans created these grasslands (Baskin et al., 1994).

Potential control of invasive herbs by fire was studied by Nuzzo (1991), who looked at the effective control of an invasive herb, *Alliaria petiolata* (garlic mustard) with fire in Northern Illinois. Results showed that moderate intensity fires in the spring reduced garlic mustard; however, low intensity burns were not sufficient to reduce garlic mustard. Another study conducted by Luken and Shea (2000) in Kentucky found that mid-intensity fire had no significant effect on the density of *Alliaria petiolata*. Although the Luken and Shea (2000) study does not support fire as a management tool for garlic mustard, the Nuzzo (1991) study allows the idea that fire, along with location, may be able to control invasive species such as garlic mustard. Throughout the United States, fire is shown to be beneficial to certain types of vegetation such as herbs in barrens, prairies, pine savannahs, and conifer forests. In addition, fire can promote good understory health for these ecosystems.

The intensity and frequency of fire can also play a large role in its influence on vegetation (McClain and Ebinger, 2007).

To gain background information and a basis of knowledge of burn effects on closely related forests to the sampling area in this study, three main articles were used. First M. A. Arthur, R. D. Parately, and B. A. Blankenship (1998) did a study of single and repeated fire on woody and herbaceous plants. A section of the Red River Gorge Geological Area in the Daniel Boone National Forest known as Gray's Arch finger ridge was burned by the U.S. Forest Service in March of 1993. This area is characterized as a sub-mesic, mixed-oak forest. In March of 1995, an escaped campfire burned a portion of the previously burned ridge. This set up four treatments for the experiment: unburned, single burn (1993), single burn (1995), and twice-burned (1993, 1995). In August of 1997, sampling was done with a nested sampling scheme to measure vegetation size in three classes. The "herb" stratum was measured in a circular plot of 1 square meter, nested within the shrub plot with the same center point. The "herb" stratum includes herbaceous plants as well as woody seedlings. Results showed that the percent of cover in the herb stratum was about two times higher in once burned plots than in the unburned plots. Percent cover was even higher in twice burned plots than once burned plots. In addition, single and repeated fire occurrences increased species richness, with least number of species in the unburned plots and highest number in twice burned plots. Also, locally, 43 rare non-woody species such as *Hieracum venosum, and Lysimachia quadrifolia* were found in twice burned plots, suggesting that multiple burns help maintain small populations. The repeated ground fires opened up the canopy and fostered the regeneration of herbaceous species (Arthur et al., 1998). A study conducted by Elliot et al. (1999) also found that, in general, percent cover of the herb-layer increased after burning (Elliot, 1999).

Secondly, Hutchinson et al. (2004) conducted a study on the effects of prescribed fires on the herbaceous layer of mixed-oak forests on the Southern Unglaciated Allegheny Plateau. The diversity of herbaceous plants varied with aspect-related gradient of microclimate and soil moisture and fertility. Four study sites were established with similar bedrock geology, soil, elevation, and topography. Study sites were either mesophytic or xerophytic in nature. From 1996-1999, within each of the sites there were three treatments: a control area (unburned), an area of infrequent burns (periodic), and an area of frequent burns (annual). During the study, the periodic burns were burned twice and annual burns were burned every year. Prescribed fires were conducted from late March to mid-April each year, and sampling of herb layer vegetation was performed in May and then again in August-September. Nonparametric multi-response permutation procedures, indicator species analysis, ordination method of nonmetric multidimensional scaling, and mixed-model analysis were all used to analyze the collected data. Results showed that prescribed fire caused only minor changes in the density of the most common plant species. Similarly, fire did not exhibit any affect on species diversity within the plots. However, species evenness and species richness were greatly affected by fire. By 1998 and 1999 species evenness and species richness in periodic plots were significantly greater than both annual and unburned plots. Small-scale species richness especially increased in the burned plots compared to the unburned plots.

In addition, species composition in both periodic and annual plots showed a significant change from unburned plots. Overall, Hutchinson et al. (2004) concluded that, even though, prescribed burns significantly increased the species richness and composition, the herbaceous layer was not greatly altered. This showed similar results for species richness to the previous study (Hutchinson et al., 2004).

