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I am submitting herewith a thesis written by David Matthew Ellis entitled "Effects of Community Type and Site Productivity on Re-Accumulation of Forest Fuels after Prescribed Burning in East Tennessee." I have examined the final paper 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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Thesis
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EFFECTS OF COMMUNITY TYPE AND SITE PRODUCTIVITY ON RE-ACCUMULATION OF FOREST FUELS AFTER PRESCRIBED BURNING IN EAST TENNESSEE

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

David Matthew Ellis
August 2004

DEDICATION

This thesis is dedicated to my parents. Sharon and David Graeflin, you have believed in me and supported, encouraged, and inspired me to do my best and to never give up. Whether it's school or athletics you both have been by my side all the way. I love you both with all my heart. To my entire family, I thank you for your support over the last few years. I could not have been able to accomplish what I have without your support and encouragement.

ACKNOWLEDGEMENTS

There are so many people who have made my degree and project possible. I want to acknowledge our Lord Jesus Christ for making all things in my life possible and for giving me so many wonderful blessings. I have already dedicated my thesis to my parents and family, but I want to thank them again. My parent's and friends put up with me through some stressful times and never stopped encouraging me.

I wish to thank Dr. David Buckley for the opportunity to obtain my Master's degree and for his continued professional advice, instruction and encouragement. I am grateful for the experience I have had here at the University of Tennessee and will never forget it. I would also like to thank Drs. Don Hodges and Jack Ranney for their service on my committee and for their continued advice and guidance. I could not have completed my thesis without their help. I appreciate Dr. Steve Knowe and Ann Reed for their assistance with statistical analysis.

I would like to thank Dr. H. Michael Rauscher of the USDA Forest Service, Southern Research Station for his role in securing Joint Fire Science Program funding that made this project possible. I would like to thank Marty Bentley and Anita Bailey from the Cherokee National Forest for their cooperation in mapping and project planning. I would also like to thank my field crew members for their hard work and patience. Jeff Strickland, Pat Rainbolt and Danny Gordon all contributed a significant amount of time and effort in collecting my field data. Drake, I would like to thank you the most for your time, companionship, lack of complaints and the laughs. Finally, I would like to thank Jordana Cassell for her contribution to my field work. She has stood by me in times of

need and helped me maintain a positive attitude. That is immeasurable and will always be remembered.

ABSTRACT

Funding and manpower dedicated to prescribed burning programs are often limited, and information on the re-accumulation rates of fuels after burning and appropriate burning schedules is needed for prioritization and planning. I investigated the effects of community type and site productivity on the re-accumulation of forest fuels after prescribed burning. This was done on the Cherokee National Forest by sampling a five year chronosequence of stands with different periods of time since burning within three different community types. The community types were: dry-mesic pine/hardwood, xeric pine/hardwood, and dry-mesic hardwood sites. Five replicate stands representing 1, 2, 3, 4, and 5 years since burning and five controls with no recent burning were studied within each of the 3 community types. In all stands, coarse woody debris, fine woody debris, duff depth and litter depths were sampled using standard U.S. Forest Service FIA (Forest Inventory Analysis) methods for sampling fuels. Increment cores were obtained within each stand to establish site index and estimate stand age.

Effects of different frequencies of prescribed burning on fuel loading were investigated using replicate stands that have been burned annually and every 5 years for the past 41 years on the University of Tennessee Highland Rim Forestry Experiment Station. The same fuel measurement protocol used on the Cherokee National Forest was used to measure these plots.

Dry-mesic pine/oak sites and xeric pine/oak sites both contained greater amounts of coarse woody debris (CWD) and fine woody debris (FWD) after burning than the dry-mesic oak sites. There were no significant differences between years since burning in

amounts of coarse woody debris. The low intensity prescribed burns used by Cherokee National Forest managers significantly reduced FWD on site, but did not affect CWD quantities. Within the FWD category, 1 and 10 hour fuels were undoubtedly consumed by the prescribed burns, but differences between years since burning and between burned stands and controls were not statistically significant, suggesting rapid re-accumulation to control levels within the 5-years since prescribed burning. In contrast, 100 hour fuels were significantly reduced by prescribed burning and did not re-accumulate to control levels within 5-years since burning. Duff depths were highly variable, but differed significantly across years since burning. Quantities of duff were significantly greater 5 years since burning than in controls and 1, 2 and 4 years since burning. Litter depths increased significantly with increasing numbers of years since burning, but remained significantly less than in controls 5 years after burning. The dry-mesic and xeric pine/hardwood sites contained greater quantities of litter than dry-mesic hardwood sites.

There were no significant differences in CWD distribution between the annual and periodic burning treatments on the Highland Rim Forestry Experiment Station. Significant differences in the amount of fine fuels occurred between the annual burn treatment, periodic burn treatment, and control, with the least amount of fine fuels in the annual burn treatment. Control sites contained significantly greater amounts of FWD than the annual and periodic burning treatments. Similar significant patterns were also found for both duff and litter depths.

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I. INTRODUCTION AND REVIEW OF LITERATURE

American Indians and Fire

Fire has played a major role in the development of many forests over the course of time. Native Americans used fire as a management tool, but on a larger scale and intensity than is currently used. The use of fire by Native Americans is a controversial topic. Some early accounts of the southern Appalachian forests describe a park-like forest and some specialists attribute these open forests to disturbance by frequent fires- both lightning and Indian caused. Other experts counter that the frequent burning of forests by Native Americans was, at most, a local occurrence (Barden et al. 1976).

American Indians purposefully used fire for many reasons. Burning reduced threats of dangerous forest fires, cleared underbrush and kept forests open, improved habitat for deer and buffalo, and made gathering of acorns and chestnuts easier. The practice of regularly burning created large open meadows with widely spaced trees and abundant wildlife (Van Lear et al. 1990). Frequent burning in the past stimulated the production of forage for Indians, and retarded the advance of woody undergrowth. American Indians used fire to drive game and enhance habitat for game species (Phillips 1985).

In the Southern Appalachians, the American Indians' livelihood depended on the use of fire to clear land and on the cultivation of crops along the floodplains of major rivers and their tributaries. Before contact with Europeans, the Cherokees and their ancestors probably cleared all the bottomland in the region at one time or another (DeVivo 1992). There is no doubt that American Indians used fire for many reasons, but the intensity and frequency is still debated.

Lightning Caused Fires

The role of lightning-caused fires in pre-colonial times on the land that is now the Cherokee National Forest (CNF) is poorly documented. Lightning caused fires in Southern Appalachia are normally ignited on southern, upper slopes that are xeric (Barden 1973). If accompanied by rain, lightning fires usually lack the intensity necessary to eliminate the existing forest canopy and initiate a new stand (Barden 1976).

The CNF has had 153 lightning-caused fires in the 30-year period between 1967 and 1996 (CNF 2003). Lightning fires, as would be expected, are very sporadic. In several years, no lightning caused fires occurred, while in other years, multiple fires were recorded. For example 40 of the 153 total lightning-caused fires on record occurred in 1988. With an average fire size of 13.5 acres before control over the last 30 years, lightning fires could reasonably have accounted for the burning of at least 2,065 acres in the past 30 years. The average fire size is much smaller than would be expected if no control actions were taken on the fire. Thus, lightning fires, if allowed to run their natural course, may have burned much more than 2,065 acres in the past 30 years (CNF 2003). Whether fire was caused by American Indians or natural causes, fire was an important environmental component over substantial areas of the present-day Cherokee National Forest.

Fire Prevention in the United States

In order to protect redeveloping second-growth forests following logging and burning in the late 19th and early 20th centuries, fire suppression has been a major goal of both State and Federal agencies during the last century in the United States (Wakimoto 1987). This has led to the current state of what is believed to be high fuel loading in

many eastern parks and forests. Fuel loading has become a pressing issue due to the large number of severe and intense wildfires during recent wildfire seasons in the West. These wildfires are growing larger and larger due to drought conditions, pest infestations and ever-increasing fuels and the current status of thinning and fuel reduction techniques (Table 1).

Fuel Reduction

Prescribed fire is a leading fuel reduction technique nation-wide. Prescribed fires are controlled burns, which reduce fuels and decrease the likelihood of wildfire outbreaks (Arno et al. 1989). Apart from the use of prescribed fire to reduce fuels, duff and associated downed woody fuel can be removed with prescribed fire to prepare seedbeds, kill selected vegetation, and stimulate desired plant growth (Brown et al. 1997). Western states have drier climates and more fire adapted species than states in the East, which results in greater vulnerability of western forests to wildfires than eastern forests. The Southeast receives more annual rain, has higher decomposition rates, and broader species composition than western forests (Delcourt et al. 1997). All of these factors contribute to whether a prescribed fire will be carried through an area or not. The southeast is not as susceptible to wildfires as the western states, but fuels need to be assessed and monitored in order to develop effective plans and efficient schedules for prescribed burning. Although prescribed fire is a highly effective tool for reducing fuel loads and maintaining fire-adapted species and community types, human and financial resources required for prescribed burning are limited, and not all areas where prescribed fire is needed can be burned. Prioritization is critical, and differences in both community type and site productivity will influence how quickly fuels and structure redevelop and what

Table 1. Number of Fires and Acres Burned by Decade in the United States (CNF 2003).

Dates	Average No. of Fires	Average Acres Burned	Average Acres/Fire
1919 - 1929	97,599	26,004,567	266
1930 - 1939	167,277	39,143,195	234
1940 - 1949	162,050	22,919,898	141
1950 - 1959	125,948	9,415,796	75
1960 - 1969	119,772	4,571,255	38
1970 - 1979	155,112	3,194,421	21
1980 - 1989	163,329	4,236,229	26
1990 - 1999	106,306	3,647,597	34
2000 ONLY	122,827	8,422,237	69
2001 ONLY	84,109	3,570,911	42
2002 to 9/15	67,561	6,444,305	95

prescribed burning schedules are needed. Little published information exists on this subject, and further investigations are warranted.

Current Fire Suppression

Fire suppression on the Cherokee National Forest (CNF) is primarily conducted by ground crews using hand tools, dozers, and engines. These efforts are supplemented in the spring by air tankers currently based at Knoxville and Asheville and a helicopter based at Copperhill airport. A base is planned for Chattanooga that will replace the Knoxville base.

The CNF has maintained an interagency incident management team since 1991. This team is composed of personnel from the CNF, Tennessee Division of Forestry, TVA, and National Park Service. The team is activated on short duration fires, which escape initial attack and are considered, extended attack fires (Type III). If the complexity of the fires exceeds Type III, a Regional overhead team will be requested.

Coarse Woody Debris Importance

Coarse woody debris (CWD) is integral to the functioning and productivity of forested ecosystems. Standing snags and large logs on the forest floor impact soil processes, fertility, hydrology, and wildlife microhabitat (McCarthy 1994). In this study, coarse woody debris is considered pieces of dead or downed wood and greater than three inches in diameter.

Coarse woody debris has long been seen by forest managers as an unsalvageable resource in managed forest (Sedell 1994). It is now understood that CWD provides habitat for wildlife and plays a major role in nutrient cycling. As CWD decays over time,

nutrients stored in the wood are slowly released. These nutrients then become available to other plants and woody vegetation (Maser 1979).

Physically, CWD protects the forest floor and mineral soil from erosion and mechanical disturbances and it protects new seedlings from damage (Graham 1994). In moist forest types, it can be a seedbed and nursery area for new conifer seedlings and store large amounts of water while in later stages of decay (Hagan 1999).

Large amounts of coarse woody debris in the Southern Appalachians have historically been generated by major disturbances (Hedman 1996). The loss of American chestnut (*Castanea dentata*), and more recent losses of several species of southern yellow pine due to the southern pine bark beetle (*Dendroctonus frontalis*) have resulted in large amounts of CWD in the region. Prescribed fire is the number one management method of reducing these highly flammable fuels, although reductions of amounts of CWD could impact some beneficial ecological functions of this material. Increased fire frequency could result in loss of CWD and other important site characteristics.

