

To the Graduate Council:

I am submitting herewith a thesis written by Rebecca Lynne Stratton entitled “Effects of Long-term Late Winter Prescribed Fire on Forest Stand Dynamics, Small Mammal Populations, and Habitat Demographics in a Tennessee Oak Barrens.” I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

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**EFFECTS OF LONG-TERM LATE WINTER PRESCRIBED  
FIRE ON FOREST STAND DYNAMICS, SMALL  
MAMMAL POPULATIONS, AND HABITAT  
DEMOGRAPHICS IN A TENNESSEE OAK BARRENS**

A Thesis  
Presented for the  
Master of Science Degree  
The University of Tennessee, Knoxville

Rebecca Lynne Stratton  
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## DEDICATION

This thesis is dedicated to Bob “the hamster of the forest.” He’s not so bright but super cute.



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I would like to thank the Tennessee Division of Forestry for providing financial support.

Lastly I would like to thank my family and friends for encouraging me and keeping me sane through the process.

## **ABSTRACT**

Stand structure and composition of pyric oak barrens communities were shaped by natural and anthropogenic fire disturbance regimes. Due to fire suppression and land use changes, oak barrens have become rare. In 1963, a study was implemented to evaluate the restorative effects of annual and five year periodic fire on an “oak barrens” hardwood forest at the University of Tennessee Forest Resources Research and Education Center near Tullahoma, TN. The initial study was a randomized block design and analyzed the effects of short-term prescribed fire on hardwood reproduction, herbaceous vegetation, fuel loading, and soil characteristics. Since inception, additional studies of short-term and long-term effects of continual prescribed fire on various components of the ecosystem have been conducted.

In 2005, a follow-up study was conducted to evaluate the effects of long-term prescribed fire on stand dynamics, wildlife habitat structure, and small mammal populations. Stand structure and development were documented and treatment differences analyzed. The effects of annual prescribed fire on small mammal abundance and habitat characteristics were compared across treatments at 3 intervals, pre-burn, post-burn, and end of season using repeated measures mixed models ANOVA. Predicting small mammal abundance using habitat characteristics was performed using multiple linear regression with stepwise selection.

Annual and 5-year periodic burning for 42 years decreased canopy cover and increased vertical and horizontal understory structure. Regeneration mortality was high

for both burn treatments and recruitment was unsustainably low. The 5-year periodic treatment was the most structurally diverse and had the highest small mammal abundance and diversity. Three models for small mammal abundance had one temporally-related variable as the most significant: percent cover of vines. Woody height, percent cover of forbs, and percent cover of bunch grasses were also significant variables.

Long-term annual and 5-year periodic prescribed fire does not restore oak barrens to historical accounts of the area and is not sustainable. The amount of overstory oak trees continues to decline with continuous burning. A period of time without burning is required for ingrowth to become established in the overstory and be large enough to withstand burning.

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# I. INTRODUCTION

## *Oak Barrens*

Prescribed fire in hardwood stands was once a common management tool throughout the Southeast and Midwest. However due to poor management and decades of successful suppression campaigns, the use of fire in hardwoods is uncommon and often considered detrimental to stand health. While prescribed fire in pine management has long been used for ecological restoration, site preparation, habitat management, and competition control, only recently have managers of hardwoods regained interest in the use of fire for these objectives.

Oak barrens, also known as oak savannas, are one of many pyric communities that have been negatively impacted from decades of fire suppression. These communities once accounted for millions acres throughout the Midwest (Leach and Givnish 1999), including Wisconsin (Heikens and Robertson 1994a, Cottam 1949, Bray 1960, Barnes 1989, Leach and Givnish 1999, Ko and Reich 1993), Minnesota (Inouye et al. 1987), Missouri (Cutter and Guyette 1994, Huddle and Pallardy 1996), Indiana (Guyette et al. 2003, Homoya 1994), Illinois (Anderson and Brown 1983, Heikens and Robertson 1994b, Robertson and Heikens 1994), and parts of Kentucky (McInteer 1946, Arthur et al. 1998, Gilbert et al. 2003) and Tennessee (DeSelm 1994, DeSelm et al. 1973), but

these systems are now considered rare. Recently, many of these areas have seen renewed interest in ecological restoration.

Oak barrens communities are most generally characterized as grasslands with open-grown groups or scattered trees (Cottam 1949) maintained by climate, natural and/or anthropogenic disturbances, and poor droughty soils which are edaphic in origin (Hutchinson 1994). Species composition of both woody and herbaceous vegetation varies greatly. The trees present tend to have a low basal area, generally between 5 and 20 square feet per acre, can vary in size distribution of a few scattered large trees to a grouping with a range of sizes, and are a density of an order of magnitude less than typical forest communities (Heikens and Robertson 1994a, Kaminiski and Jackson 1978, Kline and Cottam 1979). The overstory is predominantly low quality oak species (*Quercus spp.*), with little midstory or understory, and an open prairie-like grass and forb herbaceous layer.

## ***Role of Fire***

Fire, both natural and anthropogenic, has played an integral role in the formation and perpetuation of many oak barrens communities for thousands of years (Hutchison 1994). Although most research agrees fire is not the only key factor, noting combinations of climate, soil, and grazing as co-contributing factors (Heikens and Robertson 1994a), without fire, many of these forests progressed into closed canopy forest.

Approximately 9,000 to 4,000 years before present, during the Holocene Hypsithermal, a warm, droughty climate formed what is now the oak barrens ecosystem of Tennessee (Delcourt 1979). This climate promoted and perpetuated grasses, and lightning strike caused fire was frequent. Native Americans also entered this area during this time period. They hunted large ruminants such as bison, elk, and deer and frequently burned the area for hunting and land clearing (DeSelm et al. 1973). Baskin et al. (1994) suggests that due to differences in paleovegetation, paleoclimate, plants and animal geography, and Native Americans influences, the Tennessee and Kentucky oak barrens are their own separate pyric ecosystem and not outliers to the barrens and savannas of the Midwest. Fire frequency in this area is unknown, however literature from similar barrens suggest the fire return interval was generally 1 to 3 years and fire intensity was low (Cutter and Guyette 1994, Guyette et al. 2003) and fires occurred primarily in the dormant season, however growing season fires also occurred.

## ***Fire Effects***

The effects of prescribed fire on an ecosystem are a direct result of many biotic and abiotic factors, including fire season, fire intensity, fire frequency, weather, fuel loading, and fuel arrangement. Glitzenstein et al. (1995) found deciduous oak species have higher susceptibility to topkill, mortality, and decrease in recruitment during early spring burning than dormant season burning. Frequency of fire alters availability of fuels and overstory and understory vegetation structure and composition. Annual fire tends to

have lower annual mortality than 5-year periodic fire primarily due to decreased fire intensity (Huddle and Pallardy 1995).

Fire intensity is one of the most important but difficult factors of fire to manage and measure because intensity is highly related to and dependant on every aspect of the ecosystem. Managing fire intensity allows managers to alter vegetation structure and composition via physical manipulation of physiological characteristics of vegetation. Wind, decreased relative humidity, and drought conditions are the most important weather factors that influence and increase fire intensity (Pyne 1984).

### ***Fire Behavior***

Fire behavior in oak barrens is not typical of fire in the eastern deciduous forest because of differences in fuel types. Oak barrens generally tend to have more similar fire behavior and fuel types to grasslands than forested communities. Fuel management using fuel types allows managers to evaluate conditions by examining fuel loading and fuel arrangement to determine the optimal conditions to achieve desired results. Fuel loading, weight and distribution of fuel by size classes, fuel arrangement, and horizontal and vertical continuity of fuels, all influence fire behavior factors such as flame length, rate of spread, and intensity (Pyne 1984). Oak barrens management requires frequent low intensity fires through distribution and arrangement continuity of fine fuels such as grasses. Fine fuels are the basis for ignition and essential to fire spread; without adequate distribution of fine fuels, fire will not carry.

## ***Stand Dynamics***

Oak barren forest structure requires frequent disturbance in the form of fire to perpetuate the sub-climax pyric ecosystem. The origin of most oak barren sites in Tennessee is thought to have been heavily influenced by anthropogenic fire disturbances (Baskin et al. 1994). These disturbances are generally on an incomplete stand scale similar to longleaf pine (*Pinus palustris*) savannas (Glitzenstein et al. 1995). Unlike many mixed stands in Tennessee, oak barren stand structure tends to have unbalanced diameter distributions, low regeneration recruitment rates, and be irregular uneven-aged with fire tolerant species comprising all strata due to fire burning in a mosaic pattern (Bray 1960, Curtis 1959, McInteer 1946). Frequent fire and occasional wind disturbances cause oak barren stands to continually be in the complex stage of development with canopy gaps that allow younger trees and vegetation to develop (Oliver and Larson 1996).

## ***Habitat***

Habitat, an area which provides food and shelter for an animal (Cody 1985), is manipulated by managers to achieve specific goals for wildlife populations and ecosystems (Anderson and Gutzwiller 1996). The use of prescribed fire as a management tool in forested systems promotes vertical and horizontal structure for cover, increases browse, increases understory diversity, and increases hard and soft mast. Frequent prescribed fire increases early succession habitat diversity and early successional species flora and fauna diversity.

Quantifying treatment differences in habitat allows managers to relate populations to management actions. When managing for specific species or a group of related species, important habitat features relating to the life history and habitat preferences should be addressed in addition to broad overall habitat characteristics (Anderson and Gutzwiller 1996, Iverson et al. 1967). Modeling populations using habitat characteristics has broad applications for managers and is important for identifying key habitat characteristics, indicating quality of habitat, and assessing management actions.

### ***Small Mammal Populations***

Small mammals are an integral part of many ecosystems. They are the primary prey base and drive the higher order terrestrial food web. Small mammals are also highly adaptable and quickly colonize disturbed areas. Their populations tend to have seasonal fluctuations due to temporal and spatial changes in available habitat and environmental factors (Delany 1974). In the eastern deciduous forest early successional habitat has declined because of fire suppression and land use changes; as a result, populations of early successional species have decreased. The use of frequent fire in oak barrens promotes early successional habitat (Plocher 1999) which increases small mammal abundance and diversity (Hirth 1959).

## ***Small Mammal Modeling***

Identifying preferred and influential habitat for small mammal populations tends to have varying levels of effectiveness. Small mammal studies vary greatly by species studied, location, site characteristics, variables measured, study design, and the statistics used to determine relatedness, making identification of common habitat preferences difficult (Jorgensen 2004, Lebreton et al. 1992). Studies modeling small mammal populations using standard macrohabitat and microhabitat variables, such as percent vertical cover, percent horizontal cover, and coarse woody debris have yielded inconclusive and sometimes contradictory results (Greenburg 2002, Morris 1991, Anthony et al. 1981, M'Closkey and Lajoie 1975, Krefting and Ahlgren 1974, Hirth 1959). For example, M'Closkey and Lajoie (1975) reported old-field habitats with diverse vertical structure promote the higher abundances of *Peromyscus leucopus* than forested habitats, while Anthony et al. (1981) reported the opposite.

## II. OBJECTIVES

The goal of this study was to determine the effects of 3 treatments (annual, 5-year periodic, and control) on stand dynamics, small mammal populations, and wildlife habitat in a south central Tennessee oak barrens ecosystem. The specific objectives of this study were to:

- Document cumulative changes in stand structure and composition within the 3 treatments.

During the 42<sup>nd</sup> year of continual burning:

- Compare 42<sup>nd</sup>-year effects of annual and 5-year periodic prescribed fire on vegetation between treatments,
- Compare wildlife habitat characteristics between treatments and as a result of a single annual burn,
- Compare relative abundance of small mammal populations between treatments and as a result of a single annual burn, and
- Investigate potential relationships between small mammal abundance and forest structure and composition.

### **III. STUDY AREA**

#### ***Location and Site Description***

This study is located at 35°30'N 86°15'W on 7.3 hectares of the University of Tennessee Forest Resources Research and Education Center near Tullahoma, TN in Franklin County. The station is 860 acres and is situated on the Eastern Highland Rim of the Interior Low Plateaus Province in middle Tennessee. Although the Highland Rim is characterized by rolling hills and wide valleys, the eastern edge of the Rim is characterized as a flat plain furrowed by ravines with many streams. The climate is warm and humid with hot summers and cool winters ranging from 27.1°F to 42.1°F in January and 66.3°F to 87.8°F in July. Precipitation averages 4.4 inches in January to 5.0 inches in July with an average annual precipitation of 57.5 inches (Owenby and Ezell 1992). The soils are mapped within the Dickson series (fine-silty, siliceous, thermic Glossic Fragiudults) and slopes are from 0 to 2 percent (National Resource Conservation Service 2001, Nichols 1971, Fox et al. 1958).

The site is classified as oak barrens, site index 73 for white oak at base age 50 with a long history of frequent low intensity fires prior to the establishment of this study (National Resource Conservation Service 2007). Oak barrens generally have shallow soils with low productivity and poor timber quality and a historically frequent fire regime with a savanna stand structure. The primary species found in the overstory are post oak

(*Quercus stellata*), southern red oak (*Q. falcata*), scarlet oak (*Q. coccinea*), and blackjack oak (*Q. marilandica*). The study area has an ephemeral stream with a defined channel. Along the stream water oak (*Q. phellos*) and red maple (*Acer rubrum*) are present. Prior to study inception, the understory was predominantly a herbaceous-woody mix of native warm season grasses, forbs, and the aforementioned oak species.

## **IV. METHODS**

### ***Research Design***

This research was established in 1963 as part of a long-term fire ecology and stand dynamics study and has been burned continuously since inception. The study was approximately 7.3 hectares and the study design was a randomized block, blocked on location, with three replications of three dormant season, late-winter/early-spring, prescribed fire frequency treatments (annual, 5-year periodic, and control) (Figure 1) (Nichols 1971). Each treatment plot is approximately 0.73 hectares with a plowed fireline separating each plot. Treatments were conducted between late February and early April. Treatment applications were performed by the same station manager since inception. Each treatment plot was burned individually using a ring fire pattern. Fire was distributed evenly across the treatment plots. Fire intensity was higher at the center of the plots than the edges.

### ***Forestry Sampling***

Forest stand dynamics data were collected in June of 2005 on a single sampling occasion in accordance with the timing of Nichols (1971) and DeSelm et al. (1991) data collections. The 5-year periodic treatment was measured in 4<sup>th</sup> year of the cycle. Measurements were recorded in English units to compare with previously

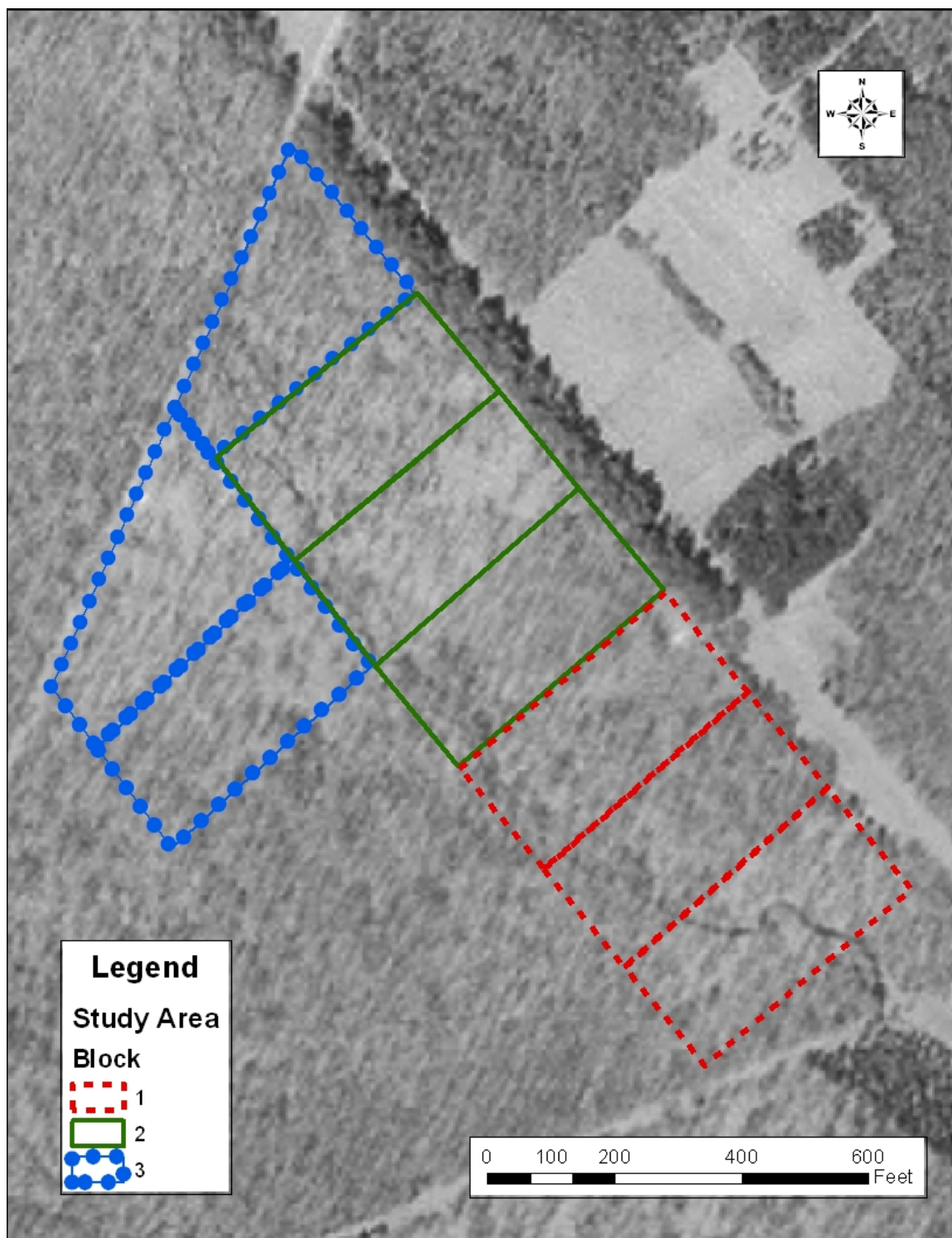


Figure 1. Aerial photograph with study area boundaries for 2005 long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.

reported data. Two permanent sampling points were established in 1963 in each of the 9 treatment plots (Nichols 1971). The points were nested and located approximately 100 feet from the northern and southern boundaries. Overstory trees (diameter at breast height (DBH) greater than 11.0 inches) was identified and measured on one-fifth acre (52.66 feet radius) sampling points. Midstory trees (DBH 5.0 to 10.9 inches) was identified and measured on one-tenth acre (37.24 feet radius) sampling points. Tree regeneration (0 feet tall to 4.9 inches DBH) was tallied by species on one-hundredth acre (11.78 feet radius) sampling points.