Finally, Reilly, Wimberly, and Newell (2006) conducted a study on the effects of wildfire on plant species richness at multiple spatial scales in a forest community in the southern Appalachians. Previous works suggest that reducing the stronger competitors with fire allows less competitive species to become established, which would increase the overall species richness. Reilly et al. (2006) set up a study site in Linville Gorge located near the Pisgah National Forest in Burke Co., North Carolina. Twenty-five plots were sampled in 1997 and 2003, with five unburned plots serving as controls. Linear regressions, paired t-tests, and species-area curves were used for all plants, trees only, and non trees to assess the effect of fire on species richness at varying spatial scales. Results show that changes in the species richness differed across the spatial scales in magnitude and in direction for some cases. Species richness decreased at the scales of $\leq 0.1m^2$. On scales $\geq 0.1m^2$ species richness changes were in a positive direction. The larger spatial scales had bigger magnitude of change in species richness between burned and unburned plots. With regards to species richness on smaller scales ($\leq 1m^2$), Reilly et al. (2006) concluded that the increase of species richness can be attributed to the reduction of competition and the recruitment of less competitive species to burned areas, as previously studies have also suggested (Reilly et al., 2006).

The previously mentioned study by Knoepp et al. (2009) also gives a slight insight into the advantages of fire. The study found that fire greatly reduced the biomass, including leaf litter, on the forest floor and could, therefore, lead to the rapid recovery of herbaceous species. Nothing related to species richness, diversity, or composition was calculated. However, this study shows the advantages of the reduction of mass on the forest floor for herbaceous understory species (Knoepp et al., 2009).

The current study has an important application with respect to Mammoth Cave National Park. Recently Mammoth Cave National Park has been conducting prescribed burns throughout its forests. Within the Park's forests, there are over 9,000 acres of mesic forests. The mesic upland deciduous forests have an assigned fire regime group of I. This regime is defined as "Frequent, 0-35 years, surface and mixed severity," (Olson & Noble, 2005). The mesic hollow/floodplain deciduous forests have fire regime group of V. Fire regime group V is defined as "Rare, >200 years, stand replacement severity," (Olson & Noble, 2005). Fire regime group fire was burned on a very limited basis (Rick Olsen, pers. com.) The results of this study may help Mammoth Cave National Park predict the change in composition after fire and determine future burning regimes for mesic areas.

Purpose and *a priori* Hypothesis

The purpose of this study is to determine whether prescribed burns will influence the species richness, presence of rare and common species, and density of exotics in the understory of late summer and fall herbaceous plants in eastern mesic forests. It is difficult to formulate a well-supported idea of what the results will show because little previous research has been conducted in mesic areas. Because burning is shown to reduce competition, creating an environment that is more suitable to less competitive species I hypothesize that species richness will be higher in the burned plots compared to the unburned plots, and, furthermore, that rarer species will also be seen in burned plots. This is supported by a study done by Arthur et al. (1998), which determined that, an increase in species richness, as well as, a higher density of rare species after burning occurred. Results from Hutchinson et al. (2004) also found an increase in species richness in a mixed-oak site. I do not believe the presence of common species will differ significantly in the two treatments because the common species are likely to be more competitive and, therefore, be able to thrive in a wider variety of conditions, including post-burn circumstances. Hutchinson et al. (2004) also saw no significant change in the presence of common species after burning, giving some support to my hypothesis, although the sites are only relatively similar.

Exotics have been shown to influence areas around them in ways that positively affect their survival while negatively affects surrounding plants. Burning bares the ground and resources to all species equally and renews the environment. Because of this, the advantage is taken away. I believe that the density of *Glechoma hederacea*, an invasive herb to Kentucky, will decrease throughout the burn plots, allowing native species, such as *Hydrophyllum canadense, Laportea canadense,* and, *Ageratina altissima* to compete with exotics and density to increase. However, Waggy (2009) concluded that the invasive herb, *Glechoma hederacea*, may be damaged, but not controlled by fire because of its shallow roots. In addition, *Glechoma hederace*a may easy recover after fire because its ability to establish in open, disturbed areas (Waggy, 2009). A study conducted by Apfelbaum et al. (2000) recorded the number of *Hydrophyllum virginianum* in burn and unburned plots in 1986 and 1999. Fire management of the area sampled took place until 1993. Results showed that *Hydrophyllum virginianum* numbers were zero in burned plots and 25 in unburned in 1986 and 25 in burned plots and 37.5 in unburned plots in 1999. Because there is a greater increase in *Hydrophyllum virginianum* in burned plots than unburned after burning treatments were conducted suggests that prescribed fire may foster long-term recovery of the *Hydrophyllum* genus (Apfelbaum et al., 2000).