Fire Effects on Soil Nutrients

Effects of prescribed fire on water quality and soil nutrients vary, depending on fire intensity, type and amount of vegetation, ambient temperature, terrain, and other factors. The main problem with prescribed fire and water quality is the potential increase in sedimentation and to a lesser degree, dissolved salts in streamflow (Van Lear 1990).

Presently, infrequent low-intensity surface fires during the spring and fall characterize the fire regime of oak-hickory forests (Stanturf 1995). Fires of this intensity typically burn only unconsolidated litter and fine woody fuels, leaving the humus and

upper soil layers uncombusted. These fires are caused almost exclusively by humans and burn small areas (Barden 1973).

Direct volatilization of nitrogen (N) during combustion of litter can result in large losses of N from the ecosystem. However, fires in the central hardwoods are typically low in intensity and consume primarily the unconsolidated leaf litter (Boerner 2000). As long as the fire can move across the open forest floor, soil temperatures generally do not increase enough to cause significant heating-induced mortality of organisms dwelling in the mineral soil. Soils under smoldering piles of woody fuels may, however, be subject to sterilization. Direct N volatilization is probably not an important pathway for fire related nutrient loss due to low fire temperatures (Boerner 2000). If there is a reduction in N, it is only temporary as nitrogen-fixing soil microorganisms replace soil nitrogen rapidly (Van Lear 1990). Annual and periodic burning on the Highland Rim in Tennessee had no affect on soil pH or exchangeable phosphorus but did reduce soil potassium (Thor and Nichols 1974). Losses and subsequent recovery of C and N pools after fire is a function of fire severity. Fire severity depends on ignition techniques, fuel load, size distribution, flammability, and moisture content, all of which can influence fire residence time (Clinton 1996).

Prescribed burning and its influences on soil water storage are expressed largely through effects on evapotranspiration. A properly conducted prescribed burn normally does not greatly affect evapotranspiration and, consequently, little change in the soil water storage is expected (Baker 1988). The effects of fire on forest ecosystems vary greatly and depend on the quality and quantity of fuels, soil properties, topography, climate, weather, and fire frequency and intensity (Richter 1982).

Research Needs

Historically, fire may have been the most common form of natural disturbance on the landscape now managed as Cherokee National Forest. Fire has played an important role in the development and maintenance of southern yellow pine ecosystems and appears to be a major factor in the development of oak forests (Zwolinski 1988). Effective use of fire is needed to maintain and restore many forested communities across the southern Appalachians, especially xeric pine and pine-oak forest; dry and xeric oak forests; and dry and dry-mesic pine-oak forests (Pfilf et al. 2002). Without fire or other vegetation management actions that approximate fire effects, many communities may decline dramatically in future years and shift towards shade-tolerant and fire-intolerant species (Elliot et al. 1999).

Due to greater production of all plant materials, it is possible to hypothesize that fuels will re-accumulate most rapidly on sites of higher productivity, and in community types dominated by conifers. Managers on the CNF recently began an ambitious prescribed fire program in which stands are burned on a 3-5 year cycle. The efficiency of this cycle needs further investigation. As with all prescribed fire programs, not all areas in need of burning can be burned on schedule. Prioritization and planning are key to their ability to manage effectively with prescribed fire, and increased information on the effects of community type, site productivity, and time since burning on the rate of fuel redevelopment would aid these processes.

II. RESEARCH OBJECTIVES AND GOALS

This project is designed to establish the rate of fuel re-accumulation after prescribed burning across sites differing in community type and site productivity, and also the effects of different burn frequencies on fuels. Specific objectives are to: 1) test the hypotheses that fuels will re-accumulate at faster rates over a 5-year period on sites of higher productivity and also in cover types dominated by conifers, and 2) to document long-term effects of different burning schedules on amounts of fuel in different categories.

III. MATERIALS AND METHODS

Objective 1: This project is designed to establish the rate of fuel re-accumulation after prescribed burning across sites differing in community type and site productivity, and to test the hypotheses that fuels will re-accumulate at faster rates over a 5-year period on sites of higher productivity and also in cover types dominated by conifers.

Study Area CNF

This objective was addressed on The Cherokee National Forest, a 639,450-acre forest located in 10 East Tennessee Counties. The forest is divided into a Northern and Southern Region on either side of the Great Smoky Mountains National Park (Figure 1). The Cherokee National Forest is managed by the USDA Forest Service.

The Tellico and Hiwassee Ranger Districts provided sites for this part of the research project (Figure 2). Three basic cover types were studied: xeric pine-oak forest; dry-mesic oak forests; and dry-mesic pine-oak forests. Mesic sites are neither decidedly wet nor dry while the xeric sites are characterized by dry moisture conditions. Many forms of management are practiced on these districts, including fuel reduction practices. Prescribed fire is used on a regular basis in some areas to help control species composition and reduce fuel loading.

Geology CNF

The CNF is underlain by igneous and metamorphic rock and by highly deformed sedimentary rock. These rock units range in age from Pre-Cambrian to Mississippian. Rocks in CNF have been greatly altered by periods of metamorphism and tectonism. At least two major metamorphic episodes have been recognized in the Blue Ridge province of Tennessee. The area contains extensive folding and numerous faults, which are

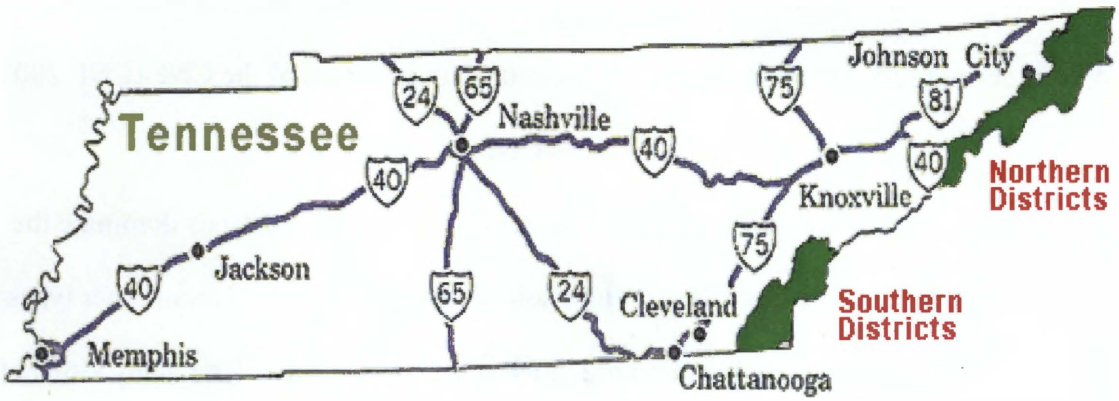

Figure 1. Entire Cherokee National Forest- Northern and Southern Regions (CNF 2002).

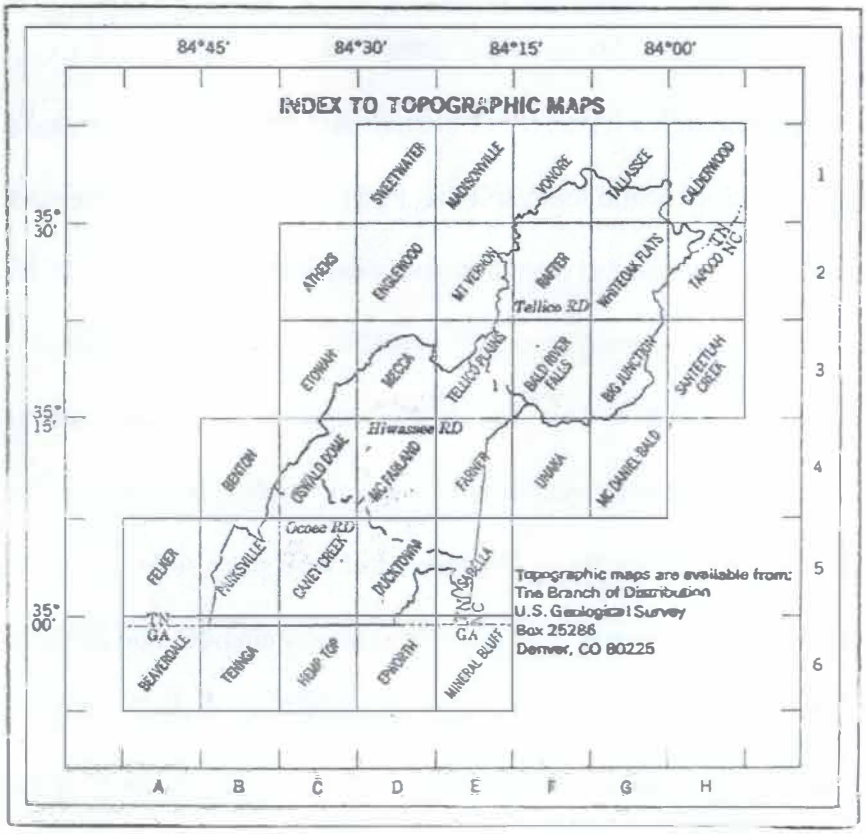

Figure 2. Southern Region of the Cherokee National Forest, Tellico Ranger District (CNF 2002).

believed to be inactive, although small tremors are occasionally felt. Anakeesta and Wilhite formations containing iron sulfide occur in many areas of the CNF (CNF 2003).

Soils CNF

Soils derived from sandstone, phyllite, and shale parent materials dominate the mountainous relief of the Cherokee. Minor soil areas have developed from other types of rocks such as limestone, granite, quartzite, gneiss, schist, and slate. The many kinds of soil differ in physical and chemical properties such as texture, depth, rock content, relief, acidity, plant nutrients, and available moisture. The differences in the erodability and stability of these soils vary with steepness of slope and amount and kind of vegetative cover, and amount and timing of soil disturbance.

Approximately 80 percent of the national forest falls in the middle range of soil productivity with clay and loam soil material present. Plots located on the Hiwassee and Tellico Ranger Districts fell into three basic soil categories; Ranger-Citico-Fletcher (RCF), Sylco-Citico-Brookshire (SCB) and Ditney-Brookshire-Jeffrey (DBJ) associations (Hall et al. 1981). The RCF association is characterized by steep and very steep soils, 2 – 6 feet deep over phyllite rock, on highly dissected mountains. Next the SCB association is characterized by steep and very steep soils, 2 – 8 feet deep over phyllite and arkosic sandstone rock, on high mountainsides and in deep coves. Finally the DBJ association is dominantly steep and very steep soils, 2 – 8 feet deep over arkosic sandstone, on high mountainsides and in deep coves. In addition, several kinds of areas require special consideration to soils; they include high mountain balds, slopes steeper than 45 percent, active and healed gully and sheet erosion areas, areas containing Anakeesta and Wilhite geologic formations, riparian areas, and certain cove units.

Climate CNF

The CNF is within the humid temperate domain, hot continental division, and Appalachian oak forest section. The average annual temperature is 59 degrees Fahrenheit; annual rainfall ranges from about 40-inches at the lower elevations to over 75-inches at the higher elevations. Mean annual runoff varies from 20 inches in areas of low rainfall to over 35 inches in areas of high rainfall. Snowfall contributes little to total annual precipitation. The growing season ranges from 150 days per year on the northern extent of the national forest to 230 days on the southern extreme (Hall et al. 1981).

Treatments

Using the CNF GIS system and reconnaissance of potential stands, several forested areas were delineated that were similar in slope, aspect, age class, management history, community type and site index. Prescribed fires in all stands studied were low intensity burns with comparable flame length, rate of spread, firing method and season of burn. Ridge tops were aerial ignited using helicopters which create many head fires, backing fires and flank fires simultaneously. Backing fires consisted of 1-2 foot flame lengths depending on fuel type and moisture content. All burns on the CNF are conducted between March 1st and April 15th. This was true over all stands. Each area contained stands that have been burned using prescribed fire on a five-year rotation. So, each area contained stands that were burned one year ago, two years ago, etc. The three community types, as well as the chronosequence of times since burning used are outlined in Table 2.