### ***Small Mammal Sampling***

Small mammal sampling using mark-recapture live trapping was conducted pre-burn (March 11 – April 20), post-burn (April 27 through June 1), and end of season (July 12 through August 2) during 2005. Each treatment plot contained 24 stations with 2 Sherman traps per station, 48 traps per plot. The stations were spaced 10 meters apart on an 8 row by 3 column grid placed in the center of each plot with a 20 meter buffer between the edge of the trapping grid and the edge of the plot (Figure 2). Each treatment plot was trapped for approximately 16 days, totaling 20,729 trap nights ( $9 \text{ plots} \times 48 \text{ traps} \times 16 \text{ days} \times 3 \text{ time periods}$ ) for the entire study. All treatment plots were trapped at the same time to reduce error due to movement and to allow for monitoring of movements between plots. The remaining control plots were trapped for three days prior to the second trapping session so all plots would have equal number of trap nights. The home range of most small mammals is approximately .08 to 10 acres (Burt and Grossenheider

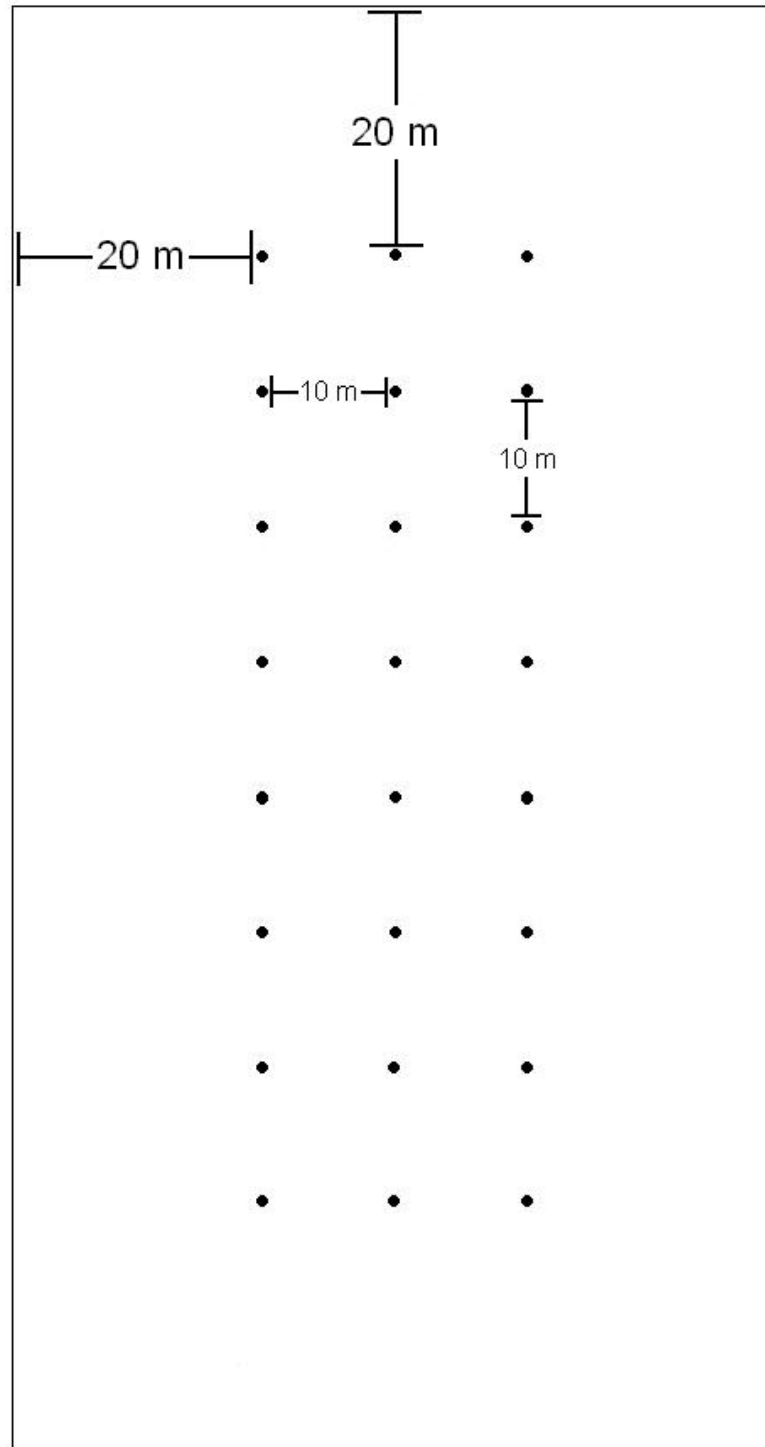


**Figure 2. Example of small mammal/habitat/understory vegetation sampling design for the 2005 long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

1980). Therefore, we assume any movements in or out of the annual burn treatments greater than that found during pre-treatment is a direct result of treatment. Traps were checked once daily between 0800 and 1300 hours and were placed out of direct sunlight to reduce the risk of heat-related mortality. All traps were baited using sunflower seeds and bedding was provided. Small mammal captures were identified, individually ear-tagged, weighed, aged, and sexed. Although pitfall traps are the preferred methodology for sampling shrews the protocol of our federal small mammal capture permit (IACUC protocol # 1201, TWRA collection permit # 1742) did not allow the use of pitfall traps. Shrews captured in the Sherman traps were released and not tagged.

### ***Understory Vegetation/Habitat Sampling***

Habitat sampling was conducted during each trap period using metric units. Horizontal, vertical, and canopy cover, and average height by vegetation type were sampled at each trap station, 24 sampling points per plot (Table 1). Horizontal cover was measured using 1-m<sup>2</sup> Daubenmire sample points (Daubenmire 1959). Percent cover of bare ground, dead organic matter, grasses, other herbaceous plants, non-woody vines, and woody plants were estimated from one meter above ground level. Vertical cover was measured in two randomly selected directions using a Nudds profile board. The Nudds profile board was divided into 4 height sections (0 to 0.5 m, 0.5 to 1.0 m, 1.0 to 1.5 m, and 1.5 to 2.0 m), each section with 30 squares (Nudds 1977). The percent cover for each section and a combined total were recorded from a distance of 5 meters. A square was considered covered if at least 50 percent was covered by vegetation. Canopy cover was

**Table 1. Habitat/understory vegetation characteristic variables with time period(s) measured and transformation type for the 2005 long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

| Variables                          | Time Period(s) <sup>1</sup> | Transformation |
|------------------------------------|-----------------------------|----------------|
| Canopy cover                       | 1, 2, 3                     | Normal         |
| Average combined vertical cover    | 1, 2, 3                     | Log            |
| 0 m to 0.5 m vertical cover        | 1, 2, 3                     | Log            |
| 0.5 m to 1 m vertical cover        | 1, 2, 3                     | Log            |
| 1 m to 1.5 m vertical cover        | 1, 2, 3                     | Log            |
| 1.5 m to 2 m vertical cover        | 1, 2, 3                     | Log            |
| Percent cover of bare ground       | 1, 2, 3                     | Log            |
| Percent cover of organic matter    | 1, 2, 3                     | Log            |
| Percent cover of grass             | 1, 2, 3                     | Log            |
| Percent cover of forbs             | 1, 2, 3                     | Log            |
| Percent cover of vines             | 1, 2, 3                     | Log            |
| Percent cover of woody vegetation  | 1, 2, 3                     | Normal         |
| Average height of grass            | 1, 2, 3                     | Normal         |
| Average height of forbs            | 1, 2, 3                     | Log            |
| Average height of vines            | 1, 2, 3                     | Log            |
| Average height of woody vegetation | 1, 2, 3                     | Normal         |

<sup>1</sup> Time periods – 1 = Pre-burn (March 11 - April 20), 2 = Post-burn (April 27 – June 1), 3 = End-of-season (July 12 – August 2).

measured using a densiometer. Average height by horizontal cover vegetation type was measured in centimeters to a maximum height of 150 centimeters.

## ***Data Analysis***

A summarization of means by treatment was performed to compare with Nichols (1971) and DeSelm et al. (1991) data and allow for description of stand development. Statistical analyses were conducted using SAS (SAS Institute Inc. 2003). Differences among treatments for density and basal area were tested using randomized block mixed models analysis of variance, blocking on location, conducted at  $\alpha = 0.05$ . Treatment was a fixed effect while location was the random effect. Differences among treatments and sampling periods were separately tested for each independent habitat variable (see Table 1 for explanatory habitat variables) and for average small mammal relative abundance using randomized block mixed models with repeated measures analysis of variance, blocking on location, conducted at  $\alpha = 0.05$ . Treatment and time were fixed effects while location was the random effect. The Shapiro-Wilk test was used to determine normality and Levene's test was used to determine equal variance. The variable total basal area was transformed using the log transformation. Transformations were used on habitat variables to attain normal distributions and equal variances (Table 1). Least squares means were compared using the Tukey's significant difference test (Quinn and Keough 2002).

Multiple linear regression (MLR) with stepwise selection was used to model average small mammal abundance by the 16 habitat/understory vegetation characteristics

measured in the habitat analysis across 3 time periods (Table 1). Average total relative abundance per plot of all unique individuals, average relative abundance per plot of unique white-footed mouse (*Peromyscus leucopus*) individuals, and average relative abundance per plot of unique pine vole (*Microtus pinetorum*) individuals were compared across all time periods, 3 replications  $\times$  3 treatments  $\times$  3 independent time periods (n=27), and analyzed at  $\alpha = 0.05$ . In a preliminary analysis, the MLR with stepwise selection model was run using the 16 habitat/understory vegetation characteristics and time period to test if time period was a significant factor. The time period factor was removed from the model and assumed independent when the MLR model did not select time period as significant and produced the same model as the 16 habitat/understory vegetation characteristics model. Although Freund and Littell (2000) indicates a variance inflation factor greater than 10 suggests a strong linear dependency, variables with a variance inflation factor greater than 5 that were highly correlated and biologically accounted for the same variation were removed for simplicity and to address collinearity (Quinn and Keough 2002).

## V. RESULTS

### *Forestry:*

#### **Stand History and Development**

The Highland Rim sub-climax pyric “barrens” historically had a low intensity frequent fire regime due to both natural and anthropogenic disturbances for thousands of years (DeSelm et al 1991, Haywood 1823). Native American cultures frequently used fire for land clearing and hunting in this area. European settlement continued the trend of frequent fire use; thus sustaining the sub-climax pyric system. Frequent fire was known to occur for at least 70 years prior to the University of Tennessee Forest Resources Research and Education Center’s acquisition of the land in 1960 (Lewis and Kneberg 1960, Seay 2005).

In 1963 at inception of the study, the forest was in poor condition with understocked, degraded hardwoods due to low site quality, poor previous forest management practices, overgrazing, and frequent fires. The structure was in the early stages of a two-aged forest; the mature, 80-year-old, overstory was sparsely stocked and open with the understory in the stand reinitiation phase. Basal area of the overstory averaged 50.9 ft<sup>2</sup>/ac, accounting for 119.0 stems/acre (Tables 2 and 3). The overstory was southern red oak. The woody understory was primarily shrub oak composed of southern

**Table 2. Basal area of midstory, overstory, and total for 1963, 1970, 1989, and 2005 for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

| Species                                | Date <sup>1,2,3,4</sup> | Burning Frequency     |           |       |                           |           |       |                  |           |       |
|----------------------------------------|-------------------------|-----------------------|-----------|-------|---------------------------|-----------|-------|------------------|-----------|-------|
|                                        |                         | -----Control-----     |           |       | -----5-year Periodic----- |           |       | -----Annual----- |           |       |
|                                        |                         | Midstory              | Overstory | Total | Midstory                  | Overstory | Total | Midstory         | Overstory | Total |
|                                        |                         | -----BA (ft²/ac)----- |           |       |                           |           |       |                  |           |       |
| Post oak<br><i>Quercus stellata</i>    | 1963                    | 15.9                  | 9.7       | 25.6  | 14.2                      | 9.3       | 23.5  | 16.0             | 11.4      | 27.4  |
|                                        | 1970                    | 16.8                  | 11.0      | 27.8  | 10.4                      | 13.3      | 23.7  | 11.6             | 12.8      | 24.4  |
|                                        | 1989                    |                       |           | 28.0  |                           |           | 18.7  |                  |           | 19.3  |
|                                        | 2005                    | 7.4                   | 27.7      | 35.1  | 0.5                       | 12.8      | 13.3  | 5.9              | 15.3      | 21.1  |
| Scarlet oak<br><i>Q. coccinea</i>      | 1963                    | 0                     | 1.3       | 1.3   | 10.7                      | 0.6       | 11.3  | 6.6              | 2.3       | 8.9   |
|                                        | 1970                    | 0                     | 1.6       | 1.6   | 12.8                      | 0.8       | 13.6  | 5.7              | 3.2       | 8.9   |
|                                        | 1989                    |                       |           | 13.7  |                           |           | 21.0  |                  |           | 7.3   |
|                                        | 2005                    | 1.4                   | 3.3       | 4.7   | 0                         | 0         | 0     | 0.9              | 6.6       | 7.5   |
| Southern red oak<br><i>Q. falcata</i>  | 1963                    | 10.4                  | 6.8       | 17.2  | 8.0                       | 6.0       | 14.0  | 11.5             | 5.0       | 16.5  |
|                                        | 1970                    | 11.1                  | 8.8       | 19.9  | 6.5                       | 8.7       | 15.2  | 11.4             | 7.2       | 18.6  |
|                                        | 1989                    |                       |           | 16.8  |                           |           | 14.1  |                  |           | 22.1  |
|                                        | 2005                    | 9.0                   | 39.5      | 48.5  | 0                         | 21.7      | 21.7  | 0.9              | 28.5      | 29.4  |
| Blackjack oak<br><i>Q. marilandica</i> | 1963                    | 0.9                   | 0         | 0.9   | 1.4                       | 0.6       | 2.0   | 0.9              | 0.7       | 1.6   |
|                                        | 1970                    | 1.0                   | 0         | 1.0   | 1.4                       | 0.6       | 2.0   | 0.6              | 0.8       | 1.4   |
|                                        | 1989                    |                       |           | 0     |                           |           | 0     |                  |           | 1.0   |
|                                        | 2005                    | 0                     | 0         | 0     | 0                         | 0         | 0     | 0                | 1.2       | 1.2   |
| Black oak<br><i>Q. velutina</i>        | 1963                    | 0                     | 0         | 0.1   | 0                         | 0         | 0.1   | 0.8              | 0         | 0.8   |
|                                        | 1970                    | 0                     | 0         | 0.1   | 0                         | 0         | 0.1   | 0.9              | 0         | 0.9   |
|                                        | 1989                    |                       |           | 0     |                           |           | 0     |                  |           | 1.1   |
|                                        | 2005                    | 0                     | 0         | 0     | 0                         | 0         | 0     | 0                | 1.7       | 1.7   |

Table 2. Continued.

| Species                                    | Date <sup>1,2,3,4</sup> | Burning Frequency                  |           |       |                           |           |       |                  |           |       |
|--------------------------------------------|-------------------------|------------------------------------|-----------|-------|---------------------------|-----------|-------|------------------|-----------|-------|
|                                            |                         | -----Control-----                  |           |       | -----5-year Periodic----- |           |       | -----Annual----- |           |       |
|                                            |                         | Midstory                           | Overstory | Total | Midstory                  | Overstory | Total | Midstory         | Overstory | Total |
|                                            |                         | -----BA (ft <sup>2</sup> /ac)----- |           |       |                           |           |       |                  |           |       |
| Willow oak<br><i>Q. phellos</i>            | 1963                    | 0.3                                | 0         | 0.3   | 0                         | 0         | 0     | 0                | 0         | 0     |
|                                            | 1970                    | 0.6                                | 0         | 0.6   | 0                         | 0         | 0     | 0                | 0         | 0     |
|                                            | 1989                    |                                    |           | 0     |                           |           | 1.4   |                  |           | 0     |
|                                            | 2005                    | 4.8                                | 10.0      | 14.8  | 0.2                       | 0         | 0.2   | 0                | 0         | 0     |
| White oak<br><i>Q. alba</i>                | 1963                    | 0                                  | 1.3       | 1.3   | 0                         | 0         | 0     | 0                | 0         | 0     |
|                                            | 1970                    | 0                                  | 1.5       | 1.5   | 0                         | 0         | 0     | 0                | 0         | 0     |
|                                            | 1989                    |                                    |           | 5.0   |                           |           | 0     |                  |           | 1.5   |
|                                            | 2005                    | 1.0                                | 5.6       | 6.6   | 0                         | 0         | 0     | 0                | 2.2       | 2.2   |
| Red Maple<br><i>Acer rubrum</i>            | 1963                    |                                    |           |       |                           |           |       |                  |           |       |
|                                            | 1970                    |                                    |           |       |                           |           |       |                  |           |       |
|                                            | 1989                    |                                    |           | 0     |                           |           | 2.4   |                  |           | 0     |
|                                            | 2005                    | 0.2                                | 0         | 0.2   | 0.4                       | 9.0       | 9.4   | 0                | 0         | 0     |
| Sweetgum<br><i>Liquidamber styraciflua</i> | 1963                    |                                    |           |       |                           |           |       |                  |           |       |
|                                            | 1970                    |                                    |           |       |                           |           |       |                  |           |       |
|                                            | 1989                    |                                    |           | 0     |                           |           | 0.5   |                  |           | 0     |
|                                            | 2005                    | 1.0                                | 0         | 1.0   | 0                         | 0         | 0     | 0                | 0         | 0     |
| Total                                      | 1963                    | 27.5                               | 19.1      | 46.6  | 34.4                      | 16.5      | 50.9  | 35.8             | 19.4      | 55.2  |
|                                            | 1970                    | 29.5                               | 22.9      | 52.4  | 31.1                      | 23.4      | 54.6  | 30.2             | 24.0      | 54.2  |
|                                            | 1989                    |                                    |           | 63.5  |                           |           | 58.1  |                  |           | 52.3  |
|                                            | 2005                    | 24.8                               | 86.1      | 110.9 | 1.1                       | 43.5      | 44.6  | 7.7              | 55.5      | 63.2  |

<sup>1</sup> 1963 data collected by Forestry Department personnel – Inventory only includes oak species.