CHAPTER 2

METHODS & MATERIALS

Site Description

The Upper Green River Biological Preserve owned by Western Kentucky University is located in Hart County, Kentucky. The Preserve is on the Crawford-Mammoth Cave Uplands and Western Pennyroyal Karst Plain (McGrain and Currens, 1978; Woods et al., 2002). The forest is less than 100 years old. In the mesic forest area of the Preserve, three nearly adjacent study sites were set up. The three locations differ in soil quality, elevation, slope, relation to alluvial floodplain of the Green River, grazing history, and distance from the edge of the tree line. To avoid edge effects, all sites are located at least 5 meters from the edge of the tree line. Site 1 is located at N37° 14’33.0” and W085° 59’00.7”, on a gentle slope with a 10% grade on Mississippian St. Genevieve limestone. The previous owner stated that it has been heavily grazed in the past (Vilma Jean Kinney, pers. comm.) and the soil type described from the soil map of Hart County is Caneyville silt loam, rocky, with a 6-20% slope. However, contrary to the soil map, this area is not very rocky, but is somewhat eroded. Site 2 is located at N37° 14’30.0”and W085° 58’58.2”on a 15 % grade. This is found on the lower portion of the Mississippian St. Genevieve limestone on a colluvial slope towing down into the alluvial flood plain of the Upper Green River. This area was subject to some grazing, but was never heavily grazed.

The soil at this site is a combination of a rocky Caneyville complex that runs into Nolin silt loam soil. Finally, site 3 is located at N37° 14’28.7”and W085° 58’58.5”on a 25 % grade on the upper Mississippian St. Genevieve limestone with a steeper slope. We know of no evidence that this site was ever heavily grazed. Soil is a rocky outcrop of Caneyville complex with a 12-20% slope mixed with some Caneyville rocky silt loam. Soil composition for all three was analyzed for essential nutrients and results are shown in Table 2.1. The overstories of each were also recorded and results are presented in Table 2.2 and Figure 2.1.

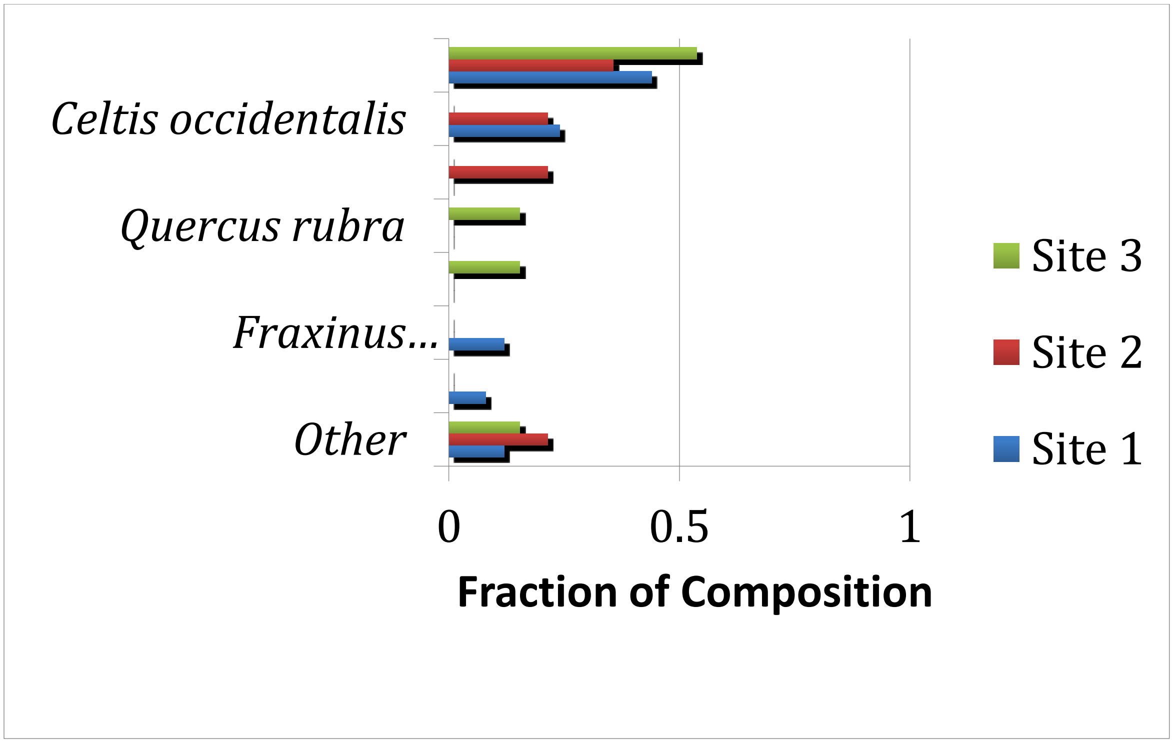
Table 2.1. Mehlich III analysis of soil reported as the average of plots in lbs/acre. (*) indicates that the variable was significant with respect site. The shaded numbers indicate the site that was significantly different from the others determined by Post hoc tests.

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

Table2.2. Fraction of overstory dominated by each tree type. Average D.B.H is reported in cm.