Five stands representing each burn year and community type were studied and received one sampling cluster plot per stand. This amounted to 75 stands and sets of

Table 2. Study Areas

1) 3 Community Types
2) 5-Year Prescribed Burns
3) All Cover Type-Year Combinations Replicated 5 Times

FORESTED LAND AREA					
Cover Type # 1		Cover Type # 2		Cover Type # 3	
Dry-Mesic Pine-Oak Forest		Xeric Pine-Oak Forest		Dry-Mesic Oak Forest	
Burn Years	1	Burn Years	1	Burn Years	1
	2		2		2
	3		3		3
	4		4		4
	5		5		5

cluster plots located on Forest Service GIS maps. The FIA cluster plots mentioned were broken down into 4 individual subplots, which were used to measure duff and litter depth, tree species and DBH, and down woody debris.

Measurements CNF

A cluster of plots were installed in each burn year/community type combination using the same plot dimensions and arrangements as those currently used by the Forest Service Forest Inventory and Analysis program (FIA 2001). Each cluster of plots was a minimum distance of 2 chains from Forest Service roads. Plot centers were located by turning the face of a compass in order to find a completely

random azimuth. Once inside the correct community type and burn year, the azimuth was used to find plot center and begin the data collection process. FIA plot layout with dimensions and forest fuel measurement categories are located in Figure 3.

Each plot was sampled according to the guidelines in the Field Instructions for the Southern Forest Inventory developed by the USDA Forest Service FIA program as follows (FIA 2001). Each plot was divided into four subplots (Figure 3). Each subplot was located by first finding plot center, and then the other three plots were located at 360°, 120° & 240° from plot center. Subplots 1 and 4 had azimuths of 150° and 270° from plot center. Subplots 2 and 3 had azimuths of 30° and 150° from plot center. The 150° azimuths represented in each subplot were used to measure Fine Woody Debris (FWD) in 3 diameter classes and Coarse Woody Debris (CWD). The 30° and 270° azimuths were used to measure Coarse Woody Debris (CWD) only.

Fine Woody Debris (FWD) was measured on the 150° azimuth. The fine fuels were grouped into three categories; Small, Medium and Large representing the 1, 10 and 100 hour fuel categories. The small diameter class measured 0.1-.24 inches and was measured over a 10-foot segment between 24 and 34 feet on the tape measure. The medium diameter class measured .25-.9 inches and was also measured over a10-foot segment between 24 and 34 feet on the tape measure. The large diameter class measured 1.0-2.9 inches and was measured for a 20-foot segment between 24 and 44 feet on the tape measure.

Fine woody fuels were tallied between the distances listed previously, and were recorded in each size class. All fuels crossing the transect from ground level to head

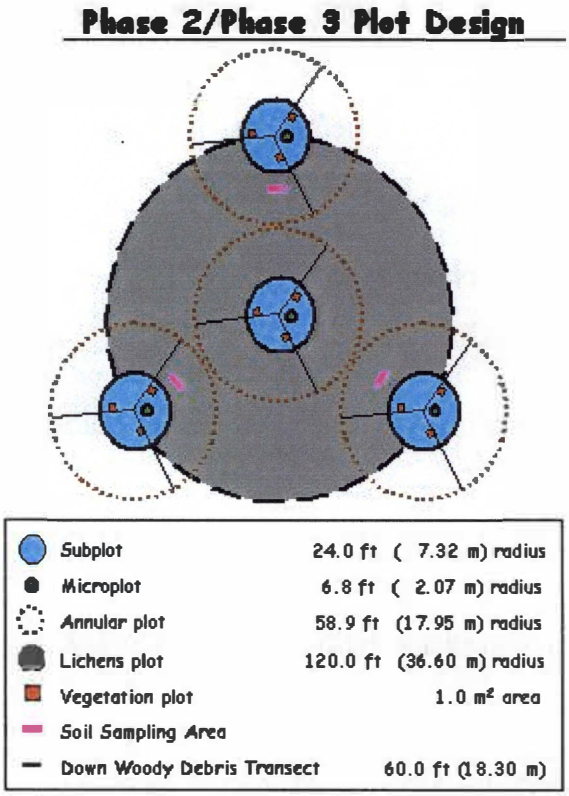

Figure 3. FIA Plot Layout (FIA 2001).

height that were dead or down were tallied, even if crossing the transect more than once. Community type, species composition and DBH were recorded along with the number of years since burning.

CWD were fuels larger than 3.0 inches in diameter. Coarse Woody Debris was measured on all azimuths from 0-58.9 feet along each transect. These fuels often require frequent prescribed burns before they are reduced (Hagan et al. 1999). Each piece was tallied and measured for its orientation, maximum and minimum end diameter, and length and decay class. These measurements were then used to calculate tons/acre for each cover type and years since prescribed fire (Brown 1974).

Duff and litter depth was also recorded on each transect (azimuth) at 14 and 24 feet. Litter was defined as the layer of freshly fallen leaves, twigs, dead moss, dead lichens, and other fine particles of organic matter found on the surface of the forest floor.

Duff was defined as the organic layer below fresh litter. It consisted of decomposing leaves and other organic material just above the mineral soil. Measurements of duff and litter were taken using a ruler. After sampling and collecting the data, comparisons were made between the xeric pine-oak forest, dry-mesic oak forests and dry-mesic pine-oak forests cover types and across years since burning using 2-way Analysis of Variance (ANOVA) and Tukey's Honestly Significant Difference (HSD). All tests were conducted with alpha = 0.05. One tree from each of the cluster plots was measured for height and cored with an increment borer to determine age. Pines and oaks were sampled in mixed stands, and oaks were sampled in oak stands. These heights and ages were used to determine stand site index at base age 50.

Objective 2: Document long-term effects of different burning schedules on amounts of fuel in different categories.

Study Area HRFES

The University of Tennessee's Highland Rim Forestry Experiment Station near Tullahoma, in Franklin County, Tennessee was the second study site (Figure 4). The 860 acre area contains plots that have been under prescribed fire management for 41 years. Prescribed fires on a 1 and 5-year interval have been implemented on replicated oak-hickory plots since 1963. Control plots are also located adjacent to treated plots. Treatments and controls are replicated 3 times each.

Geology HRFES

Franklin County is divided by two broad physiographic divisions; the Cumberland Plateau section of the Appalachian Plateau Province, and the Highland Rim and central Basin. The Highland Rim is underlain by the St. Louis and Warsaw limestone groups. Fort Payne chert forms the Rim's escarpment and a silty loess mantle is still evident. Chattanooga shale forms the dividing line between the Highland Rim and the adjoining Central Basin (Bassler, 1932).

Soils HRFES

The soils occupying the Highland Rim Forestry Experiment Station are residual materials weathered from the cherty limestone or loess. The Dickson soil series occurs on a major portion of this upland area chiefly as a silt loam. Lawrence and Guthrie soils are also associated with the Dickson series. These soils are acidic, as well as low in organic matter and plant nutrients with a siltpan occurring between 18 and 30 inches (Hall, 1981).

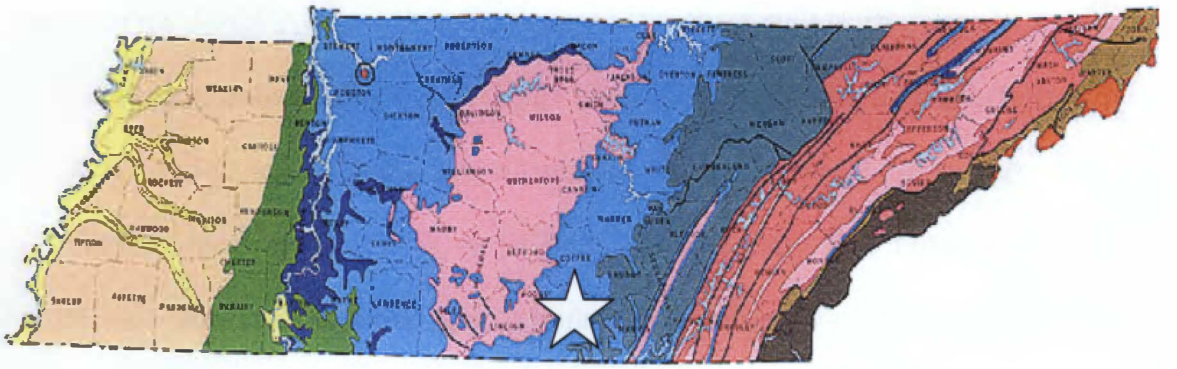

Figure 4. Highland Rim Forestry Experiment Station, Franklin County (TDEC 2003).

Climate HRFES

Franklin County has a mean summer temperature of 77° F, with a mean winter temperature of 43° F. Average precipitation is between 54 and 58 inches a year with a 196-day average growing season (Dickson, 1960).

Measurements HRFES

Measurements taken on site were the same as those taken on the Cherokee National Forest for objective 1. One cluster of plots was located in each of the three replicate plots for each treatment and control to examine effects of prescribed fire frequency on fine, medium and large fuels.

Data Analysis

Data were averaged over plots to calculate stand averages, which were analyzed using ANOVA, (General Linear Model (GLM) procedure, SAS Institute 2002). For objective 1, 2-way ANOVA was used to examine effects of the factors community type and years since the stand had been prescribed burned. Tukey's Honestly Significant Difference (HSD) was used to test for differences between cover types and years since

burning. Any significant interactions were explored with 1-way ANOVA within cover types. For objective 2, 1-way ANOVA and Tukey's HSD were used to examine differences between burning frequency treatments and controls. The alpha level of significance used for all tests was 0.05. The Shapiro-Wilk test was used to test the normality of the data in all analyses. W values of approximately 0.90 were considered to indicate normal distribution of the data. Based on the outcome of the Shapiro-Wilk tests, no transformations were necessary.

IV. RESULTS

Site Index

Measured site index was greater in the dry-mesic pine/hardwood stands (cover type 1) and in the dry-mesic hardwood stands (cover type 3) than in the xeric pine/hardwood stands (cover type 2). The xeric pine/hardwood site had a site index of 55-60. Dry-mesic pine/hardwood and dry-mesic hardwood stands had a site index of 65-70. Within cover types, site indices appeared to be comparable.

Effects of Cover Type on Re-Accumulation

Coarse Woody Debris

Quantities of CWD were significantly (P= 0.0443) greater in cover types 1 (6.9248 tons/acre) and cover type 2 (6.9584 tons/acre) than in cover type 3 (5.0853 tons/acre). No significant differences in amounts of CWD were found between years since burning, and patterns of mean values were variable within each cover type (Figures 5-7). However, there was a trend toward the greatest amount of CWD in the unburned controls.

Fine Woody Debris

Quantities of 1 hour fuels were significantly (P= 0.0001) greater in cover types 1 (0.23397 tons/acre) and cover type 2 (0.24057 tons/acre) than in cover type 3 (0.18097 tons/acre). No significant differences in amounts of 1 hour fuels were found between years since burning. Patterns of mean values were variable within each cover type. Similar to, CWD a trend toward the greatest amounts of 1 hour fuels in the unburned controls occurred (Figures 8-10).

