8-2009

Classifying the Fire Regime Condition Class for Upland Oak-Hickory Forests

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CLASSIFYING THE FIRE REGIME CONDITION CLASS FOR UPLAND OAK-HICKORY FORESTS OF THE SHAWNEE NATIONAL FOREST

By

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B.S., Southern Illinois University Carbondale, 2005

A Thesis Submitted in Partial
Fulfillment of the Requirements for the
Master of Science Degree in Forestry

Department of Forestry
In the Graduate School
Southern Illinois University Carbondale
August 2009

THESIS APPROVAL

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May 5, 2009

AN ABSTRACT FOR THE THESIS OF

PAUL TIKUSIS, for the Master of Science degree in Forestry, presented on May 5, 2009 at Southern Illinois University Carbondale.

TITLE: Classifying the Fire Regime Condition Class for Upland Oak-Hickory Forests of the Shawnee National Forest

MAJOR PROFESSOR: Dr. Charles M. Ruffner

Several reports of widespread establishment of mesophytic vegetation within oak-hickory upland forests have been documented throughout the Central Hardwoods Region. Previous studies suggest deviations from historic disturbance regimes may be a primary driver of vegetation change, necessitating the use of Fire Regime Condition Class (FRCC) guidelines to measure changes in forest structure. Current parameters of forest structure and fuel loading were assessed within mature oak-hickory uplands throughout the ecological subsections of the Shawnee National Forest, including the Greater Shawnee Hills, Lesser Shawnee Hills, Cretaceous Hills, and the Illinois Ozarks. Present species importance values and forest structure were compared with reference conditions developed from General Land Office records (Fralish et al. 2002). Current uplands contained an average 214.72 ± 16.52 trees/ac and 103.37 ± 2.16 ft^2 BA/ac, while reference stands harbored less than 90 trees/ac with a range of 16 and 120 ft^2 BA/ac. Due to the high levels of fragmentation and a lack of large contiguous upland stands within the Shawnee National Forest, stand level criteria for FRCC values were developed as opposed to landscape level

FRCC values which are commonly used. FRCC values determined during initial surveys were compared with plot level ratios of forest structure parameters regarding oaks:mesophytes and xerophytes:mesophytes, yielding clear relationships between species composition and FRCC values. Fuel loading (tons/ac) was assessed as a determinant of FRCC values, however a significant relationship between FRCC values and fuel loading was not discovered. Since widespread deviations from the historic fire regime have taken place since the early 20th century, Fire Regime Condition Class values were found to fall into the FRCC 2 and 3 categories without any stands representing FRCC 1. This determination requires future management practices to follow Fire Regime Condition Class guidelines. The study proved that mesophytic species have become established within all canopy strata, with a strong probability of gaining future dominance without active forest management. Although it is clear that forest structure has deviated from reference conditions, a strong oak-hickory overstory component found throughout the study area provides a potential resource to sustain future oak-hickory upland ecosystems.

ACKNOWLEDGEMENTS

I would like to express my gratitude for all of those who have helped me throughout my undergraduate and graduate career here at SIU, there's too many to count. A special thanks to Dr. Charles Ruffner for his instruction and friendship, as well as for the efforts in building the fire program in the Forestry Department. I would also like to thank my other committee members Dr. John Groninger and Dr. Sara Baer for their help and guidance during my graduate career. The entire SIU Forestry Department needs to be commended for providing the foundational skills essential for my career in forest management. Special thanks are in order for James Zaczek, Patti Cludray and Bonnie Middleton for providing chances to fund my graduate career as well as always being there for help. Dennis Carril as well as other past and present members of the Forest History Lab have been a great help through the years and have provided help during even the most inconvenient times. Thanks to the alumni of the Saluki Fire Dawgs for the great work as volunteers and commitment to restoring fire to southern Illinois.

Thanks to my family especially to my parents Lisa and Dave Tikusis and my sister Lauren for all of the support through the years. Thanks to my future wife Melissa Simpson for her invaluable encouragement and friendship. I would also like to thank Nick Gianetinno and the management of the Shawnee National Forest for supporting this project and my career with the USDA Forest Service. There's many more that deserve further gratitude, thanks again!