Site	*Acer saccharum*	*Celtis occindentalis*	*Fraxinus americana*	*Prunus serotina*	*Ulmus rubra*	*Aesculus flava*	*Quercus rubra*	Other	Avg DBH
1	0.44	0.24	0.12	0.08	0	0	0	0.12	30.143
2	0.357	0.214	0	0	0.214	0	0	0.214	31.714
3	0.538	0	0	0	0	0.154	0.154	0.154	33.8

Figure 2.1. Graph of fraction of overstory composition for all three sites.



Caneyville soils are characterized as "moderately deep, well-drained soils formed as a thin silty mantle over fine textured residuum of limestone." (NRCS and USDA, 2007). The A layer of this series (0-2 in) is a silt loam, dark gray-brown in color and moderately acidic. The granular structure is moderate fine and the soil is very friable with a large number of fine roots (NRCS and USDA, 2007). The Nolin series soils are "very deep, well drained soils formed in alluvium derived from limestones, sandstones, siltstone, shales, and loess." (NRCS and USDA, 2009). These soils are located on flood plains or in depressions where surrounding slopes provide runoff to maintain the level to moderately steep soil. The uppermost layer in the Nolin series, Ap (0-12 in) is a brown silt loam that is only slight acidic and has a weak fine granular structure. Like the Caneyville, it is also friable with many fine roots NRCS and USDA, 2009).

Within each site, there are four replicates, which contain 3 plots each constituting a total of 12 plots at each site. Plots are two meters by three meters and a one-meter strip separates each plot. A two-meter strip separates each replicate. Within each plot, there were 8 one-square meter subplots.

One of each of the three treatments was assigned to each of the plots in each replicate using a random numbers table. These treatments included control (unburned), spring burn, and winter burn. The spring burns were low intensity fires conducted on 10 April 2010 at 11:20 AM. Firebreaks for spring burn plots consisted of a one-meter strip on each side of the plot, cleared to mineral soil. Plot layout and treatment is shown in Figure 2.2. To measure scorch height and fire intensity two dowel rods were placed in each plot, one between subplots 1,2,3, and 4 and one between subplots 5,6,7, and 8. Figure 2.3 shows the subplot layout. The fuel mixture for the burns consisted of 70% diesel and 30% gasoline and a drip torch was used for ignition. All plots were completely burned within one hour of being ignited. Winter burns took place on February 22, 2011, but these plots were not used in this study.

Figure 2.2. Plot layout and treatment.

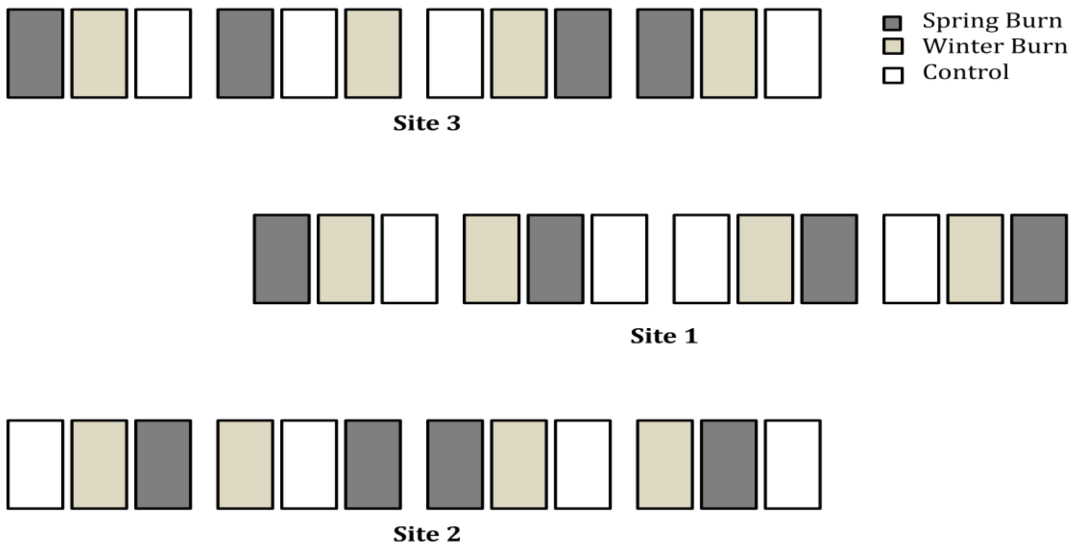
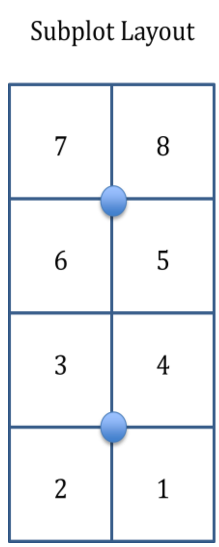


Figure 2.3. Subplot layout.