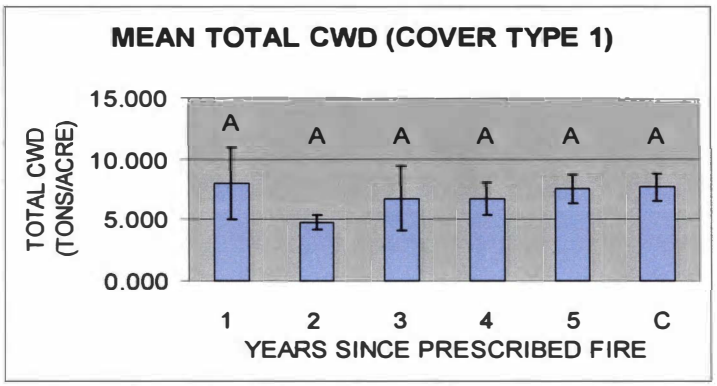

Figure 5. Cherokee National Forest Mean Total CWD (Cover Type 1). C = Control. Error bars represent one standard error beyond the mean. Bars with similar letters are not significantly different between years or between years and the control at the alpha =0.05 level. Letters correspond to the significance of differences between means for each year or control calculated over the 3 cover types.

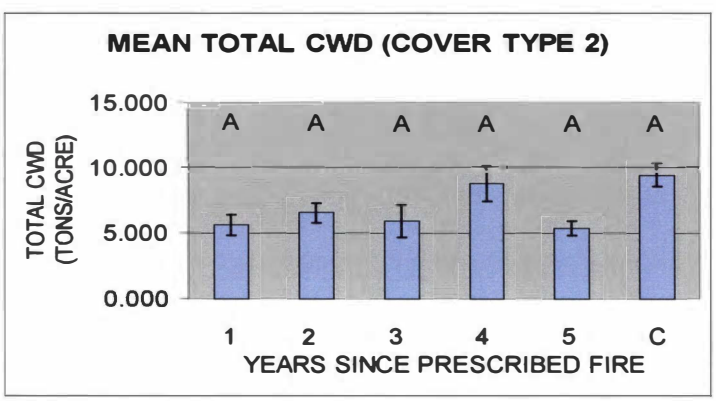

Figure 6. Cherokee National Forest Mean Total CWD (Cover Type 2). Error bars and significance as in Figure 5.

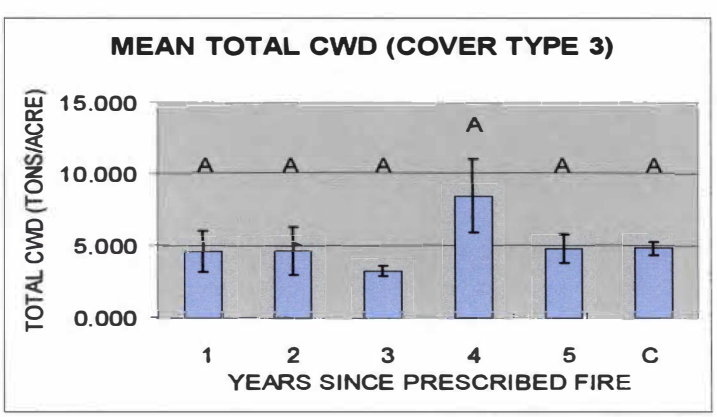

Figure 7. Cherokee National Forest Mean Total CWD (Cover Type 3). Error bars and significance as in Figure 5.

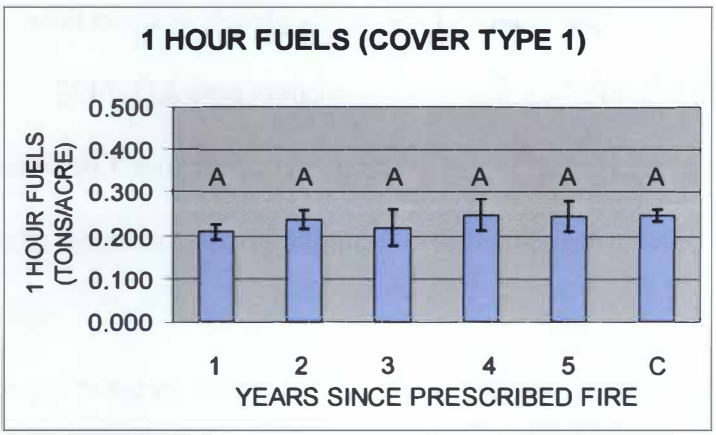

Figure 8. Cherokee National Forest Mean Total 1 Hour Fuels (Cover Type 1). Error bars and significance as in Figure 5.

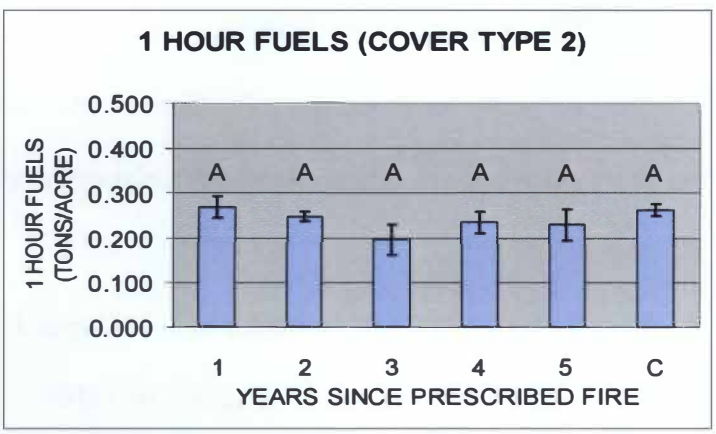

Figure 9. Cherokee National Forest Mean Total 1 Hour Fuels (Cover Type 2). Error bars and significance as in Figure 5.

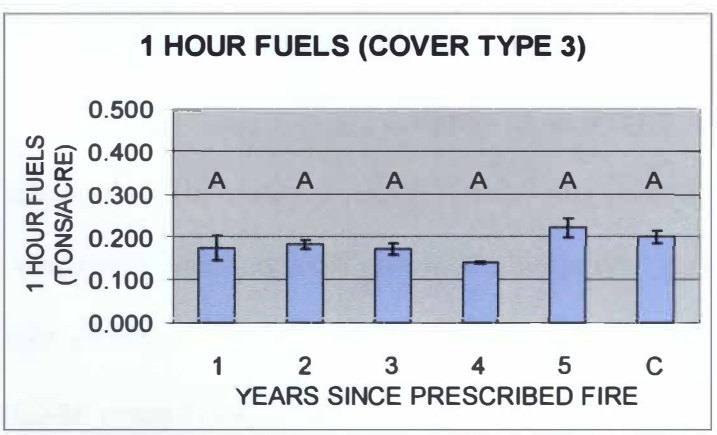

Figure 10. Cherokee National Forest Mean Total 1 Hour Fuels (Cover Type 3). Error bars and significance as in Figure 5.

Amounts of 10 hour fuels were significantly (P= 0.0001) greater in cover types 1 (2.3950 tons/acre) and cover type 2 (2.6157 tons/acre) than in cover type 3 (1.7472 tons/acre). No significant differences in quantities of 10 hour fuels were found between years since burning. Unburned control sites tended to contain the greatest amounts of 10 hour fuels (Figures 11-13).

Amounts of 100 hour fuels were significantly (P= 0.0066) greater in cover types 1 (3.2901 tons/acre) and cover type 2 (3.9309 tons/acre) than in cover type 3 (2.4629 tons/acre). Significant differences were also found in quantities of 100 hour fuels across years since burning. Years 1-5 after prescribed fire were not significantly different from each other but were significantly different from the unburned controls. Control sites were significantly different from all other years since burning and contained the highest levels of 100 hour fuels (Figures 14-16).

Quantities of total FWD were significantly (P= 0.0011) greater in cover types 1 (5.9189 tons/acre) and cover type 2 (6.7872 tons/acre) than in cover type 3 (4.3910 tons/acre). Significant differences were also found in total FWD between years since burning. Control sites contained the largest amounts of total FWD and were significantly different from stands burned 1-5 years ago (Figures 17-19).

Duff and Litter Depth

Total duff depth was significantly (P= 0.0003) greater in year 5 (0.28336 inches) than in any other years since burning, and also the controls. No significant differences were found between total duff depth and cover types. Values are highly variable across years since burning and year 5 contains greatest estimates of duff depth (Figures 20-22).

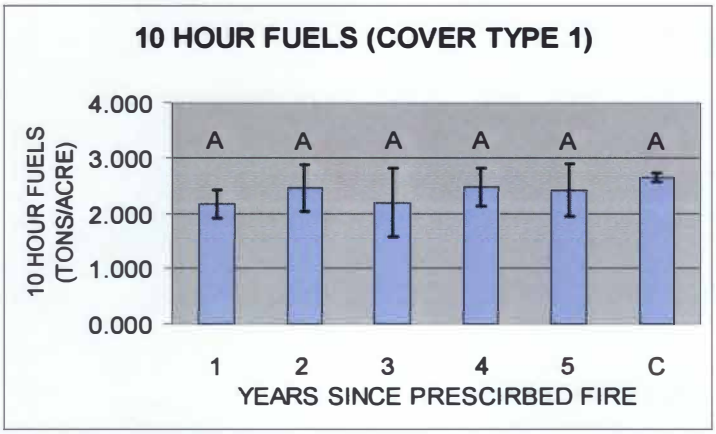

Figure 11. Cherokee National Forest Mean Total 10 Hour Fuels (Cover Type 1). Error bars and significance as in Figure 5.

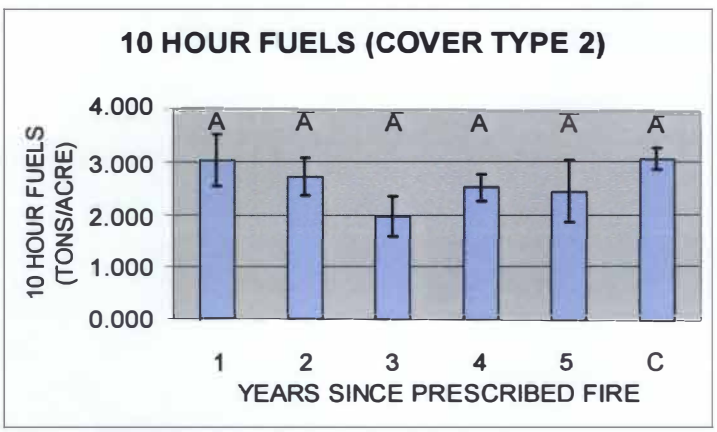

Figure 12. Cherokee National Forest Mean Total 10 Hour Fuels (Cover Type 2). Error bars and significance as in Figure 5.

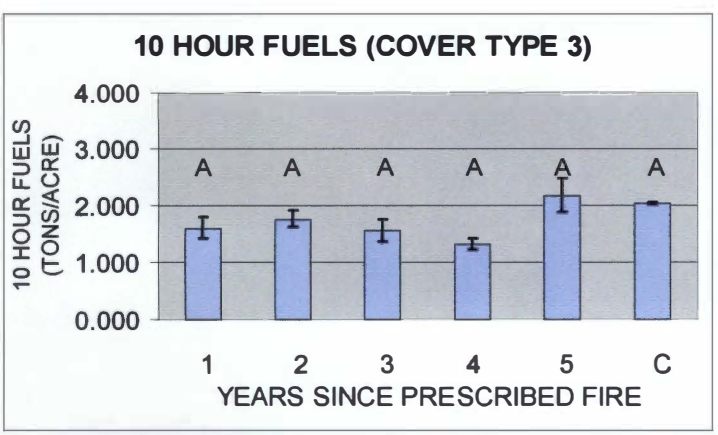

Figure 13. Cherokee National Forest Mean Total 10 Hour Fuels (Cover Type3). Error bars and significance as in Figure 5.