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INTRODUCTION

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Oak-Hickory forests are the predominant forest cover type throughout the uplands of the Central Hardwood Forest, compromising 40-65% of the forested landscape (Fralish 1997, Parker and Ruffner 2004). Oak-Hickory woodlands are thought to have dominated the landscape for the last 4000-6000 years of the Holocene epoch (Lorimer 2001), a period experiencing increasingly warmer and dryer conditions. During this long period of oak-hickory dominance, the keystone role of this cover type emerged as numerous plant and animal associations evolved with site conditions and nutritional resources provided by oak and hickory species prevalent across this region (Abrams 1992, Thompson and Dessecker 1997, Fralish 2004). Braun (1950) classified the region as being comprised of the mixed mesophytic vegetation type, whereas Küchler (1964) classified the area as being dominated by the oak-hickory vegetation type.

Although uplands throughout the Central Hardwoods seem to be overwhelmingly populated by large diameter oaks and hickories, their dominance appears temporary without the continuation of a disturbance regime favorable for their regeneration (Abrams 1992, Abrams 2005, Aldrich et al. 2005, Fralish et al. 1991). Without disturbance, the ecophysiological traits of oaks, hickories and their xerophytic associates limit their long-term competitive status within forest ecosystems, with a gradual influx of their shade tolerant mesophytic counterparts (Nowacki and Abrams 2008). Mesophytic tree species tend to fail to persist on xeric sites because they are more easily top-killed by surface fires (Dey and Hartman 2005) and they also favor mesic site conditions, typical of sheltered areas excluded from frequent disturbances (Braun 1950, Fralish 1988). However, due to the highly favorable growing conditions throughout the area and lack of disturbance, mesophytic species have become well established on all but the most hydric and xeric sites (Groninger et al. 2003, Ozier 2006, Nelson et al. 2008a, Nowacki and Abrams 2008).

Fire, in combination with topography and climate is believed to have been a large driver of vegetation patterns for much of North America (Mutch 1970, Pyne 2001) and indeed within the Central Hardwood Forest Region (Abrams 1992). Perpetuated for thousands of years by periodic anthropogenic burning in tandem with natural ignitions (Delcourt et al. 1998), these uplands burned with moderate frequency ranging between 2-25 years creating a landscape mosaic regulated by site conditions and land use practices (Robertson and Heikens 1994, Thompson and Dessecker 1997, Batek et al. 1999). Fire suppression policies implemented in the early 20th century have subsequently disrupted the pervasiveness of fire from the uplands of the Shawnee National Forest (Miller 1920, Parker and Ruffner 2004).

Study Justification

The Shawnee National Forest, under management by the USDA Forest Service, is striving to maintain oak-hickory ecosystems and landscape diversity while managing for multiple-use resources (USDA 2006). Due to the inherently high levels of biodiversity found within a diverse landscape mosaic dominated by oak-hickory woodlands, efforts to ensure oak-hickory persistence is crucial. Analyzing current forest structure, historic vegetative characteristics, as well as historic disturbance regimes is important to understanding what can be done to successfully maintain a sustainable and diverse landscape.

The ecologic sustainability of oak-hickory ecosystems is currently in jeopardy, with numerous threats to the regeneration of native xerophytic vegetation (Abrams 2005, Aldrich et al. 2005, Nowacki and Abrams 2008). Changes in land use practices and policies involving aspects of timber harvesting, fire use, and agriculture have resulted in drastic deviations from the historic disturbance regime and in the structure of forests on a local and landscape level (Abrams and Nowacki 1992, Thompson and Dessecker 1997, Schmidt et al. 2002). The favorable edaphics and climate of southern Illinois are suitable for many types of agriculture, resulting in high amounts of farm lots scattered throughout the region which cause high levels of habitat fragmentation (Parker and Ruffner 2004). Diverse public opinions and conflicting management interests between land managers of the Shawnee National Forest, the general public, and interests groups provides additional challenges to the successful maintenance of oak-hickory uplands within the Shawnee National Forest (Welch and Evans 2003).

The present oak-hickory overstory found within upland sites regenerated during the early 20th century following agricultural clearing and timber harvesting practices (Conrad 1978). However, these stands are declining due to old age with a weak cohort of new stems lacking the competitive edge necessary to gain dominance over a strong mesophytic regeneration class (Zaczek et al. 2002, Parker and Ruffner 2004, Ozier et al. 2006). Due to increases in tree density as well as alterations in microclimate and fuelbed conditions caused by mesophytic encroachment, management practices aiming to regenerate oaks are further complicated (Abrams 2005, Nowacki and Abrams 2008).