<sup>2</sup> 1970 data collected by G. M. Nichols – Inventory only includes oak species.

<sup>3</sup> 1989 data collected by DeSelm et al. – Complete inventory of all species present and total density only. Authors did not separate midstory and overstory.

<sup>4</sup> 2005 data collected by R. L. Stratton – Complete inventory of all species present.

**Table 3. Density of midstory, overstory, and total for 1963, 1970, 1989, and 2005 for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

| Species                                | Date <sup>1,2,3,4</sup> | Burning Frequency            |           |       |                           |           |       |                  |           |       |
|----------------------------------------|-------------------------|------------------------------|-----------|-------|---------------------------|-----------|-------|------------------|-----------|-------|
|                                        |                         | -----Control-----            |           |       | -----5-year Periodic----- |           |       | -----Annual----- |           |       |
|                                        |                         | Midstory                     | Overstory | Total | Midstory                  | Overstory | Total | Midstory         | Overstory | Total |
|                                        |                         | -----Density (stems/ac)----- |           |       |                           |           |       |                  |           |       |
| Post oak<br><i>Quercus stellata</i>    | 1963                    | 50                           | 6         | 56    | 38                        | 9         | 47    | 48               | 12        | 60    |
|                                        | 1970                    | 43                           | 6         | 49    | 30                        | 13        | 43    | 32               | 13        | 45    |
|                                        | 1989                    |                              |           | 33    |                           |           | 27    |                  |           | 33    |
|                                        | 2005                    | 17                           | 23        | 40    | 8                         | 9         | 17    | 15               | 13        | 28    |
| Scarlet oak<br><i>Q. coccinea</i>      | 1963                    | 0                            | 4         | 4     | 45                        | 1         | 46    | 17               | 1         | 18    |
|                                        | 1970                    | 0                            | 4         | 4     | 43                        | 1         | 44    | 12               | 2         | 14    |
|                                        | 1989                    |                              |           | 30    |                           |           | 14    |                  |           | 8     |
|                                        | 2005                    | 7                            | 3         | 10    | 0                         | 0         | 0     | 2                | 5         | 7     |
| Southern red oak<br><i>Q. falcata</i>  | 1963                    | 32                           | 6         | 38    | 23                        | 6         | 29    | 35               | 5         | 40    |
|                                        | 1970                    | 25                           | 7         | 32    | 17                        | 7         | 34    | 30               | 6         | 36    |
|                                        | 1989                    |                              |           | 12    |                           |           | 12    |                  |           | 21    |
|                                        | 2005                    | 27                           | 21        | 48    | 0                         | 13        | 13    | 2                | 18        | 20    |
| Blackjack oak<br><i>Q. marilandica</i> | 1963                    | 2                            | 0         | 2     | 5                         | 1         | 6     | 3                | 1         | 4     |
|                                        | 1970                    | 2                            | 0         | 2     | 5                         | 1         | 6     | 2                | 1         | 3     |
|                                        | 1989                    |                              | 0         | 0     |                           |           | 0     |                  |           | 2     |
|                                        | 2005                    | 0                            | 0         | 0     | 0                         | 0         | 0     | 0                | 2         | 2     |
| Black oak<br><i>Q. velutina</i>        | 1963                    | 0                            |           | 1     | 0                         | 1         | 1     | 3                | 0         | 3     |
|                                        | 1970                    | 0                            | 1         | 1     | 0                         | 1         | 1     | 3                | 0         | 3     |
|                                        | 1989                    |                              | 0         | 0     |                           |           | 0     |                  |           | 2     |
|                                        | 2005                    | 0                            | 0         | 0     | 0                         | 0         | 0     | 0                | 2         | 2     |

**Table 3. Continued.**

| Species                                        | Date <sup>1,2,3,4</sup> | Burning Frequency            |           |       |                           |           |       |                  |           |       |
|------------------------------------------------|-------------------------|------------------------------|-----------|-------|---------------------------|-----------|-------|------------------|-----------|-------|
|                                                |                         | -----Control-----            |           |       | -----5-year Periodic----- |           |       | -----Annual----- |           |       |
|                                                |                         | Midstory                     | Overstory | Total | Midstory                  | Overstory | Total | Midstory         | Overstory | Total |
|                                                |                         | -----Density (stems/ac)----- |           |       |                           |           |       |                  |           |       |
| Willow oak<br><i>Q. phellos</i>                | 1963                    | 2                            | 0         | 2     | 0                         | 0         | 0     | 0                | 0         | 0     |
|                                                | 1970                    | 2                            | 0         | 2     | 0                         | 0         | 0     | 0                | 0         | 0     |
|                                                | 1989                    |                              |           | 0     |                           |           | 2     |                  |           | 0     |
|                                                | 2005                    | 13                           | 8         | 21    | 2                         | 0         | 2     | 0                | 0         | 0     |
| White oak<br><i>Q. alba</i>                    | 1963                    | 0                            | 1         | 1     | 0                         | 0         | 0     | 0                | 0         | 0     |
|                                                | 1970                    | 0                            | 1         | 1     | 0                         | 0         | 0     | 0                | 0         | 0     |
|                                                | 1989                    |                              |           | 6     |                           |           | 0     |                  |           | 1     |
|                                                | 2005                    | 5                            | 3         | 8     | 0                         | 0         | 0     | 0                | 1         | 1     |
| Red Maple<br><i>Acer rubrum</i>                | 1963                    |                              |           |       |                           |           |       |                  |           |       |
|                                                | 1970                    |                              |           |       |                           |           |       |                  |           |       |
|                                                | 1989                    |                              |           | 0     |                           |           | 4     |                  |           | 0     |
|                                                | 2005                    | 2                            | 0         | 2     | 7                         | 7         | 14    | 0                | 0         | 0     |
| Sweetgum<br><i>Liquidamber<br/>styraciflua</i> | 1963                    |                              |           |       |                           |           |       |                  |           |       |
|                                                | 1970                    |                              |           |       |                           |           |       |                  |           |       |
|                                                | 1989                    |                              |           | 0     |                           |           | 4     |                  |           | 0     |
|                                                | 2005                    | 5                            | 0         | 5     | 0                         | 0         | 0     | 0                | 0         | 0     |
| Total                                          | 1963                    | 86                           | 18        | 104   | 111                       | 18        | 129   | 106              | 19        | 125   |
|                                                | 1970                    | 82                           | 19        | 91    | 95                        | 23        | 118   | 79               | 22        | 101   |
|                                                | 1989                    |                              |           | 83    |                           |           | 69    |                  |           | 66    |
|                                                | 2005                    | 76                           | 58        | 134   | 17                        | 29        | 46    | 19               | 41        | 60    |

<sup>1</sup> 1963 data collected by Forestry Department personnel – Inventory only includes oak species

<sup>2</sup> 1970 data collected by G. M. Nichols – Inventory only includes oak species

<sup>3</sup> 1989 data collected by DeSelm et al. – Complete inventory of all species present and total density only. Authors did not separate midstory and overstory.

<sup>4</sup> 2005 data collected by R. L. Stratton – Complete inventory of all species present.

red oak, scarlet oak, post oak, black gum (*Nyssa sylvatica*), winged sumac (*Rhus copallina*), and mockernut hickory (*Carya tomentosa*).

## **Control**

By 1970, structure of the vegetation across treatments began to diverge (Tables 2 and 3). The control treatment developed into a two-aged stratified mixture with an open overstory and a defined midstory entering the stem exclusion stage. Basal area increased from 46.6 ft<sup>2</sup>/ac to 52.4 ft<sup>2</sup>/ac while density decreased from 104.0 stems/ac to 91.0 stems/ac. The diameters of most of the trees were primarily in the midstory diameter classes and accounted for 90 percent of the density (Table 2). Understory densities of the control treatments averaged more than 8,000 stems/ac (Table 4).

In 1989, due to lack of fire, the structure of the control treatment was a closed canopy forest. The basal area increased to 63.5 ft<sup>2</sup>/ac and the density decreased to 83.0 stems/ac. The lack of sunlight in the understory resulted in decreased regeneration densities from 8,080 stems/ac to 2,517 stems/ac.

In 2005, the structure was a closed canopy, stratified mixture with a well defined midstory and little understory. The basal area and overstory density increased to 110.9 ft<sup>2</sup>/ac and 134.0 stems/ac, respectively. The diameter distribution shifted as trees recruited into the larger overstory diameter classes. The midstory density decreased slightly while overstory density increased, thus shifting the percent of total density to 57 percent and 43 percent, respectively (Figures 3, 4, and 5). Figures 3, 4, and 5 present trend data because

**Table 4. Average stems per acre of understory hardwood species for 1963, 1970, 1989, and 2005 for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

| Species                                         | Date <sup>1,2</sup> | -----Density (stems/ac)----- |                 |        |
|-------------------------------------------------|---------------------|------------------------------|-----------------|--------|
|                                                 |                     | Control                      | 5-year Periodic | Annual |
| Southern red oak<br><i>Quercus falcate</i>      | 1970                | 1,512                        | 3,424           | 3,980  |
|                                                 | 2005                | 100                          | 883             | 666    |
| Post oak<br><i>Q. stellata</i>                  | 1970                | 1,223                        | 2,001           | 2,401  |
|                                                 | 2005                | 0                            | 817             | 133    |
| Scarlet oak<br><i>Q. coccinea</i>               | 1970                | 1,356                        | 2,023           | 1,979  |
|                                                 | 2005                | 67                           | 167             | 0      |
| Blackjack oak<br><i>Q. marilandica</i>          | 1970                | 22                           | 467             | 67     |
|                                                 | 2005                | 0                            | 0               | 0      |
| Black oak<br><i>Q. velutina</i>                 | 1970                | 0                            | 0               | 0      |
|                                                 | 2005                | 33                           | 0               | 0      |
| Willow oak<br><i>Q. phellos</i>                 | 1970                | 0                            | 0               | 0      |
|                                                 | 2005                | 50                           | 0               | 0      |
| White oak<br><i>Q. alba</i>                     | 1970                | 0                            | 0               | 0      |
|                                                 | 2005                | 0                            | 233             | 0      |
| Hickory sp.<br><i>Carya sp.</i>                 | 1970                | 267                          | 378             | 400    |
|                                                 | 2005                | 167                          | 100             | 467    |
| Sweetgum<br><i>Liquidamber styraciflua</i>      | 1970                | 222                          | 0               | 0      |
|                                                 | 2005                | 400                          | 17              | 0      |
| Red maple<br><i>Acer rubrum</i>                 | 1970                | 111                          | 0               | 0      |
|                                                 | 2005                | 367                          | 1,250           | 0      |
| Yellow poplar<br><i>Liriodendron tulipifera</i> | 1970                | 0                            | 0               | 0      |
|                                                 | 2005                | 383                          | 0               | 0      |

**Table 4. Continued.**

| Species                     | Date <sup>1,2</sup> | -----Density (stems/ac)----- |                 |        |
|-----------------------------|---------------------|------------------------------|-----------------|--------|
|                             |                     | Control                      | 5-year Periodic | Annual |
| Sumac sp.                   | 1970                | 1,200                        | 2,001           | 1,734  |
| <i>Rhus sp.</i>             | 2005                | 0                            | 5,183           | 11,600 |
| Sassafras                   | 1970                | 89                           | 1,401           | 378    |
| <i>Sassafras albidum</i>    | 2005                | 33                           | 167             | 267    |
| Dogwood                     | 1970                | 378                          | 0               | 178    |
| <i>Cornus florida</i>       | 2005                | 0                            | 0               | 0      |
| Black gum                   | 1970                | 1,534                        | 1,356           | 1,423  |
| <i>Nyssa sylvatica</i>      | 2005                | 583                          | 567             | 0      |
| American elm                | 1970                | 22                           | 0               | 0      |
| <i>Ulmus americana</i>      | 2005                | 150                          | 0               | 0      |
| American Plum               | 1970                | 0                            | 0               | 0      |
| <i>Prunus americana</i>     | 2005                | 0                            | 50              | 0      |
| White pine                  | 1970                | 0                            | 0               | 0      |
| <i>Pinus strobus</i>        | 2005                | 100                          | 0               | 0      |
| Eastern redcedar            | 1970                | 0                            | 0               | 0      |
| <i>Juniperus virginiana</i> | 2005                | 83                           | 0               | 0      |
| Blueberry                   | 1970                | 134                          | 0               | 0      |
| <i>Vaccinium sp.</i>        | 2005                | -                            | -               | -      |
| Total                       | 1970                | 8,070                        | 12,051          | 12,540 |
|                             | 2005                | 2,517                        | 9,383           | 13,133 |

<sup>1</sup> 1970 data collected by G. M. Nichols.

<sup>2</sup> 2005 data collected by R. L. Stratton – Blueberry was not included in inventory.

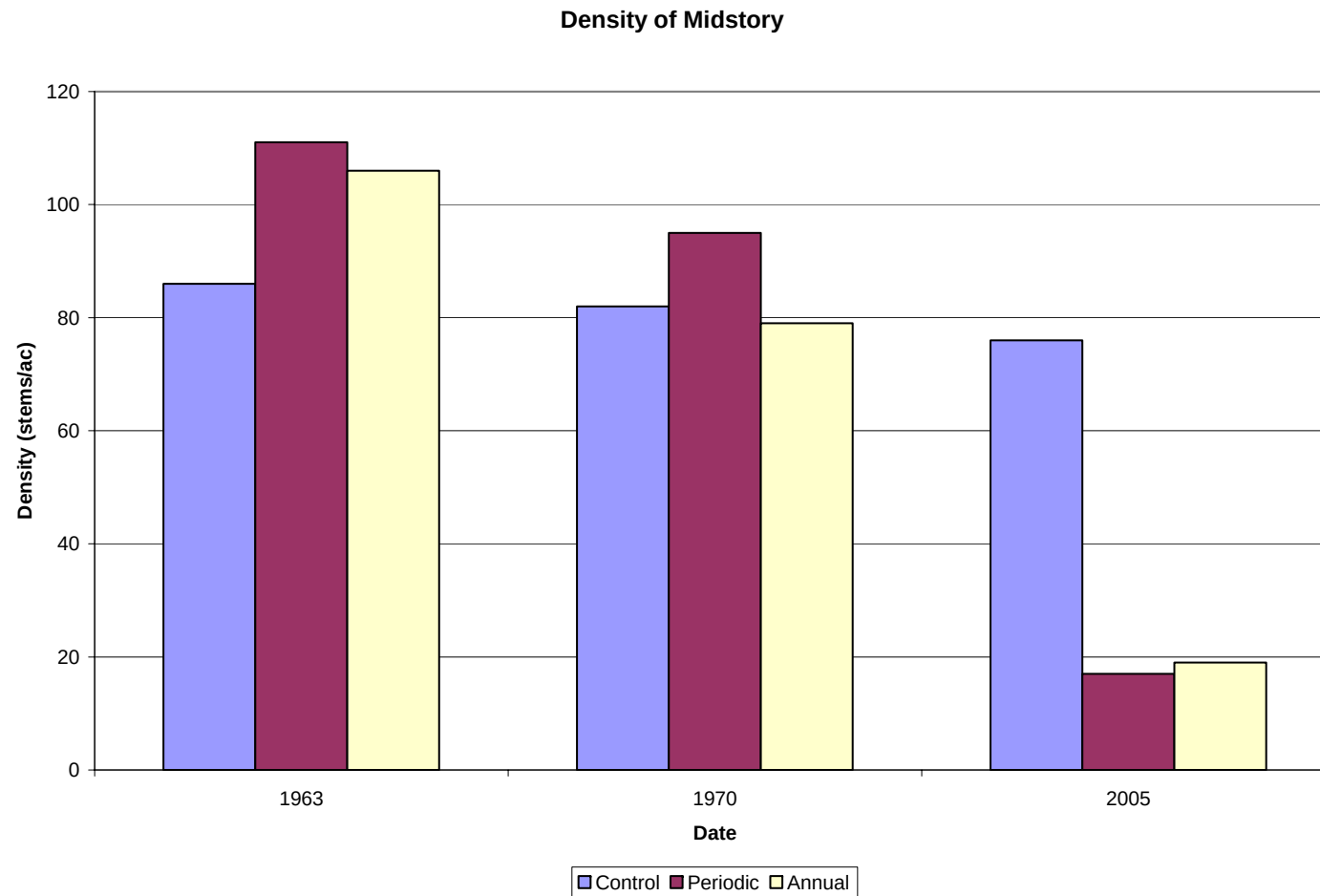


**Figure 3. Density of midstory for the 1963, 1970, and 2005 growing seasons for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN. Dates on the x-axis are not to scale.**