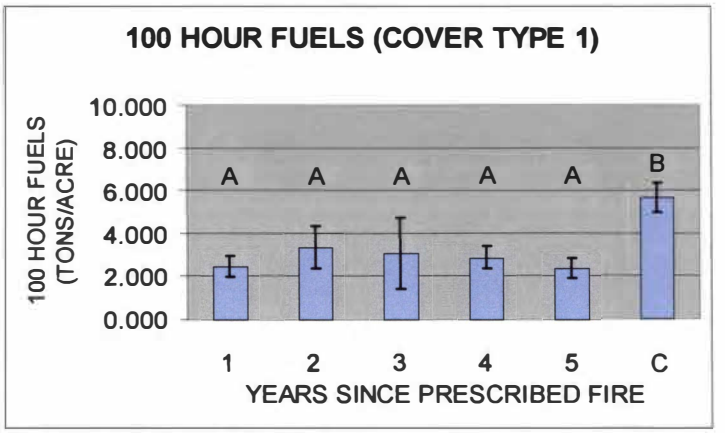

Figure 14. Cherokee National Forest Mean Total 100 Hour Fuels (Cover Type1). Error bars and significance as in Figure 5.

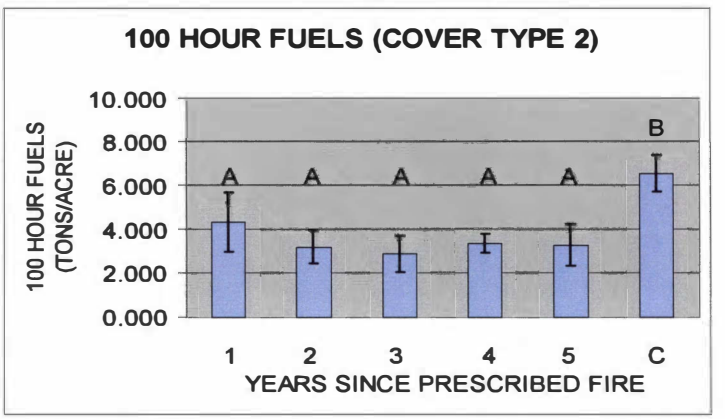

Figure 15. Cherokee National Forest Mean Total 100 Hour Fuels (Cover Type 2). Error bars and significance as in Figure 5.

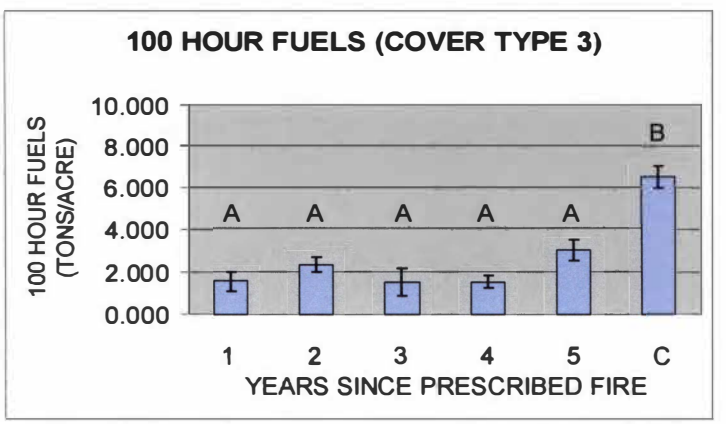

Figure 16. Cherokee National Forest Mean Total 100 Hour Fuels (Cover Type 3). Error bars and significance as in Figure 5.

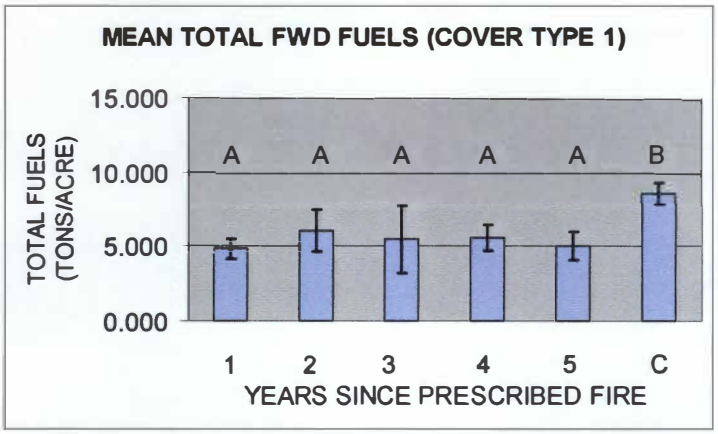

Figure 17. Cherokee National Forest Mean Total FWD Fuels (Cover Type 1). Error bars and significance as in Figure 5.

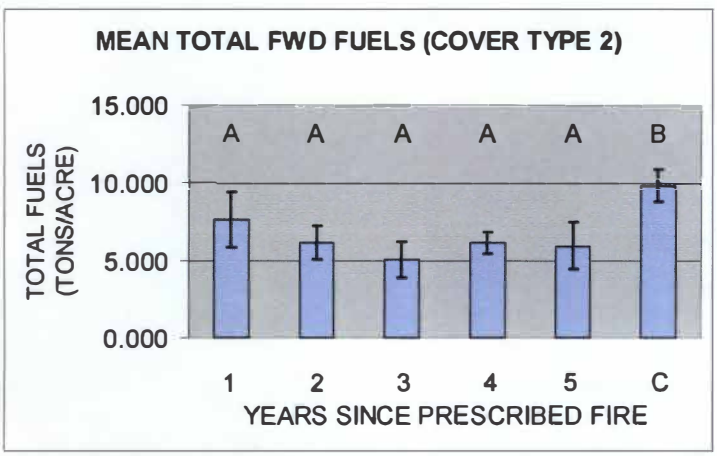

Figure 18. Cherokee National Forest Mean Total FWD Fuels (Cover Type 2). Error bars and significance as in Figure 5.

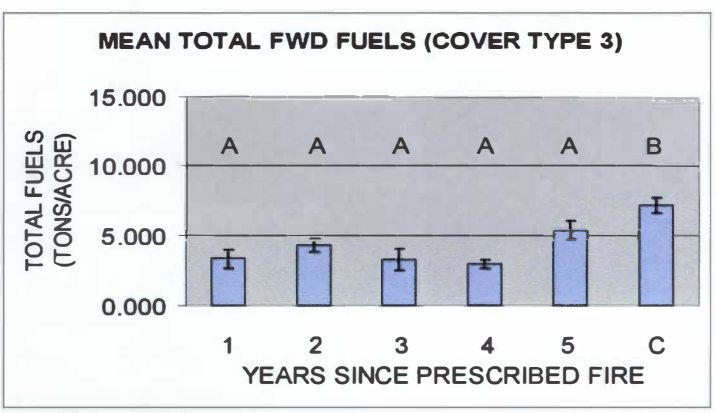

Figure 19. Cherokee National Forest Mean Total FWD Fuels (Cover Type 3). Error bars and significance as in Figure 5.

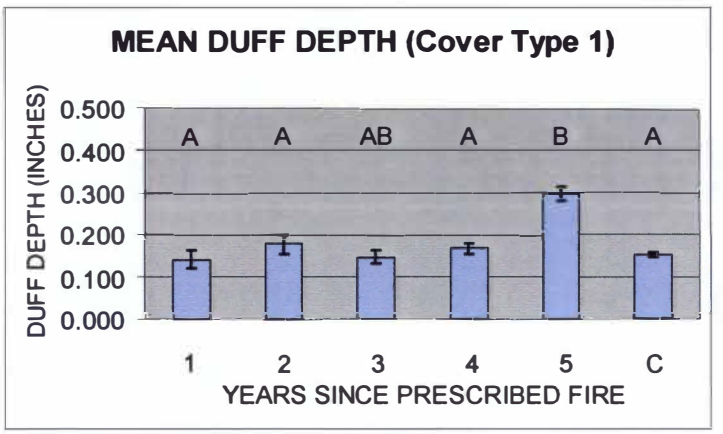

Figure 20. Cherokee National Forest Mean Duff Depth (Cover Type 1). Error bars and significance as in Figure 5.

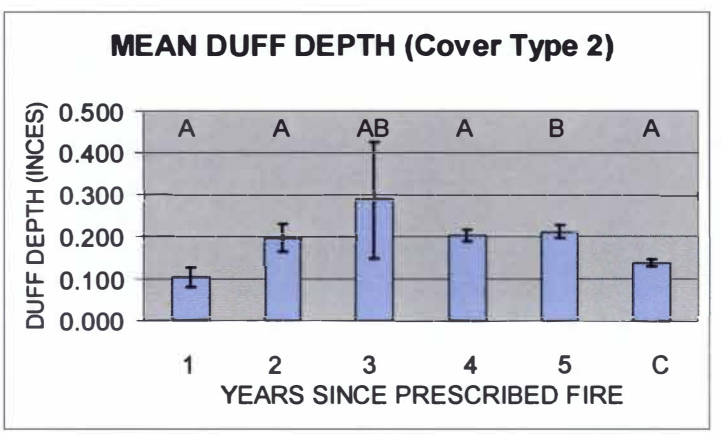

Figure 21. Cherokee National Forest Mean Duff Depth (Cover Type 2). Error bars and significance as in Figure 5.

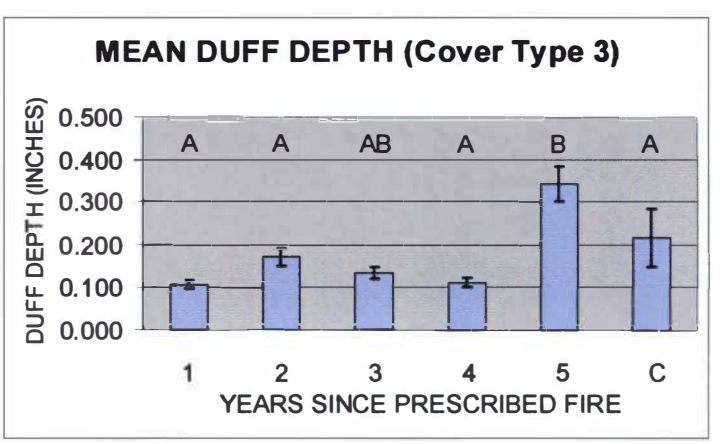

Figure 22. Cherokee National Forest Mean Duff Depth (Cover Type 3). Error bars and significance as in Figure 5.

Total litter depth was significantly (P= 0.0001) greater in control (2.54479 inches) sites and in stands burned 5 years ago (1.60417 inches) than in any other years since burning. A gradual increase in litter can be seen over time since burning, along with the control sites containing the greatest amounts of fuel (Figures 23-25). No significant differences were found between cover types, but there was a significant interaction between cover type and years since burning.

Since there was a significant interaction between cover types and years since burning, analyses were conducted within cover types to investigate this interaction. Cover type 1 contained several differences in litter depth between years since burning (Figure 26). Control sites (2.75 inches) were greatest, followed by 5 years since burning (1.6313 inches). 1, 2, & 3 years since burning were significantly different from 4 & 5 years since burning. Increasing levels of litter depth can be seen in Figure 26. Greatest amounts of litter were found in control sites (Figure 26).

Control sites contained the greatest litter depth (2.125 inches) within cover type 2 (Figure 27). Significant differences were found (P=0.0001) between control sites and all other years since prescribed burning. A general increase in litter depth can be seen in Figure 27.

Control sites contained the greatest litter depth (2.7594 inches) within cover type 3. Significant differences were found (P= 0.0001) between control sites (2.7594 inches) and the 5 years since burning (1.8250 inches). Years 4, 3, 2, & 1 since burning were significantly different from 5 years since burning and the control site. A gradual increase in litter depth over time with greatest amounts in the 5 years since burning stands and control sites occurred within cover type 3 (Figure 28).