Land managers have been concerned with alterations in vegetative structure and disturbance regimes throughout North American forests (Keane et al. 2002, Brooks et al. 2004, Parker and Ruffner 2004, Nowacki and Abrams 2008), resulting in a strong interest in active management practices aiming to restore and sustain native ecosystems. The Fire Regime Condition Class (FRCC) paradigm was developed by Schmidt and others (2002), providing land management agencies with ecosystem-specific thresholds regarding alterations in fire regimes and vegetative composition for North American ecosystems. FRCC guidelines determine current departures from historical fire regimes through analyzing fire histories and present ecosystem conditions, thus providing land managers with an assessment of potential management strategies and practices to employ in order to maintain or restore ecosystem sustainability (Schmidt et al. 2002).

Study Objectives

During the summer of 2006 and winter of 2007, 10 stands dominated by mature upland oak-hickory forest were analyzed across the Shawnee National

Forest. The primary objective of this study was to understand how forest structure of oak-hickory uplands within the Shawnee National Forest have changed since reference conditions described during the 1806-1810 General Land Office surveys of southern Illinois (Fralish et al. 2002). These observations were used to develop stand level Fire Regime Condition Class values (Schmidt et al. 2002) for upland oak-hickory forests that provide insight for land managers interested in maintaining oak-hickory forests within southern Illinois. Photographs of each plot were taken during both the growing and dormant season to develop a photo series displaying differences in forest structure for plots classified as FRCC 2 and 3. Fuel loading characteristics were measured utilizing Browns method of inventorying downed woody fuels (Brown 1974) to understand how fuel loading characteristics differed between stands.

Research and statistical analyses were addressed by these seven primary hypotheses:

Ho1. Tree density (trees/ac) has increased within mature oak-hickory uplands of the Shawnee National Forest since reference conditions.

Ho2. Basal area/ac has increased within mature oak-hickory uplands of the Shawnee National Forest since reference conditions.

Ho3. Fire Regime Condition Class values are independent of the ratio of xerophytic species:mesophytic species density within mature oak-hickory uplands of the Shawnee National Forest.

Ho4. Fire Regime Condition Class values are independent of the ratio of xerophytic species:mesophytic species dominance within mature oak-hickory uplands of the Shawnee National Forest.

Ho5. Fire Regime Condition Class values are independent of the ratio of *Quercus* species:mesophytic species density within mature oak-hickory uplands of the Shawnee National Forest.

Ho6. Fire Regime Condition Class values are independent of the ratio of *Quercus* species:mesophytic species dominance within mature oak-hickory uplands of the Shawnee National Forest.

Ho7. Fire Regime Condition Class values are independent of fuel loading (tons/ac) conditions within mature oak-hickory uplands of the Shawnee National Forest.

CHAPTER 2

LITERATURE REVIEW

Successional Theory and Disturbance Ecology

During the early development of successional theory, it was believed that each ecosystem had a predetermined composition, and each successional sere was easily identifiable with a thorough examination (Clements 1916). Although these initial theories had their flaws, it is still widely accepted that understanding the roles of both individual species and functional groups within the successional development of a site provides the framework for understanding possible species composition in each successional stage (Grime 1977). However, the impacts of historic disturbance regimes were largely ignored and accepted as significant role players for many years to come (Cook 1996).

The individualistic nature of natural communities (Gleason 1926) and the recognition of disturbance regimes as a significant factor in the successional trajectory of a given community have since become widely accepted, prompting further advances in the field of disturbance and community ecology. Species on a given site have been found to be able to facilitate their own persistence by altering site conditions, as well as inhibit the ability of other species to persist by excluding resources, or learn to exhibit extreme tolerance of unfavorable growing conditions to persist (Connell and Slatyer 1977). Community dynamics can also be explained by understanding environmental filters, which account for the ability of site-specific conditions and stochastic events to determine species survival and persistence (Keddy 1992). The responses of natural communities to irregularly occurring disturbances are based upon species-specific tolerances as well as the timing of the disturbance within current successional trends (Sousa 1984).

Being a mid-successional vegetation type, successional trends within oak-hickory forests are best described by the intermediate disturbance hypothesis, which accounts for the high levels of biodiversity created by moderate levels of disturbance (Loucks 1970). The historic disturbance regime of oak-hickory forests is largely regulated by a combination of recurring abiotic and biotic disturbances such as low-moderately intense fire and overstory removal as a result of timber harvesting and natural gap dynamics (Abrams 1992, Lorimer 2001). Within the early successional prairie ecosystems of the Flint Hills in Kansas, the regeneration of oaks and the subsequent expansion of oak gallery forests onto the prairie are correlated with declines in fire frequency (Abrams 1985). However, later successional mesophytic tree species have encroached into oak-hickory forests within the Central Hardwoods Forest Region that have been excluded from recurring disturbances such as fire (Henderson and Long 1984, Aldrich et al. 2005, Rentch and Hicks 2005, Nowacki and Abrams 2008), posing threats to the regeneration of shade intolerant tree species such as oaks and hickories (Hannah 1987, Lorimer et al. 1994, Larsen and Johnson 1998).