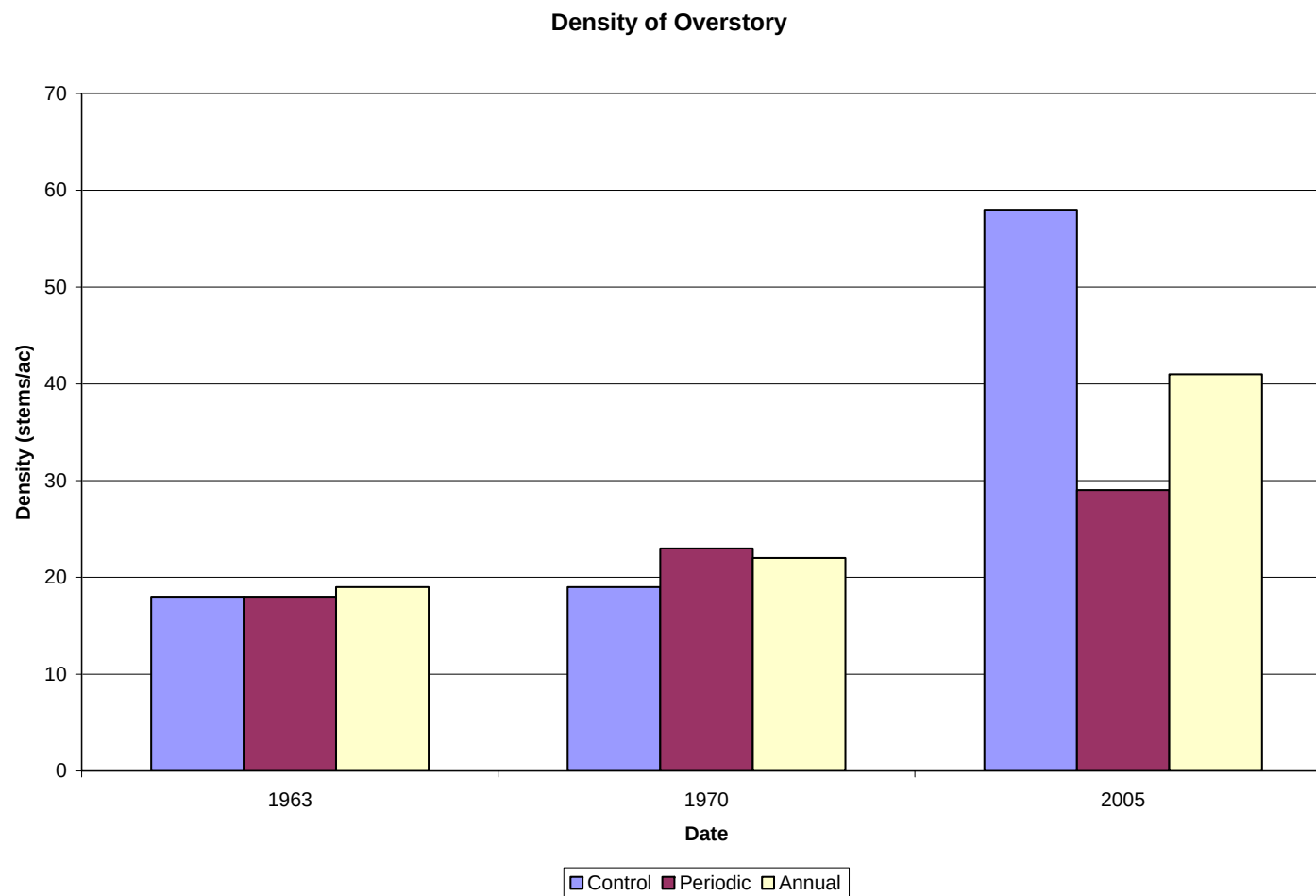


**Figure 4. Density of overstory for the 1963, 1970, and 2005 growing seasons for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN. Dates on the x-axis are not to scale.**

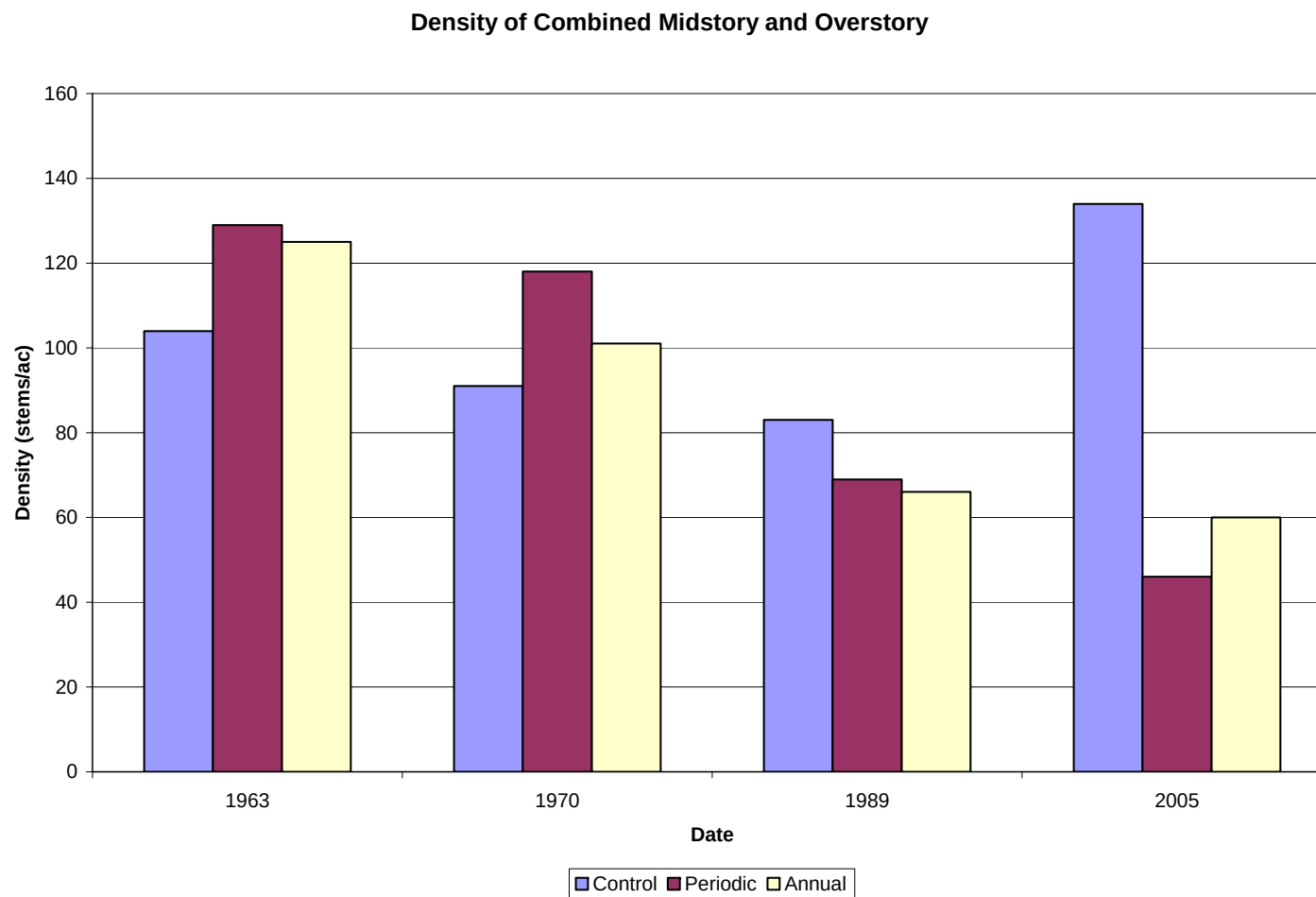


**Figure 5. Density of combined midstory and overstory for the 1963, 1970, 1989, and 2005 growing seasons for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN. Dates on the x-axis are not to scale.**

data were not directly comparable across collection periods. Only means were reported for 1963, 1970, and 1989 and data were not collected using the same sampling scheme. The 1963 and 1970 collection periods inventoried only midstory separately, the 1989 collection period inventoried all species but combined overstory and midstory, and the 2005 collection period inventoried all species for overstory and midstory separately, therefore statistical analyses were only performed on the 2005 data and will be discussed later.

### **Periodic**

The canopy structure of the 5-year periodic burn treatment changed little between inception and 1970. The understory density increased to approximately 13,000 stems/ac (Table 4) and herbaceous species densities increased (Nichols 1971). Basal area increased from 50.9 ft<sup>2</sup>/ac to 54.6 ft<sup>2</sup>/ac while density decreased from 129.0 stems/ac to 118.0 stems/ac. Similar to the control treatment the diameters of most trees were primarily in the midstory diameter classes and accounted for 81 percent of the density (Table 2).

By 1989, the open understocked overstory structure changed from having small canopy gaps to large canopy gaps. The basal area increased to 58.1 ft<sup>2</sup>/ac however, the density decreased 58 percent to 69 stems/ac. DeSelm and Clebsch (1991) described that the cyclical changes in woody and herbaceous understory species were correlated with the fire return interval.

Structure in 2005 was similar to 1989. Basal area decreased 23 percent to 44.6 ft<sup>2</sup>/ac and density decreased to 46.0 stems/ac. This decrease in density and basal area is primarily due to overstory mortality and some blow-down. The diameter distribution shifted as trees recruited into the larger overstory diameter classes and many of the midstory trees died. The midstory density has decreased while overstory density increased slightly, thus shifting the percent of total density to 37 percent and 63 percent, respectively (Figures 3, 4, and 5). There is little recruitment or ingrowth of regeneration into larger diameter classes and density of regeneration decreased to approximately 9,400 stems/ac.

### **Annual**

The structure of the annual burning treatment developed into oak woodlands with an open, understocked overstory, some midstory, and a grassy-woody understory by 1970. The understory density averaged 12,540 stems/ac (Table 4) and grass species increased. Unlike the control and 5-year periodic burning treatments, the overstory in the annual burning treatment decreased in basal area, 55.2 ft<sup>2</sup>/ac to 54.2 ft<sup>2</sup>/ac, and density, 125.0 stems/ac to 101.0 stems/ac, by 1970. Similar to the control and 5-year periodic treatments, the diameters of most trees were primarily in the midstory diameter classes and accounted for 85 percent of the density (Table 2).

By 1989, the structure was similar to oak savanna with a 65 percent decrease in the overstory density and sparse midstory present. The density and basal area decreased to 66.0 stems/ac and 52.3 ft<sup>2</sup>/ac, respectively.

Structure in 2005 was similar to 1989, oak savanna characterized by open, understocked overstory with small canopy gaps, little midstory, and a grassy understory with little woody regeneration. The basal area increased to 63.2 ft<sup>2</sup>/ac and the overstory density decreased to 60.0 stems/ac. Similar to the 5-year periodic treatment, the midstory density has decreased while overstory density increased, thus shifting the percent of total density to 32 percent and 68 percent, respectively (Figures 3, 4, and 5). There is little recruitment of regeneration into larger size classes; however density of regeneration has increased to approximately 13,100 stems/ac.

### **Diameter Distribution**

Diameter distribution between treatments varied greatly. The control treatment had the typical reverse J-shaped distribution skewed toward the smaller diameter classes (Figure 6). The greatest numbers of stems per acre were in the lowest diameter classes and stems per acre decreased as diameter increased. The annual treatment had a bimodal distribution skewed toward the overstory size classes (Figure 7). The majority of the trees were in the 9 in to 13 in diameter classes and the 19 in to 21 in diameter classes. Unlike the control treatment, the smaller diameter classes had less stems per acre than the larger diameter classes. The 5-year periodic treatment had a right-skewed flattened distribution (Figure 8). Similar to the annual treatment, the 5-year periodic treatment had few trees in the 5 in to 9 in diameter classes.

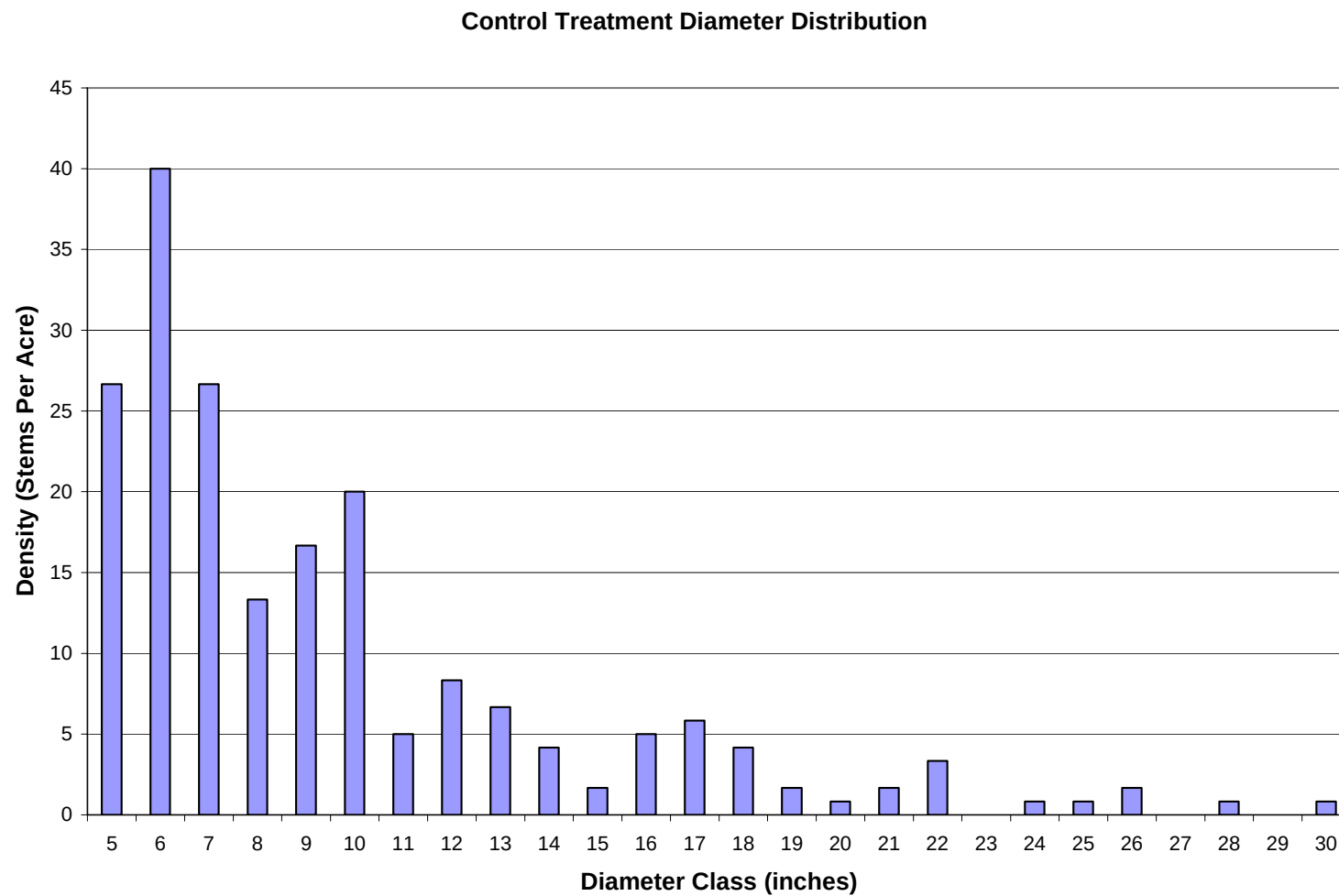


**Figure 6. Diameter distribution by one inch diameter classes of the control treatment in the 2005 growing season for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