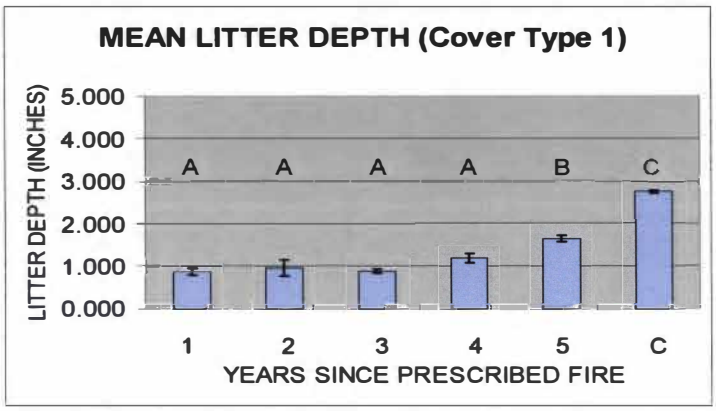

Figure 23. Cherokee National Forest Mean Litter Depth (Cover Type 1). Error bars and significance as in Figure 5.

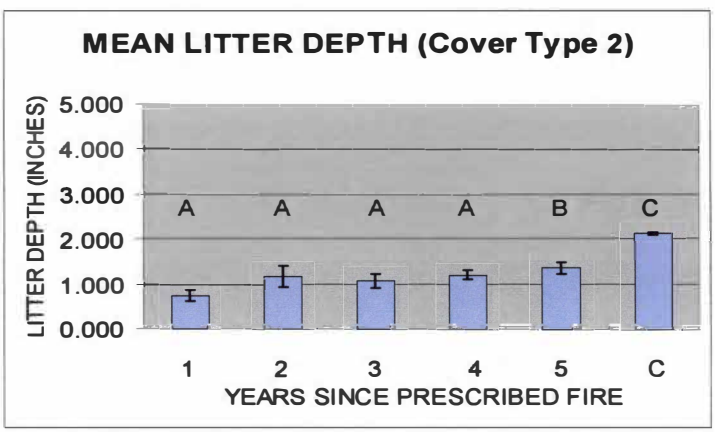

Figure 24. Cherokee National Forest Mean Litter Depth (Cover Type 2). Error bars and significance as in Figure 5.

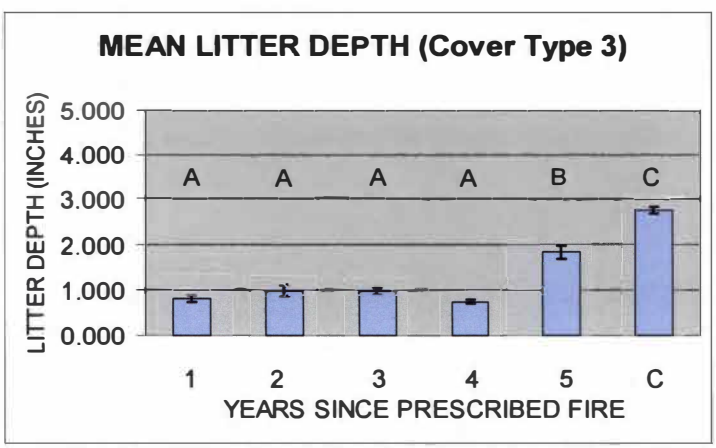

Figure 25. Cherokee National Forest Mean Litter Depth (Cover Type 3). Error bars and significance as in Figure 5.

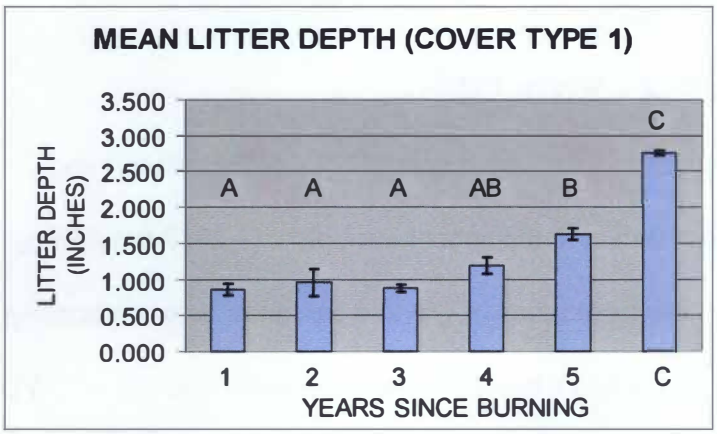

Figure 26. Cherokee National Forest Mean Litter Depth within Years Since Burning (Cover Type 1). Error bars and significance as in Figure 5.

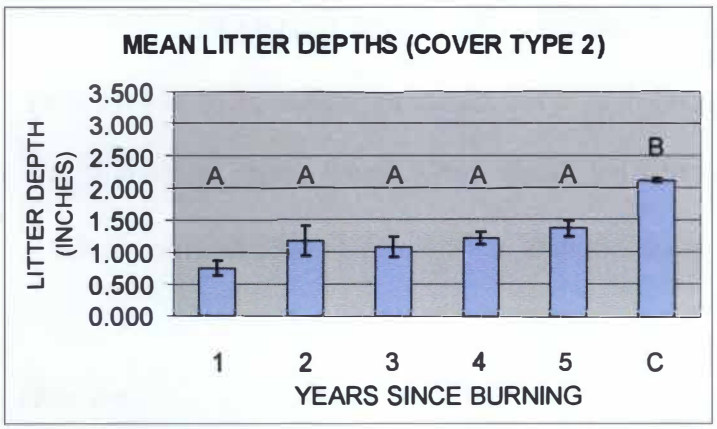

Figure 27. Cherokee National Forest Mean Litter Depth within Years Since Burning (Cover Type 2). Error bars and significance as in Figure 5.

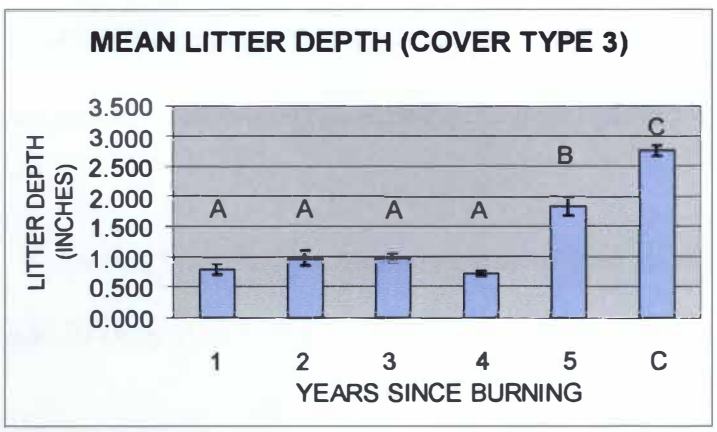

Figure 28. Cherokee National Forest Mean Litter Depth within Years Since Burning (Cover Type 3). Error bars and significance as in Figure 5.

Effects of Fire Frequency on Fuel Loading

Coarse Woody Debris

Quantities of CWD were greater in unburned controls (7.4415 tons/acre) and periodic burn plots (3.3449 tons/acre) than in the annual burn plots (1.2317 tons/acre). No statistically significant differences in amounts of CWD were found between burning treatments (Figure 29). However, there was a trend toward the greatest amount of CWD in the unburned controls.

Fine Woody Debris

The amount of 1 hour fuels was greater in the controls (0.2043 tons/acre) and periodic burn plots (0.1216 tons/acre) than in the annual burn plots (0.1026 tons/acre). Significant differences in amounts of 1 hour fuels were found between the control and annual treatment (Figure 30). Greatest amounts of 1 hour fuels were recorded in the unburned control sites.

The amount of 10 hour fuels was greater in unburned controls (2.130 tons/acre) and periodic burn plots (0.9430 tons/acre) than in the annual burn plots (0.7303 tons/acre). Significant differences in amounts of 10 hour fuels were found between burning treatments (Figure 31). Control sites were significantly different (P=0.0032) from the periodic burns and annual burns. Greatest amounts of 10 hour fuels were in the unburned control sites.

The quantities of 100 hour fuels were greater in unburned controls (2.3606 tons/acre) and periodic burn plots (1.5126 tons/acre) than in the annual burn plots (0.9680 tons/acre) (Figure 32).

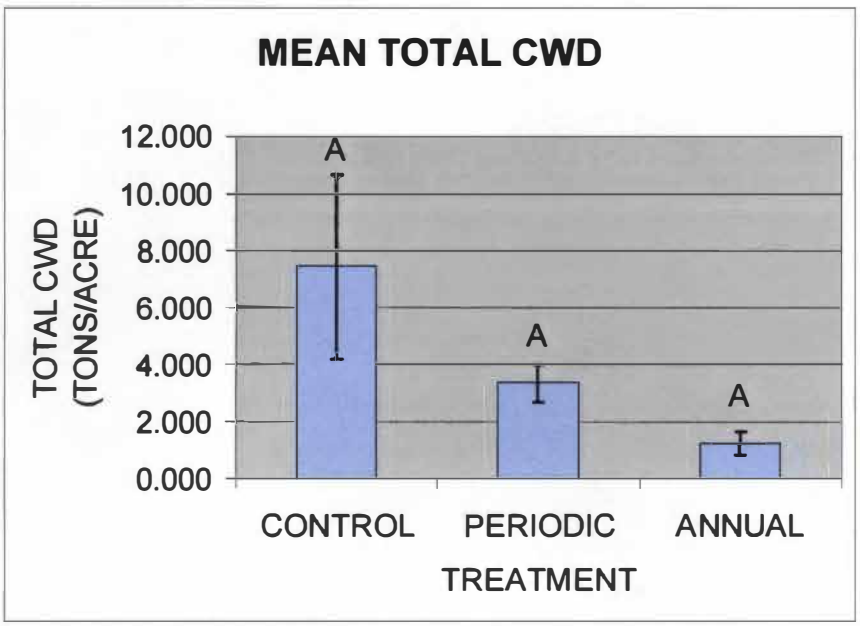

Figure 29. Highland Rim Mean Total CWD.
Error bars and significance as in Figure 5.

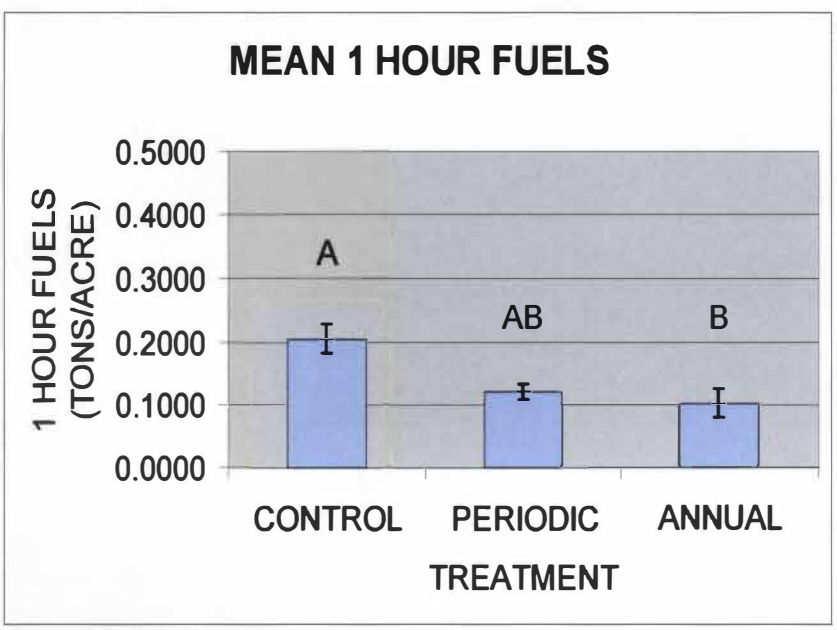

Figure 30. Highland Rim Mean 1 Hour Fuels.
Error bars and significance as in Figure 5.