Data Collection

The density and frequency of herbaceous plants in spring burned and control plots were recorded on 5 September and 6 September 2010 for summer plants. Fall plant data was recorded on 6 October and 8 October 2010. Woody plants and vines were not included. Unknown plants were photographed and then identified with the help of experts and plant identification books. Albert J. Meier collected overstory data for all three sites on 6 April, 2011. Soil samples were also collected from each plot in two places using a corer. One was taken between subplots 1, 2, 3, and 4 and the other between 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 site 2 and 3 were collected on 19 March 2011.

Data Analysis

Analysis of the herbaceous layer was conducted using a two-way ANOVA test with the SPSS statistical program. These tests used burning and site as treatments. Tests were performed on the species richness for summer and fall herbs, and density of two species in the summer and three species in fall. The individual species chosen were the most common invasive herbs and native herbs throughout the plots for the respective times of year. The ten herbs found in the least number of plots (rare species) and the ten herbs found in the most plots (common species) were analyzed with a two-way ANOVA. Using the Statisica 7 program a simple linear regression to relate density of two species to burn severity. 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 site and the soil, a General Linear Model One-way ANOVA was used in the Statistica program.

CHAPTER 3

RESULTS

Summer

There was little variation in the results for summer species. The results of the two-way ANOVA show that the tests for species richness, presence of rare species, and the density of *Glechoma hederacea* were not significant. However, the overall models for the density of *Laportea canadense* and the presence of common species proved to be significant. The results for *Laportea canadense* are shown in Table 3.1 and the results for the presence of common species are shown in Table 3.2.

Table 3.1. Two-way ANOVA results for the density of *Laportea canadense.*

Source	SS	df	F	Sig (*P*)
Corrected Model	8375.208	5	16.415	0.000
Intercept	4187.042	1	41.033	0.000
Fire	0.375	1	0.004	0.952
Site	8374.083	2	41.033	0.000
Fire*Site	0.750	2	0.004	0.996

Table 3.2. Two-way ANOVA results for the presence of common species.

Source	SS	df	F	Sig (*P*)
Corrected Model	28664.833	5	6.557	0.001
Intercept	78432.667	1	89.703	0.000
Fire	3174.00	1	3.630	0.073
Site	24994.083	2	14.293	0.000
Fire*Site	496.750	2	0.284	0.756

For both of the latter tests the overall model, intercept, and the treatment of site were significant. Post hoc tests showed that the density of *Laportea canadense* was highest in Site 2, which is the bottomland site located along the alluvial floodplain. The greatest number of common species was also found in Site 2. However, neither the density of *Laportea canadense* nor the presence of rare species was significantly affected by burning or the interaction of burning and site.

Fall

The results for the fall herbaceous plants showed a little more variation than the summer herbs. Two out of the three individual species were significantly influenced by fire. In addition, for all tests except for the presence of rare species, the overall models generated from the two-way ANOVA tests were significant. The overall model for the presence of rare species was not significant, demonstrating that no considerable difference existed between the number of rare species throughout all the plots, burned and unburned. The two individual species that were significantly affected by fire were *Hydrophyllum canadense* and *Glechoma hederacea*. The results for these two tests are shown in Table 3.3 and Table 3.4 respectively.

Table 3.3. Two-way ANOVA results for the density of *Hydrophyllum canadense*

Source	SS	df	F	Sig (*P*)
Corrected Model	840.875	5	21.206	0.000
Intercept	315.375	1	39.767	0.000
Fire	70.042	1	8.832	0.008
Site	630.750	2	39.767	0.000
Fire*Site	140.083	2	8.832	0.002

Table 3.4. Two-way ANOVA results for the density of *Glechoma hederacea.*

Source	SS	df	F	Sig (*P*)
Corrected Model	266.208	5	5.516	0.003
Intercept	345.042	1	35.745	0.000
Fire	70.042	1	7.256	0.015
Site	131.583	2	6.816	0.006
Fire*Site	64.583	2	3.345	0.058

For *Hydrophyllum canadense,* a native herb to Kentucky, all the sources proved to be significant including burning and the interaction of burning and site. The density of *Hydrophyllum canadense* was found to be the highest in site 2, the bottomland site, as well as, in unburned sites. *Glechoma hederacea*, an invasive herb in Kentucky, showed significance for all sources except for the interaction of burning and site. Post hoc tests for the variable of site show the density of *Glechoma hederacea* to be lower in site 3, which is the site with the highest slope location. However, there was no significant difference between sites 1 & 2. In addition, burning decreased the density of *Glechoma hederacea,* which is similar to the response of *Hydrophyllum canadense*. The results for the remaining three tests in the fall, species richness, presence of common species, and the density of *Ageratina altissima* are shown in Table 3.5, Table 3.6, and Table 3.7.