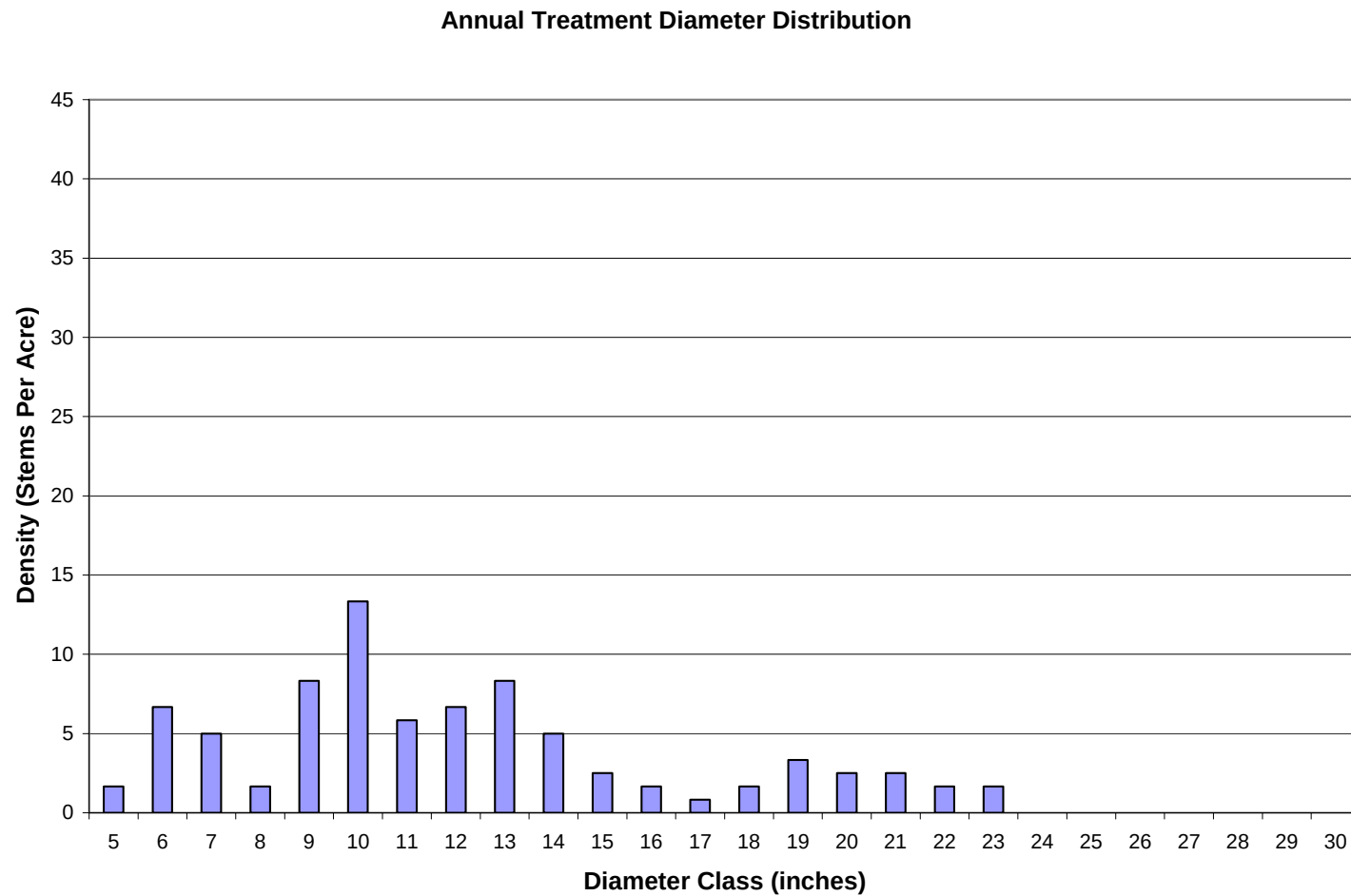


**Figure 7. Diameter distribution by one inch diameter classes of the annual burn treatment in the 2005 growing season for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

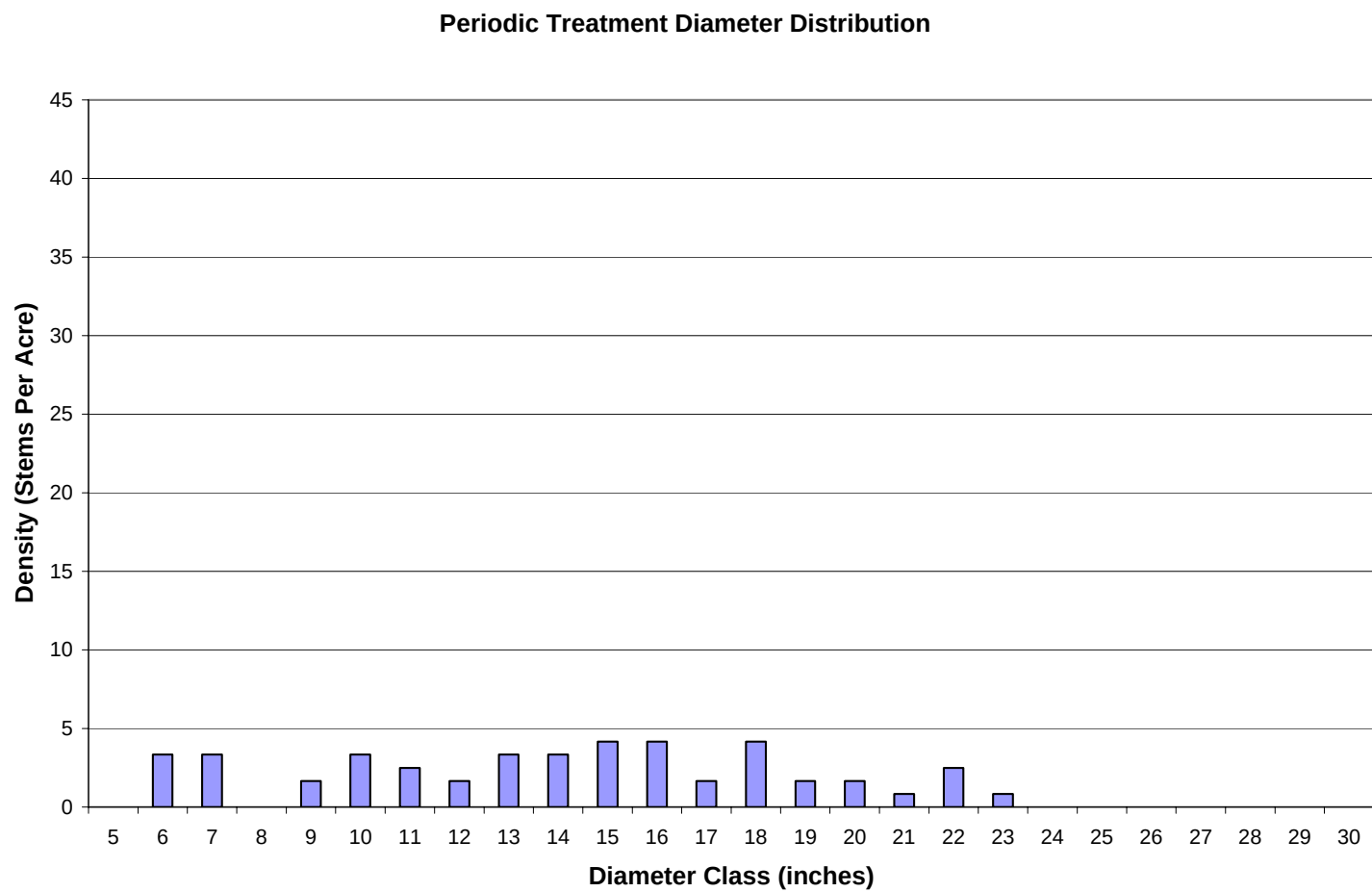


**Figure 8. Diameter distribution by one inch diameter classes of the 5-year periodic burn treatment in the 2005 growing season for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

## Density and Basal Area

Overall forest structure ( $n = 9$ ) differed among treatments in density ( $P = 0.010$ ) and basal area per acre ( $P = 0.043$ ). Average density among the annual, 5-year periodic, and control treatments were 58.3, 56.7, and 133.3 stems/ac, respectively (Table 5). The Tukey's significant difference test found differences in density between the annual treatment and control treatment and between the periodic treatment and the control treatment. Average basal area among the annual, 5-year periodic, and control treatments were 61.0, 54.8.7, and 110.4 ft<sup>2</sup>/ac, respectively (Table 5). The Tukey's significant difference test found differences in basal area between the control treatment and 5-year periodic treatment.

No differences were detected for overstory density and basal area ( $n = 9$ ) among treatments ( $P = 0.296$  and  $P = 0.181$ , respectively). Average density of the overstory among the annual, 5-year periodic, and control treatments were 40.0, 40.0, and 58.3 stems/ac, respectively (Table 5). Average basal area of the overstory among the annual, 5-year periodic, and control treatments were 55.5, 55.5, and 86.3 ft<sup>2</sup>/ac, respectively (Table 5).

Midstory density ( $n = 9$ ) differed among treatments ( $P = 0.048$ ) but no differences were detected in basal area ( $n = 9$ ) among treatments ( $P = 0.051$ ). Average density of the midstory among the annual, 5-year periodic, and control treatments were 18.3, 16.7, and 75.0, respectively (Table 5). Although the ANOVA p-value was significant, the Tukey's

**Table 5. Mixed models ANOVA for stand structure by treatment for the 2005 growing season for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

| Treatment | -----Overall-----                         |                                                  | -----Overstory-----          |                                     | -----Midstory-----           |                                     |
|-----------|-------------------------------------------|--------------------------------------------------|------------------------------|-------------------------------------|------------------------------|-------------------------------------|
|           | Stems per Acre<br>(stems/ac) <sup>1</sup> | Basal Area<br>(ft <sup>2</sup> /ac) <sup>1</sup> | Stems per Acre<br>(stems/ac) | Basal Area<br>(ft <sup>2</sup> /ac) | Stems per Acre<br>(stems/ac) | Basal Area<br>(ft <sup>2</sup> /ac) |
| Annual    | 58.8 A                                    | 61.0 AB                                          | 40.0                         | 55.5                                | 18.3                         | 7.7                                 |
| Periodic  | 56.7 A                                    | 54.8 A                                           | 40.0                         | 55.5                                | 16.7                         | 1.2                                 |
| Control   | 133.3 B                                   | 110.4 B                                          | 58.3                         | 86.3                                | 75.0                         | 24.8                                |

Results of post-ANOVA Tukey's significant difference test. Same letter indicates no significant difference within columns detected between treatments at the 0.05 level.

<sup>1</sup>Variable is significant at  $\alpha = 0.05$  level.

significant difference test found no differences between the treatments. Average basal area of the midstory among the annual, 5-year periodic, and control treatments were 7.7, 1.2, and 24.8 ft<sup>2</sup>/ac, respectively (Table 5).

## **Regeneration**

Regeneration density and composition changed by treatment and throughout time. The control treatment shows a decreasing trend in stems per acre from 1970 to 2005. Total density decreased 69% from 8,070 stems/ac to 2,517 stems/ac (Table 4). Between 1970 and 2005, 5 new species, black oak, willow oak, yellow poplar, white pine, and eastern redcedar, established in the understory, while 4 species, post oak, blackjack oak, winged sumac, and dogwood dropped out of the system.

The 5-year periodic treatment also shows a decreasing trend in density from 12,051 stems/ac to 9,383 stems/ac (Table 4). Within this 22% decrease in density, species composition shifted from primarily oak dominated to sumac dominated with a strong red maple component. Although white oak established in the understory between the time periods, oak composition decreased 72% from 7,615 stems/ac to 1,876 stems/ac and blackjack oak dropped out of the understory.

Density in the annual treatment increased from 12,540 stems/ac to 13,133 stems/ac. Similar to the 5-year periodic treatment species composition shifted from oak dominated to sumac dominated (Table 4). Sumac density increased 669% from 1,734

stems/ac to 11,600 stems/ac while oak densities decreased 91% from 8,427 stems/ac to 799 stems/ac. Four species dropped out of the understory including scarlet oak, blackjack oak, black gum, and dogwood.

## ***Understory Vegetation/Habitat Characteristics:***

### **Canopy Cover**

Canopy cover ( $n = 27$ ) differed among treatments ( $P = 0.006$ ) and between time periods ( $P < 0.001$ ). Time by treatment interactions were also present ( $P = 0.009$ ). Mean canopy cover estimates among the annual, 5-year periodic, and control treatments were 60.7, 49.5, and 90.5%, respectively (Table 6). The Tukey's significant difference test found differences in canopy cover between the control and the burn treatments but no differences between the annual and 5-year periodic burn treatments. Time period mean differences between the pre-burn, post-burn, and end of season were 48.1, 76.4, and 76.2%, respectively. The Tukey's significant difference test found differences in canopy cover between the pre-burn time period and the two post-burn time periods but no differences between the two post-burn time periods. The time by treatment interactions were due to differences in stage of leaf out as a result of density between the burn treatments and the control. The pre-burn measurements were taken prior to leaf out while the post-burn measurements and end of season measurements were taken after leaves had fully formed. The annual and 5-year periodic treatments had similar temporal leaf out responses while the control responded differently. The stem density of the overstory and midstory was greater and available growing space was less in the control treatment. Greater increases in percent cover during the three measurement periods occurred in the burn treatments because more growing space and sunlight were available for vegetation growth as compared to greater stem densities and closed canopies of the control.

**Table 6. Mixed models repeated measures ANOVA for percent canopy cover by treatment, time period, and time by treatment interactions for the 2005 growing season for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

| <b>Treatment</b> | <b>Percent Canopy Cover (%)<sup>1</sup></b> |
|------------------|---------------------------------------------|
| Annual           | 60.7 A                                      |
| Periodic         | 49.5 A                                      |
| Control          | 90.5 B                                      |

| <b>Time period</b> | <b>Percent Canopy Cover (%)<sup>1</sup></b> |
|--------------------|---------------------------------------------|
| Pre-burn           | 48.1 A                                      |
| Post-burn          | 76.4 B                                      |
| End-of-season      | 76.2 B                                      |

| <b>Time × Treatment Interaction</b> | <b>Percent Canopy Cover (%)<sup>1</sup></b> |
|-------------------------------------|---------------------------------------------|
| Annual Pre-burn                     | 34.7                                        |
| Annual Post-burn                    | 74.6                                        |
| Annual End-of-season                | 73.0                                        |
| Periodic Pre-burn                   | 28.5                                        |
| Periodic Post-burn                  | 58.2                                        |
| Periodic End-of-season              | 61.7                                        |
| Control Pre-burn                    | 81.1                                        |
| Control Post-burn                   | 96.5                                        |
| Control End-of-season               | 94.0                                        |

Results of post-ANOVA Tukey's significant difference test. Same letter indicates no significant difference detected between treatments within a factor at the 0.05 level.

<sup>1</sup>Factor is significant at  $\alpha = 0.05$  level.

## **Average Combined Vertical Cover**

Average combined vertical cover ( $n = 27$ ) differed among treatments ( $P < 0.001$ ) and between time periods ( $P < 0.001$ ). Time by treatment interactions were also present ( $P < 0.001$ ). Mean vertical cover among the annual, 5-year periodic, and control treatments were 4.2, 36.9, and 15.9%, respectively (Table 7). The Tukey's significant difference test found all three treatments were different from each other. Time period mean differences between the pre-burn, post-burn, and end of season were 7.7, 9.3, and 35.4%, respectively. The Tukey's significant difference test found differences between the end of season time period and the pre-burn time period and the end of season time period and the post-burn time period. The time by treatment interactions present resulted from the reduction of vegetation in the annual treatment post-burn as compared to the continual growth of vegetation in the unburned 5-year periodic and the control treatments. The 5-year periodic and control treatments responded similarly with increasing percent vertical cover throughout the season. The annual burn, which occurred between the pre-burn and the post-burn periods, removed much of the herbaceous understory, thus vertical cover during the post-burn period decreased rather than increased as seen in the unburned treatments.

## **Vertical Cover 0 m to 0.5 m**

Vertical cover for the 0 m to 0.5 m section ( $n = 27$ ) differed among treatments ( $P < 0.001$ ) and time periods ( $P < 0.001$ ). Time by treatment interactions were also present

**Table 7. Mixed models repeated measures ANOVA for percent vertical cover by treatment and time period for the 2005 growing season for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

| <b>Treatment</b> | <b>Combined Total (%)<sup>1</sup></b> | <b>0 m to 0.5 m (%)<sup>1</sup></b> | <b>0.5 m to 1.0 m (%)<sup>1</sup></b> | <b>1.0 m to 1.5 m (%)<sup>1</sup></b> | <b>1.5 m to 2.0 m (%)<sup>1</sup></b> |
|------------------|---------------------------------------|-------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|
| Annual           | 4.2 A                                 | 13.6 A                              | 0.9 A                                 | 0.2 A                                 | 0.2 A                                 |
| Periodic         | 36.9 B                                | 71.5 B                              | 44.5 B                                | 17.7 B                                | 5.2 B                                 |
| Control          | 15.9 C                                | 28.9 C                              | 11.2 C                                | 8.3 C                                 | 13.4 B                                |

| <b>Time period</b> | <b>Combined Total (%)<sup>1</sup></b> | <b>0 m to 0.5 m (%)<sup>1</sup></b> | <b>0.5 m to 1.0 m (%)<sup>1</sup></b> | <b>1.0 m to 1.5 m (%)<sup>1</sup></b> | <b>1.5 m to 2.0 m (%)<sup>1</sup></b> |
|--------------------|---------------------------------------|-------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|
| Pre-burn           | 7.7 A                                 | 21.5 A                              | 2.9 A                                 | 1.7 A                                 | 1.6 A                                 |
| Post-burn          | 9.3 A                                 | 17.8 A                              | 6.8 B                                 | 4.8 B                                 | 3.6 B                                 |
| End-of-season      | 35.4 B                                | 73.5 B                              | 29.8 C                                | 8.3 B                                 | 5.6 B                                 |

| <b>Time × Treatment Interaction</b> | <b>Combined Total (%)<sup>1</sup></b> | <b>0 m to 0.5 m (%)<sup>1</sup></b> | <b>0.5 m to 1.0 m (%)<sup>1</sup></b> | <b>1.0 m to 1.5 m (%)<sup>1</sup></b> | <b>1.5 m to 2.0 m (%)<sup>1</sup></b> |
|-------------------------------------|---------------------------------------|-------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|
| Annual Pre-burn                     | 3.3                                   | 13.0                                | 0                                     | 0                                     | 0                                     |
| Annual Post-burn                    | 0.7                                   | 2.1                                 | 0                                     | 0.3                                   | 0.2                                   |
| Annual End-of-season                | 22.6                                  | 77.6                                | 11.1                                  | 0.2                                   | 0.3                                   |
| Periodic Pre-burn                   | 18.7                                  | 45.8                                | 18.5                                  | 6.3                                   | 2.9                                   |
| Periodic Post-burn                  | 41.6                                  | 81.3                                | 55.6                                  | 17.6                                  | 4.1                                   |
| Periodic End-of-season              | 64.3                                  | 98.2                                | 84.9                                  | 48.5                                  | 11.2                                  |
| Control Pre-burn                    | 7.2                                   | 16.6                                | 3.8                                   | 2.8                                   | 5.3                                   |
| Control Post-burn                   | 18.1                                  | 27.9                                | 12.8                                  | 10.4                                  | 20.0                                  |
| Control End-of-season               | 30.3                                  | 52.0                                | 27.5                                  | 18.5                                  | 22.1                                  |

Results of post-ANOVA Tukey's significant difference test. Same letter indicates no significant difference within columns detected between treatments within a factor at the 0.05 level.