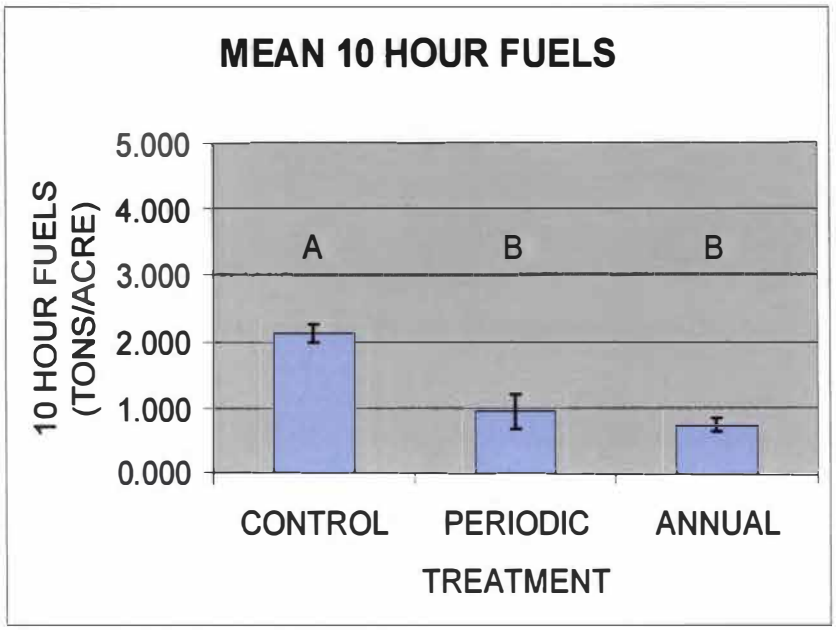

Figure 31. Highland Rim Mean 10 Hour Fuels.
Error bars and significance as in Figure 5.

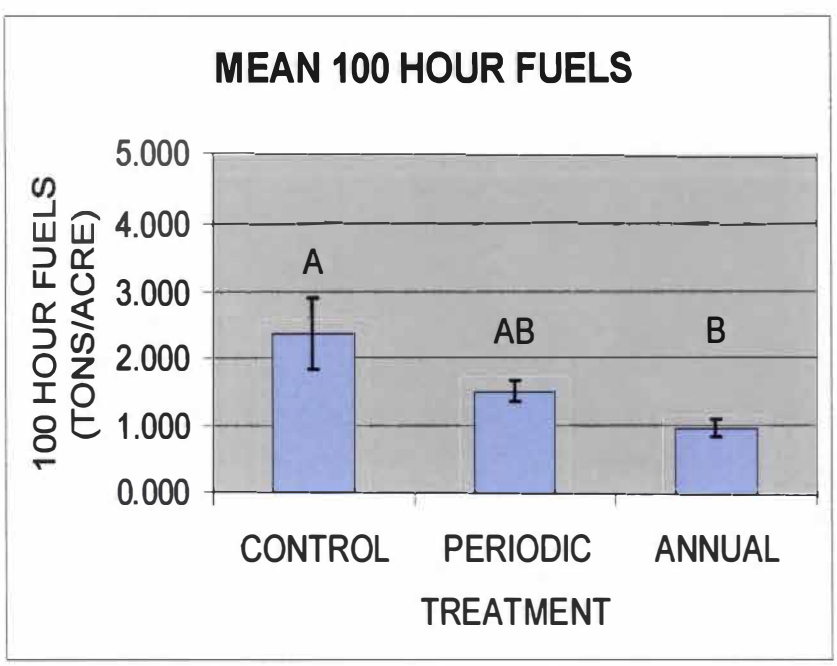

Figure 32. Highland Rim Mean 100 Hour Fuels.
Error bars and significance as in Figure 5.

Controls were not different from the periodic burn, but were marginally significantly different (P= 0.0596) from the annual burn at alpha level 0.06 (Figure 32).

Quantities of total FWD fuels were significantly (P= 0.0034) greater in control sites (4.6950 tons/acre) than in either the periodic burn (2.5777 tons/acre) or the annual burn (1.8010 tons/acre). Figure 33 shows the trend of total FWD fuels.

Duff and Litter Depth

Duff depth was significantly greater (P= 0.0001) in controls (0.1979 inches) than in either the periodic burn plots (0.01432 inches) or the annual burn plots (0.0013 inches). Duff depth in the periodic burn was not different from that in the annual burn plots, but duff depths in both are different from those in the controls (Figure 34).

Litter depth was significantly greater (P= 0.0001) in controls (2.1250 inches) than in either the periodic burn plots (0.3854 inches) or the annual burn plots (0.2708 inches). Litter depths in the periodic burn were not different from those in the annual burn plots, but litter depths in both treatments were different from those in the control sites (Figure 35).

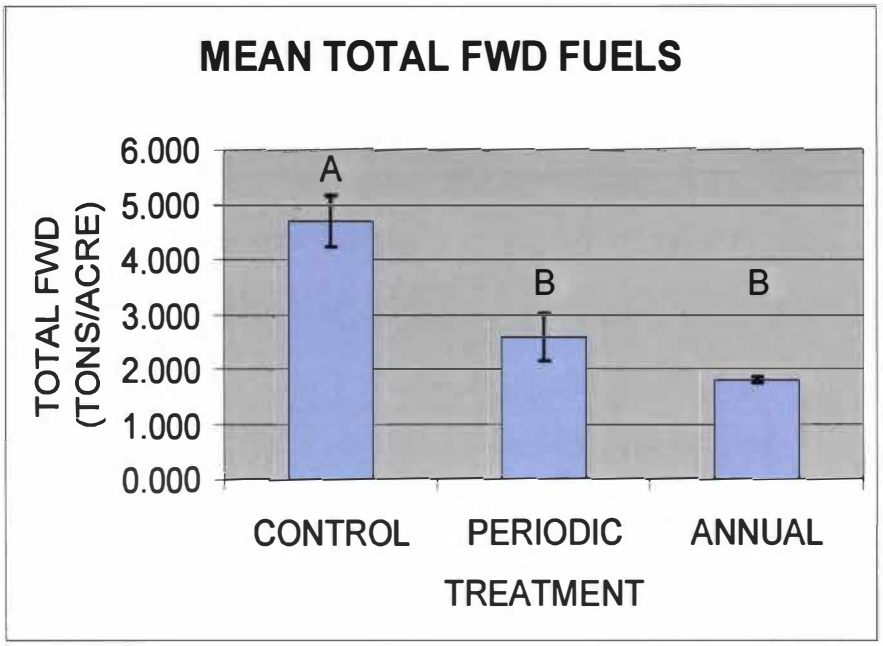

Figure 33. Highland Rim Mean Total FWD.
Error bars and significance as in Figure 5.

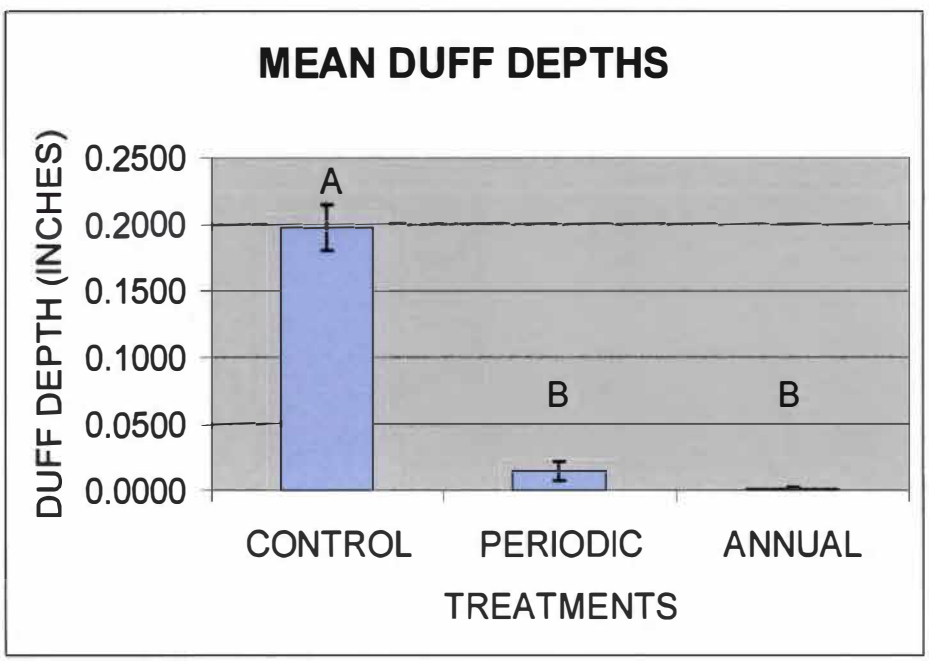

Figure 34. Highland Rim Mean Duff Depths.
Error bars and significance as in Figure 5.

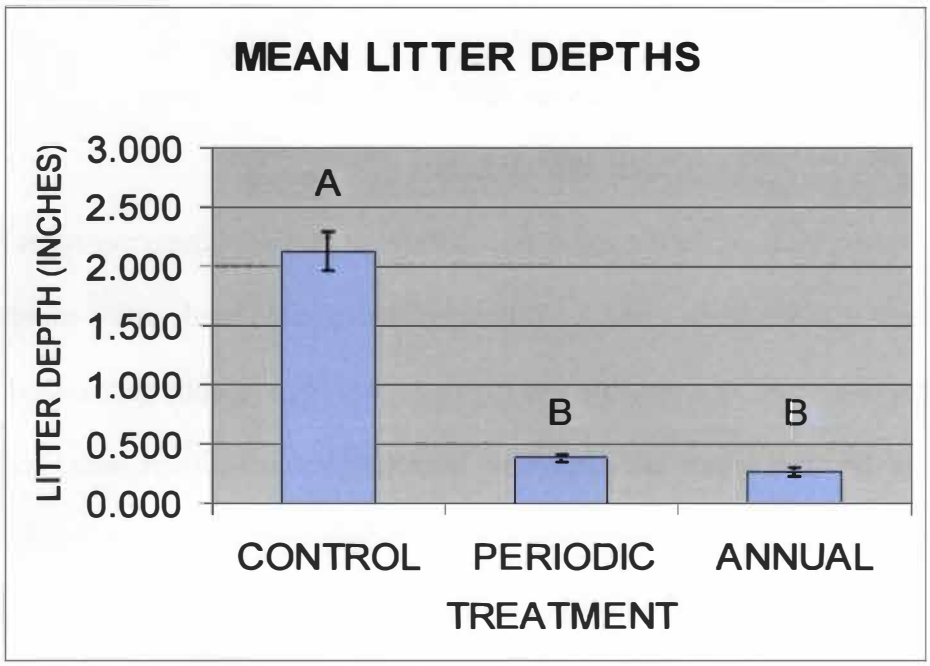

Figure 35. Highland Rim Mean Litter Depths.
Error bars and significance as in Figure 5.

V. DISCUSSION

Effects of Cover Type and Site Productivity on Re-Accumulation

Coarse Woody Debris

A possible explanation for the significant differences between the cover types is the pine component in cover types 1 and 2. Although southern pine beetle killed stands were omitted from this study, it is possible that isolated pines have recently succumbed to the beetle. Within the study region and elsewhere, the recent severe southern pine beetle outbreak has resulted in tremendous increases in coarse woody debris and other fuels (Payne 1981). Cover types 1 and 2, which both contained pine, had means of 6.9 tons/acre of coarse woody debris, while cover type 3 only had a mean of 5 tons/acre. Although differences were not significant, there seems to be slightly more rapid re-accumulation of coarse woody debris levels during 1-5 years since prescribed burning in cover types 1 and 2 than in cover type 3 (Figure 5-7). Thus, it is possible that inputs of coarse woody debris are more frequent in cover types 1 and 2 than in cover type 3. The lack of significant differences between controls and stands 1 year after fire suggest that prescribed burning did not have significant impacts on amounts of coarse woody debris. Research on effects of burning on individual pieces of CWD, (Reinhardt 1991), however, suggest that at least partial consumption of CWD likely occurred on the study sites.