Fire as a Disturbance

A natural fire regime is a general classification of the role fire would play across a landscape in the absence of modern human mechanical intervention but including the possible influence of aboriginal fire use (Agee 1993; Brown 1995). Excluding anthropogenic influences, wildland fires are primarily ignited by lightning strikes (Pyne 2001). Fire regimes are largely determined by the seasonality, severity, and timing of the ignition (Pickett and White 1985). Deviations from the historic fire regime can be caused via numerous pathways including climatic change (Dale et al. 2001) and anthropogenic meddling such as the introduction of alien species (Dibble and Rees 2005), irresponsible timber harvesting operations (Gallant et al. 2002), and the improper fire management practices (Keane et al. 2002).

Fire behavior is largely governed by local topography, as well as several dynamic environmental conditions, such as relative humidity, wind speed, temperatures, and fuel moistures (Rothermel 1983, Scott and Burgan 2005). Due to variable site and environmental conditions, wildland fires typically do not burn with uniform intensity, resulting in a fire mosaic with unpredictable disturbance severity (Turner et al. 1997, Stambaugh and Guyette 2008). Fire regimes are largely influenced by regional climate patterns, which regulate fire occurrence, behavior, and spread (Pyne 2001). Available fuels provided by plant necromass also influence fire behavior, with variability in foliar chemistry either intensifying or decreasing its activity (Mutch 1970, Nowacki and Abrams 2008).

Reinhardt and others (2001) describe fire as a thinning agent, with first order fire effects causing mortality of individuals subjected to lethal temperatures, and second order fire effects pertaining to indirect, long-term effects following a fire event such as erosion and vegetation succession. Tree species are most vulnerable to above ground disturbance when their root reserves are at their lowest, primarily during leaf out following long periods of dormancy (Landhäusser and Lieffers 2002). Seasonality is extremely important within grassland ecosystems where burning during the summer may reduce the dominance of C4 grasses (Howe 1995). Fires occurring during a species reproductive stage may eliminate a species ability to successfully set seed, favoring those released either prior or after a fire event (Howe 1995).

Post-disturbance fire landscapes are influenced by second order fire effects such as alterations in soil properties and microclimate conditions (Reinhardt et al. 2001). Nitrogen loss from fire impacted soils can occur through direct volatilization of soil nitrogen when soil temperatures are heated above 300°c, as well as the convection of ash (Boerner 1982). Franklin and others (1997) reported soils heated from prescribed fires within oak forests of western Kentucky to only reach temperatures of 52°c -260°c, with no adverse effect on nitrogen levels within the system. Soil heterogeneity can be influenced by an increase in nitrogen mineralization caused by prescribed fire within the Central Hardwood Forest Region (Boerner and Brinkman 2005).

Prescribed fires within oak-hickory forests have also been attributed to creating spatial heterogeneity within forest soils by increasing nitrogen mineralization in areas receiving fire, thereby increasing species richness in herbaceous communities in oak forests (Hutchinson et al. 1999, Hutchinson et al. 2000, Boerner and Brinkman 2005). The combustion of litter on the forest floor can be crucial for the successful germination of seeds from species requiring soil scarification and bare mineral soil including oaks (Hutchinson et al. 2005, Wang et al. 2005). Vermeire and others (2005) found that mid-day soil temperatures were found to be as much as 1°c to 3°c warmer than unburned plots in a mixed grass prairie in Oklahoma.

Oak-Hickory Ecosystems

Oak-hickory forests dominate the Central Hardwoods Region (Fralish 2002), and currently comprise over 40 percent of the Shawnee National Forest (Parker and Ruffner 2004). Paleoecological studies suggest that oak species gained dominance during the Holocene Epoch a period which experienced a warmer and dryer climate which favored species tolerant of drought and recurring fires (Lorimer 2001, Abrams 1992). During this period of oak-hickory dominance, a distinct ecosystem evolved around the unique conditions provided by oak-hickory forests (Fralish 2004).