<sup>1</sup>Factor is significant at  $\alpha = 0.05$  level.

( $P < 0.001$ ). Mean vertical cover among the annual, 5-year periodic, and control treatments were 13.6, 71.5, and 28.9%, respectively (Table 7). Similar to the combined vertical cover, the Tukey's significant difference test found all three treatments were different from each other. Time period mean differences between the pre-burn, post-burn, and end of season were 21.5, 17.8, and 73.5%, respectively. Similar to the average vertical cover, the Tukey's significant difference test found differences between the pre-burn time period and the end of season time period and the post-burn time period and the end of season time period. Similar to the combined vertical cover, the time by treatment interactions resulted from the annual burn treatment responding differently due to the lack of vegetation after burning than the 5-year periodic and control treatments.

### **Vertical Cover 0.5 m to 1.0 m**

Vertical cover for the 0.5 m to 1.0 m section ( $n = 27$ ) differed among treatments ( $P = 0.001$ ) and time periods ( $P < 0.001$ ). Time by treatment interactions were also present ( $P = 0.001$ ). Mean vertical cover among the annual, 5-year periodic, and control treatments were 0.9, 44.5, and 11.2%, respectively (Table 7). Similar to the combined vertical cover and the 0 m to 0.5 m percent vertical cover, the Tukey's significant difference test found all three treatments were different from each other. Time period mean differences between the pre-burn, post-burn, and end of season were 2.9, 6.8, and 29.8%, respectively. The Tukey's significant difference test found all three treatments were different from each other. Similar to the combined vertical cover and vertical cover

for the 0 m to 0.5 m section, the time by treatment interactions resulted from the annual burn treatment responding differently due to the lack of vegetation than the 5-year periodic and control treatments.

### **Vertical Cover 1.0 m to 1.5 m**

Vertical cover for the 1.0 m to 1.5 m section ( $n = 27$ ) differed among treatments ( $P < 0.001$ ) and time periods ( $P < 0.001$ ). No time by treatment interactions were detected ( $P = 0.096$ ). Mean vertical cover among the annual, 5-year periodic, and control treatments were 0.2, 17.7, and 8.3%, respectively (Table 7). Similar to the combined vertical cover, the 0 m to 0.5 m percent vertical cover, and the 0.5 m to 1 m percent vertical cover, the Tukey's significant difference test found all three treatments were different from each other. Time period mean differences between the pre-burn, post-burn, and end of season were 1.7, 4.8, and 8.3%, respectively. The Tukey's significant difference test found differences between the pre-burn time period and the end of season time period and the pre-burn time period and the post-burn time period.

### **Vertical Cover 1.5 m to 2.0 m**

Vertical cover for the 1.5 m to 2.0 m section ( $n = 27$ ) differed among treatments ( $P = 0.009$ ) and time periods ( $P = 0.017$ ). No time by treatment interactions were detected ( $P = 0.290$ ). Mean vertical cover among the annual, 5-year periodic, and control

treatments were 0.2, 5.2, and 13.4%, respectively (Table 7). The Tukey's significant difference test found differences between the annual treatment and the 5-year periodic treatment and the annual treatment and the control treatment. Time period mean differences between the pre-burn, post-burn, and end of season were 1.6, 3.6, and 5.6%, respectively. Similar to the 1 m to 1.5 m percent vertical cover, the Tukey's significant difference test found differences between the pre-burn time period and the end of season time period and the pre-burn time period and the post-burn time period.

### **Horizontal Cover Percent Bare Ground**

Mean percent cover of bare ground ( $n = 27$ ) differed among treatments ( $P < 0.001$ ), time periods ( $P < 0.001$ ), and time by treatment interactions ( $P < 0.001$ ). Mean bare ground horizontal cover among the annual, 5-year periodic, and control treatments were 9.7, 0.1, and 0.7%, respectively (Table 8). The Tukey's significant difference test found differences between all of the treatments. Time period mean differences between the pre-burn, post-burn, and end of season were 1.8, 1.8, and 1.0%, respectively. The Tukey's significant difference test found the end of season time period differed from the pre-burn and post-burn time periods. The time by treatment interactions present resulted from each of the treatments responding differently. The annual treatment increased in bare ground due to removal of the litter layer from the burn treatment then decreased as vegetation recovered by the end of season time period. The periodic and control treatments had little change in percent cover of bare ground due to lack of disturbance of the litter or vegetation layers.

**Table 8. Mixed models repeated measures ANOVA for percent horizontal cover by treatment and time period for the 2005 growing season for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

| <b>Treatment</b> | <b>Bare Ground (%)</b> | <b>Organic Matter (%)<sup>1</sup></b> | <b>Grass (%)<sup>1</sup></b> | <b>Forbs (%)<sup>1</sup></b> | <b>Vines (%)<sup>1</sup></b> | <b>Woody Vegetation (%)<sup>1</sup></b> |
|------------------|------------------------|---------------------------------------|------------------------------|------------------------------|------------------------------|-----------------------------------------|
| Annual           | 9.7 A                  | 57.3                                  | 12.2 A                       | 6.1 A                        | 0.9 A                        | 4.2 A                                   |
| Periodic         | 0.1 B                  | 43.2                                  | 6.9 AB                       | 9.4 A                        | 2.9 B                        | 21.1 B                                  |
| Control          | 0.7 B                  | 81.0                                  | 1.0 B                        | 1.6 B                        | 1.8 AB                       | 9.0 A                                   |

| <b>Time period</b> | <b>Bare Ground (%)</b> | <b>Organic Matter (%)<sup>1</sup></b> | <b>Grass (%)</b> | <b>Forbs (%)<sup>1</sup></b> | <b>Vines (%)<sup>1</sup></b> | <b>Woody Vegetation (%)<sup>1</sup></b> |
|--------------------|------------------------|---------------------------------------|------------------|------------------------------|------------------------------|-----------------------------------------|
| Pre-burn           | 1.8 A                  | 81.0 A                                | 4.1              | 1.5 A                        | 0.2 A                        | 2.1 A                                   |
| Post-burn          | 1.8 A                  | 60.1 AB                               | 4.6              | 7.9 B                        | 1.3 B                        | 11.7 B                                  |
| End-of-season      | 1.0 B                  | 41.2 B                                | 5.6              | 7.7 B                        | 8.3 C                        | 20.6 C                                  |

| <b>Time × Treatment Interaction</b> | <b>Bare Ground (%)<sup>1</sup></b> | <b>Organic Matter (%)</b> | <b>Grass (%)</b> | <b>Forbs (%)</b> | <b>Vines (%)</b> | <b>Woody Vegetation (%)<sup>1</sup></b> |
|-------------------------------------|------------------------------------|---------------------------|------------------|------------------|------------------|-----------------------------------------|
| Annual Pre-burn                     | 3.8                                | 79.8                      | 12.3             | 2.2              | 0                | 0.3                                     |
| Annual Post-burn                    | 18.1                               | 60.9                      | 10.4             | 6.0              | 0.4              | 0.4                                     |
| Annual End-of-season                | 12.8                               | 38.7                      | 14.3             | 15.9             | 5.5              | 11.9                                    |
| Periodic Pre-burn                   | 0.3                                | 72.9                      | 8.0              | 2.6              | 0.6              | 3.9                                     |
| Periodic Post-burn                  | 0.2                                | 44.2                      | 7.7              | 19.6             | 2.2              | 24.0                                    |
| Periodic End-of-season              | 0                                  | 24.9                      | 5.3              | 15.4             | 12.5             | 35.4                                    |
| Control Pre-burn                    | 3.1                                | 91.5                      | 0.4              | 0.5              | 0.1              | 2.1                                     |
| Control Post-burn                   | 0.5                                | 80.6                      | 0.9              | 4.0              | 1.8              | 10.5                                    |
| Control End-of-season               | 0                                  | 72.1                      | 2.2              | 1.6              | 8.2              | 14.5                                    |

Results of post-ANOVA Tukey's significant difference test. Same letter indicates no significant difference within columns detected between treatments within a factor at the 0.05 level.

<sup>1</sup>Factor is significant at  $\alpha = 0.05$  level.

## **Horizontal Cover Percent Organic Matter**

Mean percent cover of organic matter ( $n = 27$ ) differed among treatments ( $P = 0.019$ ) and time periods ( $P = 0.004$ ). No time by treatment interactions were detected ( $P = 0.324$ ). Mean organic matter horizontal cover among the annual, 5-year periodic, and control treatments were 57.3, 43.2, and 81.0%, respectively (Table 8). The Tukey's significant difference test found differences between the control treatment and 5-year periodic treatment. Time period mean differences between the pre-burn, post-burn, and end of season were 81.0, 60.1, and 41.2%, respectively. The Tukey's significant difference test found the pre-burn time period and the end of season time period differed from each other.

## **Horizontal Cover Percent Grass**

Mean percent cover of grass ( $n = 27$ ) differed among treatments ( $P = 0.016$ ) but no differences were detected among time periods ( $P = 0.450$ ) or for time by treatment interactions ( $P = 0.145$ ). Mean grass horizontal cover among the annual, 5-year periodic, and control treatments were 12.2, 6.9, and 1.0%, respectively (Table 8). The Tukey's significant difference test found differences between the control treatment and annual treatment. Time period mean differences between the pre-burn, post-burn, and end of season were 4.1, 4.6, and 5.6%, respectively.

## **Horizontal Cover Percent Forbs**

Percent cover of forbs ( $n = 27$ ) differed among treatments ( $P < 0.001$ ) and time periods ( $P < 0.001$ ). No time by treatment interactions were detected ( $P = 0.073$ ). Mean forbs horizontal cover among the annual, 5-year periodic, and control treatments were 6.1, 9.4, and 1.6%, respectively (Table 8). The Tukey's significant difference test found the burn treatments differ from the control treatment but no differences between the burn treatments. Time period mean differences between the pre-burn, post-burn, and end of season were 1.5, 7.9, and 7.7%, respectively. The Tukey's significant difference test found differences between the pre-burn time period and the post-burn time period and the pre-burn time period and the end of season time period.

## **Horizontal Cover Percent Vines**

Percent cover of vines ( $n = 21$ ) differed between treatments ( $P = 0.007$ ) and time periods ( $P < 0.001$ ). No time by treatment interactions were detected ( $P = 0.879$ ). Mean vine horizontal cover among the annual, 5-year periodic, and control treatments were 0.9, 2.9, and 1.8%, respectively (Table 8). The Tukey's significant difference test found differences between the annual treatment and 5-year periodic treatments. Time period mean differences between the pre-burn, post-burn, and end of season were 0.2, 1.3, and 8.3%, respectively. The Tukey's significant difference test found all three time periods were different from each other.

## **Horizontal Cover Percent Woody Vegetation**

Percent cover of woody vegetation ( $n = 27$ ) differed among treatments ( $P = 0.002$ ) and time by treatment interactions were present ( $P = 0.002$ ). No time period differences were detected ( $P = 0.159$ ). Mean woody vegetation horizontal cover among the annual, 5-year periodic, and control treatments were 4.2, 9.0, and 21.1%, respectively (Table 8). The Tukey's significant difference test found the 5-year periodic treatment differed from the control and annual treatments. Time period mean differences between the pre-burn, post-burn, and end of season were 2.1, 11.7, and 20.6%, respectively. Similar to percent vertical cover, the time by treatment interactions present resulted from the annual treatment responding differently than the 5-year periodic and control treatments. The percent cover in the annual treatment changed little between the pre-burn and post-burn time periods then increased by the end of season period due to fire removing vegetation. The 5-year periodic and control treatments continually increased in percent cover due to lack of disturbance of the litter or vegetation layers.

## **Average Height of Grasses**

Average height of grasses ( $n = 27$ ) differed among treatments ( $P < 0.001$ ), time periods ( $P = 0.008$ ), and time by treatment interactions were present ( $P < 0.001$ ). Average height of grasses among the annual, 5-year periodic, and control treatments were 49.6, 35.3, and 5.2 cm, respectively (Table 9). The Tukey's significant difference test found all three treatments were different from each other. Time period mean differences

**Table 9. Mixed models repeated measures ANOVA for average height (cm) of vegetation classes by treatment and time period for the 2005 growing season for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

| <b>Treatment</b> | <b>Grass<sup>1</sup></b> | <b>Forbs<sup>1</sup></b> | <b>Vines<sup>1</sup></b> | <b>Woody<sup>1</sup></b> |
|------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Annual           | 49.6 A                   | 25.9 A                   | 1.4 A                    | 27.6 A                   |
| Periodic         | 35.3 B                   | 71.9 B                   | 37.4 B                   | 104.0 B                  |
| Control          | 5.3 C                    | 9.4 C                    | 4.4 A                    | 42.2 A                   |

| <b>Time period</b> | <b>Grass<sup>1</sup></b> | <b>Forbs</b> | <b>Vines<sup>1</sup></b> | <b>Woody</b> |
|--------------------|--------------------------|--------------|--------------------------|--------------|
| Pre-burn           | 35.6 A                   | 21.2         | 1.5 A                    | 47.9         |
| Post-burn          | 22.3 B                   | 24.2         | 5.4 A                    | 62.5         |
| End-of-season      | 32.4 A                   | 34.9         | 28.6 B                   | 63.4         |

| <b>Time × Treatment Interaction</b> | <b>Grass<sup>1</sup></b> | <b>Forbs<sup>1</sup></b> | <b>Vines<sup>1</sup></b> | <b>Woody</b> |
|-------------------------------------|--------------------------|--------------------------|--------------------------|--------------|
| Annual Pre-burn                     | 71.4                     | 32.7                     | 0                        | 25.5         |
| Annual Post-burn                    | 22.1                     | 10.1                     | 0.2                      | 23.9         |
| Annual End-of-season                | 55.4                     | 52.2                     | 18.7                     | 33.3         |
| Periodic Pre-burn                   | 35.1                     | 66.9                     | 21.7                     | 101.0        |
| Periodic Post-burn                  | 36.7                     | 63.7                     | 35.4                     | 105.5        |
| Periodic End-of-season              | 34.2                     | 87.2                     | 66.8                     | 105.7        |
| Control Pre-burn                    | 0.3                      | 4.1                      | 0.3                      | 17.1         |
| Control Post-burn                   | 7.9                      | 21.8                     | 7.8                      | 58.0         |
| Control End-of-season               | 7.5                      | 9.1                      | 18.6                     | 51.4         |

Results of post-ANOVA Tukey's significant difference test. Same letter indicates no significant difference within columns detected between treatments within a factor at the 0.05 level.

<sup>1</sup>Factor is significant at  $\alpha = 0.05$  level.

respectively. The Tukey's significant difference test found differences between the post-burn time period and the pre-burn time period and the post-burn time period and the end-of-season time period. Similar to the percent vertical cover, the time by treatment interactions present were a result of the annual treatment responding differently than the 5-year periodic and control treatments. Although the 5-year periodic had higher percent cover of grasses than the control treatment, the growth trend of the vegetation was similar and changed little across the time periods. The percent cover of grasses in annual treatment decreased as a result of fire then increased by the end of the season as the vegetation recovered.

### **Average Height of Forbs**

Average height of forbs ( $n = 27$ ) differed among treatments ( $P = 0.001$ ) and a time by treatment interactions were present ( $P < 0.001$ ), but no differences were detected between time periods ( $P = 0.051$ ). Average height of forbs among the annual, 5-year periodic, and control treatments were 25.9, 71.9, and 9.4 cm, respectively (Table 9). The Tukey's significant difference test found all three treatments were different from each other. Time period mean differences between the pre-burn, post-burn, and end of season were 21.2, 24.2, and 34.9 cm, respectively. The time by treatment interactions present was a result of each of the treatments responding differently across time. The annual treatment decreased post-burn then increased by the end of season period. The 5-year periodic treatment remained constant between the pre-burn and the post-burn periods

then increased by the end of season period. The control increased between the pre-burn and post-burn time periods then decreased by the end of season period.

### **Average Height of Vines**

Average height of vines ( $n = 27$ ) differed among treatments ( $P = 0.006$ ), time periods ( $P = 0.001$ ), and time by treatment interactions were present ( $P = 0.045$ ).

Average height of vines among the annual, 5-year periodic, and control treatments were 1.4, 37.2, and 4.4 cm, respectively (Table 9). Tukey's significant difference test found differences between the 5-year periodic treatment and the annual treatment and the 5-year periodic treatment and the control treatment. Time period mean differences between the pre-burn, post-burn, and end of season were 1.5, 5.4, and 28.6 cm, respectively. The Tukey's significant difference test found differences between the end-of-season time period and the pre-burn time period and the end-of-season time period and the post-burn time period. Similar to the percent cover of grasses, the time by treatment interactions present resulted from the annual treatment responding differently than the 5-year periodic and control treatments. The annual treatment showed little change in height of vines between the pre-burn and post-burn periods then increased by the end of season period due to the recovery from the burning treatment. The 5-year periodic and control treatments both continuously increased in percent cover due to lack of disturbance.