Fine Woody Debris

Similar to CWD, it is likely that the significant differences in 1 hour fuels between cover types were due to the pine component contained by both cover types 1 and 2 (Figures 8-10). Cover types 1 and 2 contain Virginia pine (*Pinus virginiana*) and short leaf pine (*Pinus echinata*) which probably increased the mean tons/acre. Cover type 3 is

a dry-mesic hardwood site which contained no coniferous species. Differences over time were not significant, but 1 hour fuels appeared to be reduced by burning in cover type 1, and then re-accumulated gradually as expected over time. Amounts of 1 hour fuels were much more variable over time in cover types 2 and 3.

It is possible to speculate once again that the pine component in cover types 1 and 2 significantly increased amounts of 10 hour fuels. Patterns in 10 hour fuel amounts were variable across time, and differences were not significant (Figures 11-13). However, it appears amounts of 10 hour fuels were reduced by burning to some degree in cover types 1 and 3.

Significant differences in amounts of 100 hour fuels were found between both cover types and years since burning (Figures 14-16). Cover type 1 is a mesic pine/hardwood site, which did not have significantly different amounts of 100 hour fuels from amounts in either cover type 2 or cover type 3. Amounts of 100 hour fuels in cover type 2 were significantly greater than amounts in cover type 3, and I suspect this difference was due to the facts that cover type 2 is a xeric pine/hardwood site, and cover type 3 is a dry-mesic hardwood site. The 2 dry-mesic sites, cover types 1 and 3, are not different because of site characteristics, but the pine component in cover type 1 did accumulate more tons/acre than cover type 3. Cover types 1 and 2 contain greater amounts of 100 hour fuels than those of cover type 3 (Figures 14-16).

The pine component in cover types 1 and 2 probably increased the loading of total fine woody debris fuels on these sites (Figures 17-18). Cover type 3 is a hardwood site only and has significantly lower amounts of fine woody debris (Figure 19). Controls

were significantly different from 1-5 years since burning and contained the greatest quantities of total fine woody debris (Figures 17-19).

Duff and Litter Depth

The duff depth was always greater at some point during 1-5 years since burning than in the controls in all 3 cover types (Figure 20-22). I speculate that this may be due to large amounts of debris that fall to the ground following prescribed fire. It seems that the longer the time period between fires, the lesser the duff depth. This may be due to differences in litter and duff decomposition rates caused by burning. Duff and litter decomposition is generally rapid in temperate hardwood forest, and litter typically takes 1-3 years to decay (Kimmins 1997). Duff depth was highly variable across years since burning and controls (Figure 20-22).

A significant difference was found between litter depth and years since burning as well as a significant interaction between cover type and years since burning. Controls were significantly different from 1-5 years since burning (Figures 23-25). Years 1, 2, 3 and 4 were also significantly different from both the controls and year 5 since burning (Figures 23-25). This implies that all three cover types regardless of year since burning had not regained current amounts typical of control sites. The significant interaction between cover types and years since burning implies that the effects of time depend on cover type.

Cover type 1 is a Dry-Mesic Pine/Hardwood site. One-way ANOVA run within cover type 1 indicated significant differences in amounts of litter across years since prescribed burning (Figure 26). Even after five years post-burning, the mean litter depth in cover type 1 has not built up to the current levels of litter depth in the controls. The

control was significantly different from 1-5 years since burning. Year 5 was significantly different from 1, 2, & 3 years since burning and the control. Year 4 was not significantly different from years 1, 2, &3 and 5, but was significantly different from the control site (Figure 26).

Cover type 2 is a Xeric Pine/Hardwood site. One-way ANOVA run within cover type 2 also indicated strong significant differences in amounts of litter across years since prescribed burning. Even five years after burning, the mean litter depth for cover type 2 has not built up to the current levels of litter depth in the controls (Figure 27). Controls were significantly different from 1-5 years since burning. There were no significant differences in litter amounts between years 1, 2, 3, 4 and 5 (Figure 27).

Cover type 3 is a Dry-Mesic Hardwood type containing hardwoods only. One-way ANOVA run within this cover type indicated significant statistical differences in litter amounts across years since prescribed burning. Litter amounts in controls were significantly different from 1-5 years since burning. Litter in year 5 was significantly different from the control site and years 1, 2, 3 and 4 (Figure 28). Once again, even after five years of prescribed fire, the litter depth has not re-accumulated enough to equal control sites (Figure 28). The significant interaction between cover type and years since burning in influencing mean litter depth was probably caused by differences in litter composition and production between cover types.

Effects of Fire Frequency

Coarse Woody Debris

The magnitude of differences between treatment and control means suggest that controls contained the greatest amounts of coarse woody debris, followed by the periodic

burn plots, and finally the annual burn plots (Figure 29). It is likely that the repeated burning over 41 years on the Highland Rim Forestry Experimental Station resulted in substantial reduction of coarse woody debris in both the periodic burn plots and annual burn plots. The fact that there were no statistically significant differences was unexpected, and was probably caused by the low number of replicates and high variances associated with the means (Figure 29).

Fine Woody Debris

Controls contained the greatest amounts of 1 hour fuels followed by the periodic burn plots and finally the annual burn plots (Figure 30). It is likely that the frequency of prescribed fire in both the periodic burn plots and the annual burn plots significantly reduced the amounts of 1 hour fuels.

Controls contained the greatest amounts of 10 hour fuels, followed by the periodic burn plots and finally the annual burn plots (Figure 31). It is likely that the frequency of prescribed fire has significantly reduced the amounts of 10 hour fuels in both the periodic and annual burn plots.

Controls contained largest amounts of 100 hour fuels followed by the periodic burn plots and finally the annual burn plots (Figure 32). Frequency of fire has greatly lowered the quantities of 100 hour fuels in the annual burn plots.

Controls contained the greatest amounts of total fine woody debris; followed by the periodic burn plot and the annual burn plot (Figure 33). It is likely that frequent fire greatly lowered the quantities of fine woody debris on both the periodic burn plots and annual burn plots. The annual burn plots have been burnt consecutively for 41 years and therefore contained significantly lower amounts of fine woody debris. The periodic burn

plots contained greater amounts of fine woody debris than the annual burn plots and this is likely due to the lower fire frequency of the periodic burn plots (Figure 33).

Duff and Litter Depth

Controls contained the greatest amounts of duff depth followed by the periodic burn plots and the annual burn plots (Figure 34). Duff depth was significantly reduced in both the periodic burn plots and the annual burn plots. Repeated fire over the last 41 years has clearly severely depleted duff depths in both the periodic and annual burn plots (Figure 34). The duff layer was almost nonexistent after repeated prescribed fires have been used on these 2 burning treatments.

Controls contained the greatest amounts of litter depth followed by the periodic burn plots and finally the annual burn plots (Figure 35). Litter depth was significantly reduced in both the periodic and annual burn plots. It is likely that the frequency of the periodic and annual prescribed burns has greatly lowered the depth of litter over the last 41 years.

The loss of duff and litter can cause potential problems for tree growth through changes in nutrient dynamics and soil fertility. Duff and litter are important components of organic matter and when these layers are removed, site productivity decreases (Kimmins 1997). Soil erosion increases with loss of duff and litter layers, as well as nutrient leaching. Duff and litter layers also help retain soil moisture, which is very important in decomposition. Worms, mites, springtails, beetles and various other insects and bacteria all aid in the decomposition process and are found throughout the duff, litter and soil layers (Kimmins 1997). Re-measurement of soil properties as in the earlier Thor and Nichols (1974) study on these sites is warranted.

VI. SUMMARY AND CONCLUSION

The first objective of this research was to test the hypothesis that fuels will re-accumulate at faster rates over a 5-year period on sites of higher productivity and also in cover types dominated by conifers. I found that coarse woody debris did not significantly differ in amounts of tons/acre between years since burning (Figures 5-7). Low intensity fires are used to reduce fuel hazards in the Cherokee National Forest and consequently, larger fuels often require repeated prescribed burns to be consumed. Amounts of coarse woody debris did, however, significantly differ between cover types. Cover type 1 is a Dry-Mesic Pine/Hardwood stand and cover type 2 is a Xeric Pine/Hardwood type, while cover type 3 is a Dry-Mesic type containing hardwoods only. Cover types 1 and 2 both contained a pine component which likely generated greater quantities of coarse woody debris. In cover type 2, amounts of CWD varied between years since burning but, were greatest in year 4 and in the controls (Figure 6). The variable amounts of coarse woody debris over time and lack of differences between coarse woody debris 1 year after burning and coarse woody debris in controls indicates the prescribed burns applied will have little impact on the ecological role of coarse woody debris in these forests.

Both years since burning differences and cover type differences occurred in total FWD. I found that cover types 1 and 2 both contained greater amounts of total tons/acre of fine woody debris than cover type 3 (Figures 17-19). Once again, it is likely the pine component in both cover types 1 and 2 significantly contributed to the total tons/acre of fine woody debris. Amounts of FWD in control stands significantly differed from those 1-5 years since prescribed burning. Controls contained the greatest amounts of total tons/acre of fine woody debris in all cover types (Figures 17-19). Tons/acre varied across

cover types and years since burning. Cover type 2 not only re-accumulated fine woody debris faster but also contained greatest amounts of total fine woody debris (Figure 18). Because Cherokee National Forest managers used low-intensity prescribed burns, only the FWD was affected, not CWD. It is likely that litter, some duff, 1 hour fuels, 10 hour fuels and 100 hour fuels were consumed. Due to the relatively rapid production of 1 hour fuels and 10 hour fuels, these categories of fuel rapidly approached pre-burn and control levels. The 100 hour fuels, on the other hand, are slower to re-accumulate and only beginning to rebuild in the 4th and 5th year. Leaf litter may be slower to re-accumulate due to increased decomposition, which may also explain the significantly thicker duff layer 5 years after burning than in the controls. Therefore, effects of burns on a 5-year cycle persist longest in the 100 hour and litter fuel categories. It appears more intense, and perhaps less frequent, burns might be needed to reduce CWD, but these may not be ecologically appropriate except for regeneration of selected species requiring mineral soil seedbeds and tolerant of lower soil nutrient status such as pine and some oak species.

The hypothesis that fuels would re-accumulate faster on more productive sites and those with conifers was partially supported. Cover types with pine accumulated more fuels, but accumulation was greater on xeric sites than dry-mesic sites. Thus, I suspect that stand composition was more important than site productivity.

The second objective of this research was to document long-term effects of different burning schedules on amounts of fuel in different categories. The Highland Rim Forestry Experiment Station has been conducting prescribed fires on a periodic and annual basis for 41 years. The annual burn plots and periodic burn plots both contained little dead or downed woody material. Fine woody debris was greatly reduced in

tons/acre in both the periodic burn plots and the annual burn plots (Figures 30-33). Duff and litter depths were almost nonexistent in some areas and the understory vegetation was comprised of tall grasses and few woody species (Figures 34-35). The fire frequency of the Highland Rim Forestry Experiment Station significantly reduced fuels in all categories except for coarse woody debris. It is likely that no significant differences were found in coarse woody debris due to low replication, which caused high variance in the means (Figure 29).

In conclusion, it appears prescribed burning on the Cherokee National Forest has been most effective in maintaining litter and 100 hour fuels at low levels. Fuels were least abundant in cover type 3, the dry-mesic hardwood type, and it appears burning this type to control fuels may be a lower priority than in the xeric and dry-mesic pine-oak types. However, regular burning of the dry-mesic hardwood type may be desirable to maintain representative fire-adapted species. The repeated prescribed fires of the Highland Rim Forestry Experiment Station have undoubtedly decimated the levels of dead and down woody material as well as duff and litter depths, indicating that uninterrupted, repeated burning over many, many years could have negative impacts on ecosystem attributes such as site productivity and the availability of coarse woody debris for wildlife. However, similar pre-settlement fire frequencies and savanna and prairie ecosystems with similar fuel distributions have been described for the Highland Rim Forestry Experiment Station region and other locations in the Southern Appalachians (Waldrop and Van Lear 1990).

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