Table 3.5. Two-way ANOVA results for the species richness.

Source	SS	df	F	Sig (*P*)
Corrected Model	235.375	5	7.106	0.001
Intercept	1890.375	1	285.340	0.000
Fire	3.375	1	0.509	0.485
Site	225.750	2	17.038	0.000
Fire*Site	6.250	2	0.472	0.631

Table 3.6. Two-way ANOVA for the presence of common species.

Source	SS	df	F	Sig (*P*)
Corrected Model	32743.708	5	17.073	0.000
Intercept	60501.042	1	15.732	0.000
Fire	392.042	1	1.022	0.326
Site	32320.333	2	42.143	0.000
Fire*Site	22.333	2	0.029	0.971

Table 3.7. Two-way ANOVA results for the density of *Ageratina altissima.*

Source	SS	df	F	Sig (*P*)
Corrected Model	3857.500	5	7.704	0.001
Intercept	2904.000	1	29.000	0.000
Fire	48.167	1	0.481	0.497
Site	3787.000	2	18.909	0.000
Fire*Site	22.333	2	0.112	0.895

These three tests show very similar results. All have an overall significant model and are significant in respect to site. Post hoc tests showed that the species richness, presence of common species, and density of *Ageratina altissima* were all greatest in site 2, the bottomland site.

Results for the simple linear regression between burn severity and density of individual species are not significant at a 95% confidence level for either, *Hydrophyllum canadense* (R^2=0.120, df (model)= 1, df(residual)=11, F=2.64, P=0.132) or *Glechoma hederacea* (R^2= 0.15, df(model)=1, df(residual)=11, F=3.135, P=0.104). Finally, a summarization of the findings for summer is shown in table 3.8 and for fall in Table 3.9. Significance is shown for each variable in respect to site and fire.

Table 3.8. Summary of significance in summer results.

	Laportea Canadense	*Glechoma hederacea*	Species richness	Presences of common species	Presence of rare species
Fire	0.952	0.287	0.577	0.073	0.736
Site	0.000	0.109	0.301	0.000	0.816

Table 3.9. Summary of significance in fall results.

	Hydrophyllum canadense	*Ageratina altissima*	*Glechoma hederacea*	Species richness	Presence of common species	Presence of rare species
Fire	0.008	0.497	0.015	0.485	0.326	1.000
Site	0.000	0.000	0.006	0.000	0.000	0.767

CHAPTER 4

DISCUSSION

Although, many studies like Arthur et al. (1998) and Hutchinson et al. (2004) showed that prescribed fire increases species richness, density, and favors native plants over invasive plants, results from the current study suggests that this it is not necessarily the same for mesic sites in the western mesophytic forest region. The summer and fall herbs of this forest showed a much different response to fire. No difference in species richness between burned and unburned plots for summer or fall herbaceous plants was seen contradicting the findings of Arthur et al. (1998), Hutchinson et al. (2004), and Reilly et al. (2006). Rare and common species were equally likely to be seen in burned and unburned plots. Fire is not as common in mesic habitats as in other habitats such as conifer forests or the shrublands of southern California that show significant changes in composition after prescribed burns (Barbour & Billings, 2000). This may be a reason that fire was shown to have little to no affect on the herbaceous plants in a mesic deciduous forest. The high moisture content of the soil that is characteristic of mesic regions may also provide an insight into the response of vegetation from fire occurrences. The soil may not be as affected by fire as others, and because of this the composition of plots is not going to differ greatly after fire. The invasive herb *Glechoma hederacea,* however, showed a decrease in density in burn plots in the fall sampling collection, suggesting that fire may be an effective way of reducing some invasive plants throughout eastern mesic forests. The lack of significance found in the summer may be because the number of individual plants was not yet large enough to see a difference. Studies performed on garlic mustard show conflicting results. Results from the study conducted by Nuzzo (1991) showed that burning has the potential to be a management control of *Alliaria petiolata* (garlic mustard). However, Luken & Shea (2000) did not find that fire had any influence on the density of garlic mustard. Further research should be conducted to determine effectiveness of fire in controlling *Glechoma hederacea*. More research should be done on additional exotics to see if they respond similarly to *Glechoma hederacea* and to see whether burning may be a successful management practice. The native herb, *Hydrophyllum canadense*, also showed a decreased density in burn plots in the fall, which was not expected, but may be because of the short recovery time between burning and sampling. It might also be because it has some characteristics that favor pre-fire conditions which do not allow it to recover as well as other herbs. These are common results from the Apfelbaum et al. (2000) study that showed the *Hydrophyllum* genus only recovered in the burn plots several years after prescribed fires. These findings were isolated to one native herb, and it must be considered as an individually distinct result with the possibility that outcomes were just a secluded occurrence where further study may not produce the same findings. All of the native species showed very little difference between burned and unburned plots suggesting, in general, that native herb density is neither helped nor harmed by fire.