## **Average Height of Woody Vegetation**

Average height of woody vegetation ( $n = 27$ ) differed among treatments ( $P = 0.001$ ) but no differences were detected between time periods ( $P = 0.070$ ) or time by treatment interactions ( $P = 0.091$ ). Average height of woody vegetation among the annual, 5-year periodic, and control treatments were 27.6, 104.0, and 42.2 cm, respectively (Table 9). The Tukey's significant difference test found differences between the 5-year periodic treatment and the annual treatment and the 5-year periodic treatment and the control treatment. Time period mean differences between the pre-burn, post-burn, and end of season were 47.9, 62.5, and 63.4 cm, respectively.

## ***Small Mammals:***

### **Species Abundance and Occurrence**

There were 187 individuals with 605 total captures (418 recaptures) encompassing 9 species across all treatments and time periods for 20,729 trap nights, however not all species were present in each treatment or time period (Table 10). The capture rate was 2.9 percent with an average of 2.2 captures per individual. The number of species caught per treatment was the greatest in the 5-year periodic treatment with 9 total species. The control treatment supported 6 species, while the annual treatment was the lowest with 5 species (Table 10).

The most abundant species trapped in all treatments for all time periods was white-footed mouse (*Peromyscus leucopus*) with 146 individuals accounting for 316 of total captures (Table 10). Pine voles (*Microtus pinetorum*) were the second most abundant species, 75 individuals accounting for 147 of the total captures, but pine voles did not occur in the annual treatment in the end of season time period. Other species present in the annual treatment were short-tail shrew (*Blarina brevicauda*), southern flying squirrel (*Glaucomys volans*), eastern gray squirrel (*Sciurus carolinensis*), and eastern chipmunk (*Tamias striatus*, Table 10). Three of the 8 species, golden mouse (*Peromyscus nuttalli*), meadow jumping mouse (*Zapus hudsonius*), and hispid cotton rat (*Sigmodon hispidus*), were present in the 5-year periodic treatment and occurred with varying frequencies only in that treatment. Other species found in the 5-year periodic

**Table 10. Abundance of unique individuals and total captures by time period within each treatment for the 2005 growing season for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

| Species <sup>1</sup> | -----Treatment-----  |          |         |                     |          |         |                         |          |         | Total <sup>2</sup> |
|----------------------|----------------------|----------|---------|---------------------|----------|---------|-------------------------|----------|---------|--------------------|
|                      | -----Pre-burn-----   |          |         | -----Post-burn----- |          |         | -----End-of-Season----- |          |         |                    |
|                      | Annual               | Periodic | Control | Annual              | Periodic | Control | Annual                  | Periodic | Control |                    |
| PELE                 | 16 (36) <sup>3</sup> | 21 (61)  | 9 (19)  | 27 (58)             | 24 (59)  | 18 (40) | 17 (29)                 | 6 (7)    | 8 (10)  | 146 (319)          |
| PENU                 | 0 (0)                | 5 (12)   | 0 (0)   | 0 (0)               | 7 (17)   | 0 (0)   | 0 (0)                   | 0 (0)    | 0 (0)   | 12 (29)            |
| MIPI                 | 4 (9)                | 21 (38)  | 1 (1)   | 4 (6)               | 33 (73)  | 6 (13)  | 0 (0)                   | 5 (6)    | 1 (1)   | 75 (147)           |
| ZAHU                 | 0 (0)                | 0 (0)    | 0 (0)   | 0 (0)               | 3 (3)    | 0 (0)   | 0 (0)                   | 0 (0)    | 0 (0)   | 3 (3)              |
| BLBR                 | 2 (2)                | 3 (3)    | 5 (5)   | 0 (0)               | 1 (1)    | 10 (10) | 0 (0)                   | 0 (0)    | 0 (0)   | 21 (21)            |
| SIHI                 | 0 (0)                | 4 (10)   | 0 (0)   | 0 (0)               | 2 (10)   | 0 (0)   | 0 (0)                   | 3 (4)    | 0 (0)   | 9 (25)             |
| TAST                 | 0 (0)                | 0 (0)    | 0 (0)   | 0 (0)               | 1 (10)   | 1 (1)   | 1 (1)                   | 1 (2)    | 0 (0)   | 4 (17)             |
| GLVO                 | 0 (0)                | 1 (1)    | 6 (10)  | 1 (3)               | 2 (4)    | 8 (17)  | 0 (0)                   | 1 (1)    | 1 (1)   | 20 (40)            |
| SCCA                 | 0 (0)                | 0 (0)    | 0 (0)   | 1 (1)               | 1 (1)    | 1 (1)   | 0 (0)                   | 0 (0)    | 0 (0)   | 3 (4)              |
| Total                | 22 (49)              | 55 (125) | 21 (35) | 33 (68)             | 74 (178) | 44 (83) | 18 (35)                 | 16 (20)  | 10 (12) | 293 (605)          |

<sup>1</sup>Small mammal species: PELE = white-footed mouse (*Peromyscus leucopus*), PENU = golden mouse (*Peromyscus nuttalli*), MIPI = pine vole (*Microtus pinetorum*), ZAHU = meadow jumping mouse (*Zapus hudsonius*), BLBA = short-tailed shrew (*Blarina brevicauda*), SIHI = hispid cotton rat (*Sigmodon hispidus*), TAST = eastern chipmunk (*Tamias striatus*), GLVO = southern flying squirrel (*Glaucomys volans*), SCCA = eastern gray squirrel (*Sciurus carolinensis*).

<sup>2</sup>Number of unique individuals captured were tallied within each time period, recounting individuals trapped in previous time periods when caught in later time period. Total number of unique individuals regardless of time period is 187 individuals.

<sup>3</sup>Number outside parenthesis = unique individuals, number within parenthesis = total captures including recaptures.

treatment included short-tail shrew, eastern chipmunk, southern flying squirrel, and eastern gray squirrel. The control treatment had the highest occurrence of any of the treatments for short-tail shrew, 15 of 21 total captures, and southern flying squirrel, 28 of 40 total captures and 15 of 20 individuals (Table 10). Other species present infrequently in the control treatment included eastern chipmunk and eastern gray squirrel.

### **Treatment Abundance**

Small mammal abundance ( $n = 27$ ) differed among treatments ( $P = 0.002$ ) and time periods ( $P = 0.008$ ). No time by treatment interactions were detected ( $P = 0.921$ ). Mean small mammal abundance among the annual, 5-year periodic, and control treatments were 0.6, 1.7, and 0.8 individual captures, respectively (Table 11). The Tukey's significant difference test found differences between the 5-year periodic treatment and the annual treatment and between the 5-year periodic treatment and the control treatment. Time period mean differences between the pre-burn, post-burn, and end of season were 1.1, 0.7, and 1.2 individual captures, respectively. The Tukey's significant difference test found differences between the post-burn time period and the pre-burn time period and the post-burn time period and the end of season time period.

**Table 11. Repeated measures ANOVA for small mammal abundance by treatment and time period for the 2005 growing season for each of 3 treatments for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

| <b>Treatment</b> | <b>Relative Abundance<sup>1</sup></b> |
|------------------|---------------------------------------|
| Annual           | 0.6 A                                 |
| Periodic         | 1.7 B                                 |
| Control          | 0.8 A                                 |

| <b>Time period</b> | <b>Relative Abundance<sup>1</sup></b> |
|--------------------|---------------------------------------|
| Pre-burn           | 1.1 A                                 |
| Post-burn          | 0.7 B                                 |
| End-of-season      | 1.2 B                                 |

| <b>Time × Treatment Interaction</b> | <b>Relative Abundance</b> |
|-------------------------------------|---------------------------|
| Annual Pre-burn                     | 0.7                       |
| Annual Post-burn                    | 0.4                       |
| Annual End-of-season                | 0.8                       |
| Periodic Pre-burn                   | 1.7                       |
| Periodic Post-burn                  | 1.4                       |
| Periodic End-of-season              | 2.0                       |
| Control Pre-burn                    | 1.0                       |
| Control Post-burn                   | 0.4                       |
| Control End-of-season               | 1.0                       |

Results of post-ANOVA Tukey's significant difference test. Same letter indicates no significant difference detected between treatments within a factor at the 0.05 level.

<sup>1</sup>Factor is significant at  $\alpha = 0.05$  level.

## Small Mammal Abundance Modeling

Three variables (percent horizontal cover of forbs, percent horizontal cover of vines, and height of woody vegetation) were found to be significant ( $P < 0.001$ ) in the multiple linear regression analysis for total abundance of all unique individuals. The adjusted coefficient of determination accounted for 65.1% of the variability. Normality of the residuals could not be rejected ( $P = 0.9902$ ). The standardized estimates for percent horizontal cover of forbs indicated as percent cover increased, small mammal abundance increased ( $R^2_{\text{adj}} = 5.8\%$ , Table 12). The standardized estimates for percent horizontal cover of vines indicated as percent cover decreased, small mammal abundance increased ( $R^2_{\text{adj}} = 43.3\%$ ). The standardized estimates for height of woody vegetation indicated as height increased, small mammal abundance increased ( $R^2_{\text{adj}} = 20.1\%$ ).

Two variables (percent horizontal cover of grass and percent horizontal cover of vines) were found to be significant ( $P = 0.0016$ ) in the multiple linear regression analysis for abundance of unique white-footed mouse individuals. The adjusted coefficient of determination was 36.7%. Normality of the residuals could not be rejected ( $P = 0.9592$ ). The standardized estimates for percent horizontal cover of grass indicated as percent cover increased, small mammal abundance increased ( $R^2_{\text{adj}} = 26.3\%$ , Table 12). The standardized estimates for percent horizontal cover of vines indicated as percent cover decreased, small mammal abundance increased ( $R^2_{\text{adj}} = 15.3\%$ ).

**Table 12. Multiple linear regression models predicting small mammal abundance using habitat characteristics for the 2005 growing season for the long-term prescribed fire in oak barrens study on the University of Tennessee Forest Resources Research and Education Center, Tullahoma, TN.**

| Species <sup>1</sup> | -----Estimates-----   |           |              |       |        |                  |                        |
|----------------------|-----------------------|-----------|--------------|-------|--------|------------------|------------------------|
|                      | Metric <sup>2,3</sup> | Parameter | Standardized | T     | P      | VIF <sup>4</sup> | Partial R <sup>2</sup> |
| AllSpecies           | Intercept             | 0.45      | 0            | 2.84  | 0.0092 | 0                | 0                      |
|                      | AvgF                  | 0.03      | 0.28         | 2.08  | 0.0489 | 1.39554          | 0.0580                 |
|                      | AvgV                  | -0.13     | -0.81        | -6.03 | <0.001 | 1.33416          | 0.4327                 |
|                      | WHt                   | 0.01      | 0.66         | 4.83  | <0.001 | 1.40966          | 0.2009                 |
| PELE                 | Intercept             | 0.45      | 0            | 4.68  | <0.001 | 0                | 0                      |
|                      | AvgG                  | 0.02      | 0.45         | 2.82  | 0.0096 | 1.02914          | 0.2626                 |
|                      | AvgV                  | -0.03     | -0.40        | -2.51 | 0.0192 | 1.02914          | 0.1533                 |
| MIPI                 | Intercept             | 0.08      | 0            | -1.40 | 0.1763 | 0                | 0                      |
|                      | AvgF                  | 0.01      | 0.33         | 2.88  | 0.0084 | 1.39554          | 0.0775                 |
|                      | AvgV                  | -0.05     | -0.72        | -6.45 | <0.001 | 1.33416          | 0.3230                 |
|                      | WHt                   | 0.01      | 0.78         | 6.77  | <0.001 | 1.40966          | 0.3846                 |

<sup>1</sup>Small mammal species: AllSpecies = all species, PELE = white-footed mouse (*Peromyscus leucopus*), MIPI = pine vole (*Microtus pinetorum*).

<sup>2</sup>Metrics retained by stepwise selection process using entry and stay significance levels at  $\alpha=0.05$ , overall *F*-tests on AllSpecies, PELE, and MIPI models were significant ( $P\leq 0.0001$ ,  $P = 0.0016$ , and  $P\leq 0.0001$ ) and coefficients of determination adjusted for number of variables in the model (i.e.,  $R^2_{adj}$ ) = 0.6606, 0.3673, and 0.7990 for AllSpecies, PELE, and MIPI, respectively.

<sup>3</sup>Retained habitat variables were: AvgF (percent horizontal cover of forbs), AvgV (percent horizontal cover of vines), AvgG (percent horizontal cover of grasses), and WHt (height in cm of woody vegetation).

<sup>4</sup>VIF = variance of inflation factor where  $VIF>5$  is suggestive of a linear dependency between variables  $>5$ .

Three variables (percent horizontal cover of forbs, percent horizontal cover of vines, and height of woody vegetation) were found to be significant ( $P < 0.001$ ) in the multiple linear regression analysis for abundance of unique white-footed mouse individuals. The adjusted coefficient of determination was 75.7%. Normality of the residuals could not be rejected ( $P = 0.9815$ ). The standardized estimates for percent horizontal cover of forbs indicated as percent cover increased, small mammal abundance increased ( $R^2_{\text{adj}} = 7.9\%$ , Table 12). The standardized estimates for percent horizontal cover of vines indicated as percent cover decreased, small mammal abundance increased ( $R^2_{\text{adj}} = 32.3\%$ ). The standardized estimates for height of woody vegetation indicated as height increased, small mammal abundance increased ( $R^2_{\text{adj}} = 38.5\%$ ).

## **VI. DISCUSSION**

The results indicate that long-term 5-year periodic and annual prescribed fire significantly alters stand structure and small mammal populations. Although the understory response to prescribed fire was evident by 1970, the overstory structure response occurred at a much slower rate and significant differences were not evident until the 2005 measurement. In addition to prescribed fire, many factors in this study appear to have contributed to current stand structure including firing pattern, size the treatment units, and season of burning.

Total small mammal abundance modeling using standard habitat variables proved effective however the total abundance model was primarily driven by pine vole abundance. The effectiveness of modeling specific species was variable. Success of abundance modeling for generalist species, such as the white-footed mouse, tends to be variable because, even at small scales, populations tend to be highly variable due to a wide range of suitable habitat and seasonal fluctuations in populations (Delany 1974). Quantifying preferred habitat characteristics for generalist species modeling is difficult given the numerous biotic and abiotic factors such as food and cover resources and niche adaptations.

## ***Forestry:***

### **Stand Structure**

Stand structure has changed both as a result of succession and treatment. Due to limited historical data, it is difficult to separate the variation explained by succession. Successional changes are most evident in the control treatments in which stand structure developed a mixed hardwood closed canopy with fire intolerant species, such as *Liquidamber styraciflua*, *Liriodendron tulipifera*, *Ulmus americana*, *Pinus strobus*, and *Juniperus virginiana*, comprising the understory and midstory (Smith et al. 1997, Harlow et al. 1996), similar to studies reported by Ozier et al. (2006), Brose et al. (2001), Reich et al. (1990), Abrams (1985), Cottam (1949), and McInteer (1946).

The successional changes occurring in the burn treatments are less obvious than the control treatment as a result of the prescribed fire treatments reducing the midstory densities. Since inception, the midstory in the fire treatments has decreased in density due to fire related mortality and ingrowth into the overstory size classes while the overstory has continually increased in density. Other studies, including Taft (2005), Taft (2003), and Tester (1989), reported similar findings and suggest increased bark thickness of mature trees provides greater protection of the vascular cambium thus increasing survival.

Although the understory structure quickly responded to the prescribed fire treatments, the overstory structural response was delayed. The different long-term fire

regimes with differing associated fire intensities altered each aspect of the community at a different rate depending on species and treatment. The burn treatments restored the herbaceous mix understory early in the study; however restoration of the open canopy took 42 years before significant differences were observed. The midstory and overstory species composition in the burn treatments changed little since inception with an overall decrease in density. Oak species have been a decreasing component in the regeneration while sumac has been increasing since 1970. By 2005, the total density and basal area for the burn treatments tended to be higher than historical accounts and what is generally considered an oak barrens or oak savanna. Statistical differences between the treatments were only found in the overall density and basal area probably due to small sample sizes.

The understory structure was significantly affected by differences in fire intensities and frequencies between the burn treatments. The annual burn treatment has a higher fire frequency with less intense fires which perpetuated grasses and forbs. Fires were less intense and fire-induced overstory mortality tended to occur at a slower rate than the 5-year periodic treatment. Fire-induced midstory and overstory mortality was higher in the 5-year periodic treatment because the longer fire-return interval created higher fuel loadings and contiguous vertical structure creating higher fire intensities with longer residence time and therefore killing and damaging more trees and decreasing density (Pyne 1984). The understory structure was a woody-herbaceous mix due to the lower fire frequency. Recruitment of regeneration for both treatments was low. Withholding fire from the system allowed the control treatments to develop into a closed canopy structure, very different from the historical accounts of the area. Comparing the

structure of burning treatments to the control treatments, it is evident that repeated fire is necessary for the development and perpetuation of this sub-climax pyric ecosystem but annual and 5-year return intervals do not restore the system to historical accounts.

## **Regeneration and Recruitment**

Frequent fire is necessary to maintain oak barren stand structure but also reduces recruitment of regeneration and kills smaller diameter classes. Although the annual and 5-year periodic treatments had higher densities of regeneration than the control treatment, recruitment of the regeneration was very low. Dey and Hartman (2005) found oaks had high probability of survival following multiple fires, however survival probability decreases and growth is slowed as fire frequency and intensity increases. The height of the regeneration present in the annual treatment averaged approximately 30 cm and there was little regeneration present between 30 cm and the 8 in diameter classes. With this low rate of recruitment, as the 130 to 140 year old overstory senesces and dies, there will be a significant drop in density and basal area. Once the overstory dies the structure will most likely return to the traditional 5 to 20 ft<sup>2</sup>/ac oak barrens structure; however perpetuation of the system is questionable given the current rate of recruitment.

The 5-year periodic treatment had larger regeneration than the annual treatment however the recruitment rate appeared to be lower with gaps in the smaller diameter classes. Similar to the annual treatment development, as the older overstory dies, a significant drop in density and basal area will occur. The drop in density and basal area

will most likely convert the stand into oak barrens with a very low basal area, approximately 5 ft<sup>2</sup>/ac. Similar to the annual treatment, the immediate future of the stand appears to remain an oak barrens, but perpetuation of the system is questionable.

## **Firing Pattern**

Pattern of ignition effects how a fire will burn and influences stand structure (Pyne 1984). Natural fires generally burn sporadically depending on weather and terrain. In the eastern deciduous forest, wildfires tend to burn in a mosaic pattern lasting from a few hours to several months with fire activity highest primarily during the day when relative humidity is lowest and wind is present. The ring firing pattern used in this study probably does not resemble natural fire spread and behavior. The ring method has all the fire spread aspects of a natural fire but because the firing pattern forces the fire to burn together in a small area very quickly, the fire intensity is higher, especially in the middle. As a result, a more even coverage of fire across the area is attained than occurs naturally. The increased intensity causes higher mortality rates and increased consumption rates of understory vegetation, litter, duff, and coarse woody debris, thus altering stand structure.

## **Treatment Size**

The size of a burn area will probably affect stand structure due to differences in intensity and edge effects (Pyne 1984). A small burn area in combination with the ring firing pattern has different effects on vegetation and structure than wildfires, larger fires,

or areas burned with more naturally occurring type of ignition pattern. A small area allows the ring pattern to burn together faster and at a higher intensity than larger fires. Edge effects are known to have a different vegetation structure than the interior of large treatment areas. Given the small treatment plot size in this study, identifying the difference between edge effect and treatment difference is a possible concern. The control treatments appear to receive more light and have more regeneration than the surrounding unburned forest with the same fire exclusion history. Edge effects are also seen in the burn treatments in which there is a gradient in mortality caused by the ignition pattern because the fire is less intense along the edge and more intense in the center.

### **Season of Burn**

This study was initiated as a late winter/early spring burn in part to promote herbaceous growth while trees were dormant to reduce mortality. Many studies, Groninger et al. (2005), Huddle and Pallardy (1996), and Glitzenstein et al. (1995), suggest burning during the fall and winter burns reduces mortality while spring and summer fires are suggested for killing hardwood species. The long-term results of this study suggest continuous dormant season burning will increase the density of regeneration primarily due to sprouting; however continuous burning will inhibit height growth and recruitment.

## ***Understory Vegetation/Habitat Characteristics:***

### **Structure**

Understory vegetation structure is managed for both forestry and wildlife management purposes. Oak barren restoration involves manipulation of both the overstory and understory vegetation structures and species composition. The understory structure is a critical element of the oak barrens system and is the primary ecological component influenced by prescribed fire management. Changes in forest structure, especially understory structure, influences small mammal populations on a site. The use of annual and 5-year periodic prescribed fire in this study produced similar responses in vegetation structure. Although interactions were found in this study, they are primarily related to the removal and regrowth of vegetation throughout time as a result of each treatment (annual, 5-year periodic, or control). The vegetational response of the treatments within each of the three time periods rather than across time periods is more consequential. Overall structure of annual burning after 42 years provided an open savanna-like habitat while 5-year periodic burning created an old field, thick woody-herbaceous mix habitat. Both habitats are preferred by early successional species although the 5-year periodic treatment offers more for semi-arboreal species and species requiring more vertical cover. The control treatment provides a closed canopy habitat with little understory cover.

## Site Characteristics

The prescribed fire regime of a pyric ecosystem determines forest structure and composition. As fire becomes more frequent, fire adapted and early successional vegetation will increase and fire intolerant species will decrease. Frequency and intensity of fire will alter vegetation height and ability to reproduce (Dey and Hartman 2005). Increasing fire frequency reduces vegetation height and reproduction capability, decreases organic matter and increases amount of bare ground, and increases mortality. A soil study by Phillips et al. (2000) on this study area found annual burning significantly reduced organic matter and leaf litter and compacted the soil. Decreasing organic matter and increasing bare ground potentially leads to erosion and increased soil temperatures. Prescribe fire, like all disturbances, also increases an ecosystems susceptibility to invasive species. Japanese stilt grass (*Microstegium vimineum*) was first documented in 1989 and has since invaded small patches of the study area (DeSelm and Clebsch 1991).

## Habitat

The role of vegetation as a habitat resource to provide food and cover for animals has temporal and spatial components in addition to physical structure (Guisan and Zimmerman 2000). Temporal variations in population dynamics are common for mammalian species in eastern deciduous forests due to location, climate, season, and disturbances constantly changing the conditions of the habitat. Temporal differences in habitat variables were observed across trapping periods and were correlated with small mammal abundance estimates. Although the structure within each treatment was similar,

edge effects were apparent and an indication of spatial heterogeneity. However, spatial variation was not measured because it was not within the scope of this study.

The physical structure of the habitat created by each treatment was significantly different. The two burn treatments tended to have more similar overstory characteristics and responses than the control treatment but understory characteristics varied across treatments. These responses were primarily due to treatment response between the pre-burn and post-burn time periods of the annual burn removing the majority of the vegetation while the 5-year periodic burn was not burned and grew continuously throughout the season. The percent canopy cover factor was significantly lower for both of the burn treatments than the control treatment. The lower percent canopy cover allowed more light to reach the forest floor and promoted understory vegetation growth. High fire frequency associated with the annual burn treatment had an overall reduction in vegetation height and percent vertical cover as compared to the 5-year periodic burn treatment. The lower fire frequency of the 5-year periodic treatment allowed for more significant percent woody and vine horizontal cover, higher percent vertical cover, and average height components. Fire frequency increased percent horizontal cover of bare ground in the annual treatment while fire intensity promoted increased height and percent vertical cover of vegetation in the unburned 5-year periodic treatment.

## ***Small Mammals:***

### **Populations**

Few studies have analyzed differences in small mammal populations as a result of long-term prescribed fire for restoration purposes. The majority of the research compares burned to unburned wildfire areas or single prescribed burns (Greenberg et al. 2006, Letnic et al. 2004, Keyser et al. 2001, Kirkland et al. 1996, Krefting and Ahlgren 1974, Cook 1959). Although no pre-burn data was collected at inception and we do not know the historic species abundance and occurrence, the differences found between treatments suggests long-term prescribed fire using different fire regimes will affect the small mammal populations present on the site.

The two most abundant species found across all the treatments, white-footed mouse and pine vole, are generalist species (Burt and Grossenheider 1980, M'Closkey and Lajoie 1975). Both are adaptive species and have broad habitat and resource requirements. The white-footed mouse tended to have higher abundances in the annual treatment, while the pine vole tended to have higher abundances in the 5-year periodic treatment. Higher soil compaction, higher temperatures, and dryer soil may have contributed to the lower abundances of pine voles in the annual treatment (Fisher and Anthony 1980, Rhodes and Richmond 1985). M'Closkey and Lajoie (1975) found no clear association between habitat type and white-footed mouse density and absence of white-footed mouse in grasslands. This study had similar habitat findings. However, the highest abundances of white-footed mouse populations in this study were found in the

annual burn treatment in which the dominant understory composition was grass. Species such as golden mouse, hispid cotton rat, and meadow jumping mouse found only in the 5-year periodic have more specialized habitat requirements. All of these species prefer a thick grassy and brushy understory (Allen 1900, Goodpaster and Hoffmeister 1954, and Linzey 1968).

### **Treatment and Time Period**

The 5-year periodic treatment was found to have a higher total abundance of unique individuals for both treatment and time period than the annual and control treatments, similar to finding by Pearson (1959) and Wirtz and Pearson (1960). The 5-year periodic burn treatment also had a higher occurrence of total mammalian species. Cover resources were highest in the 5-year periodic treatment because the fire frequency is less frequent than the annual treatment. The lower fire frequency allows vegetation to recover between fires and therefore grow taller and produce more seed. Annual burning allows for less recovery time for vegetation and consumes the litter and duff layer on an annual basis, reducing the available resources. The closed canopy control treatment does not allow sunlight to reach the forest floor limiting the understory vegetation and food resources. The litter and duff layer is thicker and less disturbed than the other treatments and the canopy density is higher, but the limited understory vegetation limits available cover.

Although not significant in predicting abundance of small mammals, differences occurring in time periods are most likely a result of temporal variation in vegetation and life history of each of the species. Fluctuations in trapping are common throughout the year due to fluctuations in available resources and interactions with competitors (Llewellyn and Jenkins 1987, Delany 1974). As food resources become readily available, trap success decreases. Although many of the species breed year round, an increase of pregnant and lactating females was noted during the post-burn period, the period with the highest abundance. An influx of species, such as pine vole, meadow jumping mouse, and eastern chipmunk, occurred in early spring presumably due to hibernation.

### **Capture/Recapture Rates**

The low capture rates found in this study were probably a result of oversampling in a small area. Ten meter spacing using an 8 row by 3 column grid with 2 traps per station allowed for a minimum of 6 traps within the home range of each animal. This sampling design provided that each individual was captured an average of 3.2 times but reduced the overall capture rate. An advantage of the oversampling is it allowed for a high amount of recaptures and the ability to track the movement of individuals. Little movement occurred between treatments as a result of treatment type or prescribed annual fire. The main disadvantage of oversampling is the low capture rate made population modeling impractical and abundance modeling difficult.

## **Small Mammal Abundance Modeling**

Modeling small mammal abundance proved effective for total captures and for pine voles, but was relatively ineffective for white-footed mice. Small mammal abundance, even at small scales, tends to be highly variable due to constant changes in biotic and abiotic factors of the ecosystem such as food and cover resources, weather, vegetation growth, and disturbances. Quantifying similar habitat characteristics across 3 different habitat types with different compositions and structures presumably adds unaccounted variation, yet overall preferences were observed. Combining all trapped species from 2 different families and several different genera also adds variation due to different resource requirements of each species.

Given these drawbacks and known sources of non-quantified variation, such as spatial heterogeneity and population dynamics, total captures and pine vole abundance modeling both indicate average percent horizontal cover of forbs, average percent horizontal cover of vines, and average height of woody vegetation as the most significant factors for both models. Average percent horizontal cover of vines and average height of woody vegetation explain the highest amounts of the variation. The woody height factor is significant because it quantifies the importance of vertical structure at the level small mammals use and is related to amount of cover resources (Harney and Dueser 1987). The average percent of vines factor is significant because it represents the importance of vegetation growth and available food and cover resources throughout the trapping season. As horizontal cover of vines increases throughout the season, the more food and cover

resources become available. Thus, apparent relative abundance appears to decrease because food resources are more readily available. Average percent horizontal cover of forbs was found significant for both models and represents available food, cover resources, and structural diversity. However, due to its relatively low partial  $R^2$  value and the small sample sizes, its significance may be due to over-fit in model.

The model for white-footed mouse abundance indicates that the average percent horizontal cover of vines and average percent horizontal cover of grass factors explain the highest percent of variation. Similar to the factors selected for overall and pine vole models, average percent horizontal cover of vines represents resources availability and vegetation growth aspects. The average percent horizontal cover of grass factor represents available food and cover resources. The dominant grasses present on sites were bunch grasses. Although percent cover of bare ground and organic matter were not found significant, bunch grasses provide overhead cover for protection against predators while providing open foraging at ground level. Due to the highly adaptive and generalist nature of the white-footed mouse, defining similar specific preferred habitat components across each of the three habitat types for abundance prediction was ineffective, yet findings were similar to related studies such as Wirtz and Pearson (1960). Although, given the positive relationship found between the average percent horizontal cover of grass variable and small mammal abundance, the variable serves a dual purpose as it is also an important variable in determining the effectiveness of oak barrens restoration.

## **VII. MANAGEMENT AND RESEARCH IMPLICATIONS**

### ***Prescribed Fire Management/Fire Ecology***

Prescribed fire is the primary management tool for pyric systems, however proper planning and implementation is essential to achieve desired results. The appropriate timing, frequency, and intensity of fire for the oak barrens of south central Tennessee is unknown because little research has been done on the dendrochronological history of this area and restoration-related research is sparse. This study suggests annual burning is too frequent while 5-year periodic burning is not frequent enough for long-term restoration and maintenance purposes. The annual burning was successful at restoring the grassy herbaceous ground cover and an open canopy. However, a study done by Phillips et al. (2000) on this study site reported annual burning compacts the soil and depletes it of organic matter. This degradation of the soil reduces productivity, removes the seed bank, and is potentially detrimental to long-term sustainability of the system. Though 5-year periodic burning was not found to be detrimental to the soil, it did not restore the desired structure.

Because annual and 5-year periodic burning creates right skewed unsustainable diameter distributions, decreased regeneration height and recruitment, and undesirable understory composition and structure, we suggest examining the effects of 2 to 3 year burning regimes using adaptive management in which more intensive burning is

implemented until the desired structure is achieved, then scaled back to a less intensive fire regime for the maintenance of the system with monitoring and adjustment when necessary. After 42 years of continuous burning, evidence suggests these fire regimes are potentially unsustainable, especially at small scales and without breaks in the fire return interval or burning in a mosaic pattern. We also recommend implementing an fire ecology study on a larger scale to reduce size and edge effects and allow for a more natural mosaic burning pattern.

### ***Sampling Design/Data Collection***

The vegetation and small mammal sampling designs for this study were not ideal. The forest sampling was initially set up as nested permanent plots with midstory and overstory trees individually marked to track changes throughout time. The original midstory and understory nested plots were too few and not large enough to be representative of an adequate sample size. Tags on the marked trees were not kept up to date and the original data was lost. Tracking changes through time on individual trees from the original study to present was impossible.

Small mammal sampling was conducted in within the standard recommendations but oversampling occurred. The average number of animals per acre was within the normal range for all of the species trapped. The capture rate was low but individual recapture rates were high suggesting too many traps for too few animals to be trapped. Low capture rates are common with small mammal sampling, but having 2 traps per

sampling station were probably too many. Although some trap stations occasionally caught an animal in both traps, using one trap per station would have doubled capture rate without significantly reducing the number of captures.

The habitat sampling was adequate for a representative sample size and aided in classifying stand structure. However, using the habitat variables for predicting small mammal abundance was ineffective. The models showed a strong temporal factor associated with seasonal changes in food and cover resources but little preferences of specific habitat variables were observed. Given the range of species included and the significant differences in the habitat types, multiple linear regression modeling is not recommended. Modeling small mammal abundance using habitat variables is better with species with more habitat specific requirements or when only one species is used. We recommend adding or changing some of the variables collected to better suit the species being modeled because the amount of variation explained by each of the models was low and tended to be variables related to vegetation structure less than 0.5 meters. Shortening the time period between trapping periods and within trapping periods is also recommended to reduce some of the potential temporal variation and variation associated with changes in growth of vegetation and resources available.

## VIII. CONCLUSION

After 42 years, annual and 5-year periodic prescribed fire treatments have altered overstory and understory structure and composition and have created three different habitats with differing associated small mammal populations. Both 5-year periodic and annual treatments showed a significant decrease in recruitment and have the majority of the trees in the greater than 11 inch DBH size classes. As these stands mature and the overstory senescens and dies, density and basal area will significantly decrease to densities similar to oak barren historical accounts; however due to lack of recruitment, long-term sustainability is debatable. On larger scales in which fire would burn in a mosaic pattern providing patchwork unburned areas, sustainability is plausible. Although sustainability is plausible, continual annual and 5-year periodic fire for restoration and maintenance of oak barrens does not create the desired system. Annual burning works well for restoration of oak barrens; however once the desired condition is attained the use of annual burning for maintenance is too intensive and will severely degrade the site. Five-year prescribed burning does not restore oak barren structure, either. The higher intensity fires on a longer fire return regime increases overstory mortality, reduces recruitment and promotes a high woody shrubby component rather than an open park-like understory.

Low intensity annual prescribed fire appears to bear little immediate effect on small mammal populations but the long-term effect of fire intensity and frequency greatly alters available habitat and small mammal diversity and abundance. Species abundance

and occurrence varied between trapping periods and treatments due to differences in food and cover resources. The annual burn treatment showed no significant effect on small mammal populations as compared to the unburned 5-year periodic and control treatments beyond treatment and time period differences. Fire frequency and intensity play important roles in shaping small mammal habitat and populations.

The difference in species abundance and occurrence between treatments appears to be a result of the different habitat types created by fire. Small mammal abundance and occurrence are highest with the thick woody-herbaceous habitat type created by 5-year periodic burning. The 5-year periodic treatment has the highest structural diversity and complexity providing habitat for generalist and arboreal species. Resources are higher and understory composition is more diverse in the 5-year periodic treatment because vegetation has a longer recovery time allowing more resources for seed production. Annual burning and control treatments had similar lower abundances and occurrences because structural diversity and resources were lower. The intensive annual prescribed burning allows little recovery time and decreases resources for seed germination. Lack of fire in the control treatment provides little sunlight to the forest floor resulting in reduced understory structure and lack of herbaceous food and cover resources.

Abundance modeling suggested understory structure and trapping season were related to small mammal abundance. As understory diversity, structure, and height increase, small mammal populations have a positive response. Populations also showed temporal differences that are associated with changes in habitat and resources availability

throughout the year. Long-term prescribed fire shifts succession back and provides managers with the ability to alter available habitat to promote early successional species.

A common misconception regarding the use of fire for forestry and habitat management is that fire is beneficial to ecosystems and should be restored to the landscape. Fire is not necessary or advantageous for all ecosystems. Although many ecosystems require fire for system maintenance and others respond well to fire; proper frequency, season, and intensity is required for beneficial results.

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