Results from the soil analyses showed that all three study sites have significantly different soils, which may influence the species richness and density of herbs. An interesting finding from the soil analysis is that the most heavily grazed site showed the lowest phosphorus concentration, contrary to studies like Viltinat et al. (2008) that have shown grazing to increase phosphorus concentration. Because each of the study sites have significant differences in soil and species richness, experiments should be conducted that exclude this variable. For example, all study sites should be located at the same site and contain very similar soil.

Some factors to consider, when looking at the results of the current study in comparison to with previous studies, are the time frame of the study, the number of prescribed burns, and number of samplings. The current study was conducted within one year and the plots were only sampled once whereas most of the previous studies reviewed had a time frame of 3 to 6 years with more numerous samplings. For example, the study conducted by Arthur et al. (1998) showed increased species richness, increased percent cover, as well as, an increase in rare species in twice-burned plots was carried out over a four year period. Similar results in species richness was shown in the study performed by Hutchinson et al. (2004), which was conducted over a period of three years. For the current study, data collection was only conducted in the summer and fall immediately following the spring burns where the short recovery times may have influenced the findings. Additional years would give a more sufficient recovery time for the herbaceous understory of the mesic forest as additional samplings, with a larger time frame may show different results in species richness and composition of the herb community (Arthur et al., 1998).

In addition, most of the previous studies included at least two prescribed burns, whereas in the current study only one burn was conducted the spring before data was collected. Single and repeated burns in an area where fire is known to play a significant role in the community dynamics could have significant effects on the composition of the herbaceous layer as seen in the species richness, species density, and presence of invasive species. Therefore, a single prescribed burn may not be sufficient to cause changes in the herbaceous understory. In mesic forests repeated burns may be needed to cause significant changes in the composition because they appear to be a relatively fire-independent community (Barbour & Billings, 2000).

Finally, the intensity of the prescribed fire and spatial scale must be taken into account. The plots in the current study were burned with low intensity prescribed fires. Higher intensity fire, although much less common, can occur in certain conditions and may produce different results than those seen in this study. For example, if high intensity fires took place in a drier period, they may have more of a negative effect on the recovery of herbs in mesic areas. In addition, the spatial scale of the current study was much smaller the many previously studies and may have an influence on findings. At larger scales, results may show differences for species richness, and presence of rare and common species. Further research should be conducted with a longer time frame, repeated prescribed burns, larger spatial scales, and, if conditions allow, higher intensity fire to see if results will show changes.

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Appendix 1: Burn severity data including scorch height and code for each dowel rod placed in burned sites and unburned sites.

The burn severity data is shown in the following table. Each plot that was burned had two dowel rods, one between subplots 1, 2, 3, and 4 marked as D for down and one placed between subplots 5, 6, 7, and 8 marked with U for up after the plot number. The scorch height is given and then coded. UB is representative of unburned and coded as 1. The "X" means that the dowel rod was burning all the way and fell into the fire, preventing measurement. The rest of codes are as follows: 2= 0.1-21.75 cm, 3= 21.76-43.5 cm, 4=43.6-65.25 cm, and 5= 65.26 and up.

Table 1.

Plot Number	Site	Rep	Plot	Scorch Height	Coded
210-D	1	1	2	7.5 cm	2
210-U	1	1	2	UB	1
213-D	1	2	2	8 cm	2
213-U	1	2	2	41 cm	3
216-D	1	3	2	18 cm	2
216-U	1	3	2	UB	1
220-D	1	4	3	X	5
220-U	1	4	3	87 cm	5
222-D	2	1	2	6 cm	2
222-U	2	1	2	UB	1
226-D	2	2	3	7.5 cm	2
226-U	2	2	3	UB	1
227-D	2	3	1	12 cm	2
227-U	2	3	1	UB	1
230-D	2	4	1	UB	1
230-U	2	4	1	X	5
235-D	3	1	3	UB	1
235-U	3	1	3	UB	1
236-D	3	2	1	X	5
236-U	3	2	1	X	5
241-D	3	3	3	UB	1
241-U	3	3	3	UB	1
244-D	3	4	3	67 cm	5
244-U	3	4	3	87 cm	5

Appendix 2: Collected, raw data for summer and fall herbaceous plants. Tables are shown on next two pages for summer and fall respectively. (*) indicates spring burns that took place in April, 2010.

COLLECTED DATA FOR SUMMER HERBACEOUS PLANTS, SEPTEMBER 2010

	210*	211	213*	214	215	216*	218	220*	221	222*	224	226*	227*	228	230*	232	233	235*	236*	238	240	241*	242	244*
Ageratina altissima	numerous	41	8	37	36	16	numerous	44	8									1		4	2	3	9	2
Viola sororia	4		1	18	3		3		14	8	9	1		9	2	4							1	
Glechoma hederaceae	7			1	3		24	16	11	2	7		5	7	4	10		1		3				
Asarum canadense				7	9		17	33			18	2	1	14		22								4
Rice grass	4	42		9				29		1			4										4	
Sedge (broad)	6	7	2	5			1	4	3	2	6	1		3	1		1						1	
sedge (thin)		3					18	14	15	7	12					4		2	1	3	1			
Verbesina alternifolia	8	6		3		2	4		27	33		22	6		3		1							
Polygonum virginianum	4	3					1		4	2	1													
Pilea pumila	3			1		1	3		1	3		1	1					7	2	22		1	22	2
Parthenocissus quinquefolia																								
Ruellia makoyana			2	2	1																			
Lonicera japonica			4	4			2											3	5					
campsis radicans				8	1	3			3	6											4			
Polystichum acrosticoides				1																			2	
unknown 1																							2	
Aristolochia serpentaria								2																
Crytotaenia canadensis									4		5	1												
Hydrophyllum canadense									22	5	27	3	2	13	6									
Laportea canadensis									25	7	50	numerous	numerous	numerous	numerous	35								
Amphicarpaea bracteata									3	4	2													
Solidago canadensis										2														
Polygonum hydropiperoides									3	4														
Boehmeria cylindrica										10										2				
Aster vimineus										1														
Diplazium pycnocarpon																								
Cystopteris fragilis											4		2		1					2			3	
Echinocystis lobata													1											
Thalictrum revolutum																								
Taxicodendron radicans																	3	4		4			2	1
Asplenium platyneuron																			1			2	4	1
Stylophorum diphyllum																								
Trifolium sp.																				1				
Dentaria diphylla													1							1				
Acalypha sp.																					1			

(*) Indicates spring burn plots. Burned April, 2010

COLLECTED DATA FOR FALL HERBACEOUS PLANTS, OCTOBER 2010

Species ↓ / Plot →	210*	211	213*	214	215	216*	218	220*	221	222*	224	226*	227*	228	230*	232	233	235*	236*	238	240	241*	242	244*
Ageratina altissima	numerous	35	8	32	22	11	28	44	19					3						4			6	2
Viola sororia	4	1				2	1		18	6	9	2	5	7	7	4								
Glechoma hederaceae	7	10	1		2	1	12	8	10		8	1	5	11	1	10		1		3				
Asarum canadense				2	1		5	10			15	3	1	4		2								
Rice grass		20		9				9					4										7	
Sedge (broad)	6	8				2	1	2	3	6	5	3			5	3	4						1	
sedge (thin)		3	2	5			15	3	21	13	25	5	1	2	6	8	2	2		3	1			
Verbesina alternifolia	5	10		2	1	2	3	2	22	36	8	22	5		4						1			
Polygonum virginianum	4	5		3		1	2	1	3	1														
Pilea pumila		1				1	3	6	4	3		1	3					7	2	17		1	11	10
Parthenocissus quinquefolia																								
Ruellia makoyana			2																					
Lonicera japonica		7	5	5			3											4	3					
campsis radicans				8		4			8	4											2			
Polystichum acrosticoides				1																			2	
unknown 1																							1	
Crytotaenia canadensis				1						2	6	3												
Hydrophyllum canadense									21	10	20	2	4	15	7	8								
Laportea canadensis									20	25	28	numerous	numerous	41	48	18								
Amphicarpaea bracteata									2	6	1													
Solidago canadensis										2														
Polygonum hydropiperoides									3	2														
Aster vimineus										1	2	1			2									
Diplazium pycnocarpon																								
Cystopteris fragilis								1							1									
Echinocystis lobata													1											
Thalictrum revolutum																								
Taxicodendron radicans																		3		6			1	
Asplenium platyneuron																			1			1	3	1
unknown 2																	1							
Stylophorum diphyllum																								
Acalypha sp.																					1			
false acalypha	2							1										1		2		1	1	1
Sanicula canadensis		2	1							9														
unknown 5			1																					
unknwon 4				2																				
Geum canadense																								
Allium canadense									10		6	19	1	2	6	6								
Stellaria pubera									5		4	1		2						1				
Enemion biternatum									5		6	2		3						1				
Dentaria diphylla										3			9	10	12	21	2							

(*) Indicates spring burn plots. Burn in April 2010