Within the Central Hardwoods Region, oak-hickory forests are regarded as being of extreme importance due to the various benefits they provide such as hard mast production and den structures (Fralish 2004). White-footed mouse (*Peromyscus leucopus* Rafinesque.) populations are dependant on the abundance of oak acorns within the fall and winter, with the populations of their predators positively correlated with their population dynamics (Ostfeld et al. 1996). Eastern chipmunk (*Tamias striatus*) populations are positively correlated with an increased availability of cacheable winter food, primarily oak and hickory mast (Wolff, 1996; Lacher, 1996). Eastern oak-hickory forests provide more favorable conditions for local insectivorous avian communities than forests dominated by maple, with greater species richness present due to the availability of insects and caching areas (Rodewald and Abrams 2002).

Oak-hickory forests support diverse xerophytic herbaceous plant communities that require the maintenance of specific site conditions to persist. Oak-hickory forests have historically contained small prairie openings (Hanson 1921), creating diverse habitat and a chance for grassland species to coexist within a forest habitat. The loss of typical oak-hickory microsite conditions through the increases in mesophytic density within the Illinois Ozarks was found to decrease herbaceous biodiversity (Fralish 1997).

Landscape heterogeneity within Central Hardwoods Forest Region has been regulated by various disturbances and site conditions, preventing the development of monotonous landscapes dominated by mesophytics and later successional species (Lorimer 2001). Early successional habitats such as barrens and savannas were maintained by both fire and edaphic constraints, and were scattered across the landscape (Heikens and Robertson 1995). Numerous animal populations such as the locally extirpated ruffed grouse (*Bonasa umbellus*) are dependent on the creation and maintenance of a diverse habitat mosaic including stands of variable successional types in close proximity to their home ranges (Thompson and Dessecker 1997).

Xerophyte Ecophysiology

Oaks and hickories, as well as many other xerophytic associates owe their ability to persist on xeric sites and withstand frequent fires due to numerous ecophysiological adaptations (Abrams 1996). Xerophytic species maintain a high root to shoot ratio, which is helpful on sites prone to drought as well as ensuring the ability to resprout readily after being topkilled (Kruger and Reich 1997). Several species of oak accumulate a high concentration of starch within their root biomass, which ensures adequate resources of energy following a disturbance (Kruger and Reich 1997). A reduced need for nitrogen (Abrams 1996) is also a valuable asset xerophytes depend on when growing on nutrient deficient sites.

Typical of fire-adapted communities (Mutch 1970), dominant species within oak-hickory forests have also developed adaptations to promote active fire behavior including pyrogenic fuels, high carbon to nitrogen ratios, and rigid foliage (Abrams 2006). The high carbon:nitrogen ratio and lignin content within oak leaves prevents rapid decay and leaf compression, facilitating a dry and well aerated leaf litter layer during dry periods (Abrams 2006, Nowacki and Abrams 2008). Rare traits that *Quercus* spp. also possesses is a unique ability to readily compartmentalize wounds following fire (Smith and Sutherland 1999).

Fire Regimes of Oak-Hickory Forests

The natural fire regime of oak-hickory forests of the Central Hardwood Forest Region has been classified as surface burning with low to moderate severity, at a relatively frequent return interval within the range of 0-35 years (Schmidt et al. 2002), although evidence for lower return intervals within these systems are common (Robertson and Heikens 1994, Guyette et al. 2003). Ignitions have been primarily dependant on anthropogenic burning practices, since lightning caused fires are very rare in this region (Lorimer 2001, Crist 2009). Anthropogenic fire use within the Central Hardwoods Forest Region has been the primary ignition source for thousands of years both prior to (Batek et al. 1999, Delcourt and Delcourt 1997, Delcourt et al. 1998) and during European settlement (Roberton and Heikens 1994, Nelson et al. 2008b).

Although presettlement fire histories are currently non-existent for southern Illinois oak-hickory uplands, numerous studies within the Central Hardwoods Region have developed fire frequencies by analyzing fire scars during the historic period. The analysis of fire frequency during the middle 20th century within black oak woodlands on sandy soils within northern Indiana yielded a mean fire return interval of 5.2 years (Henderson and Long 1984). A 156 year chronological fire history record for the time period 1846-2002 within an oak dominated forest within West Virginia yielding a fire return interval of 7-32 years with the last fire occurring during 1962 (Schuler and McClain 2003). A fire history record covering the period of 1654-1992 for a post oak barren in southern Indiana determined that the mean fire return interval was 8.4 years (Guyette et al. 2003). Guyette and Spetich (2003) analyzed fire scars within the Boston Mountains of Arkansas to develop fire frequencies for the time period of 1680-2000 and found that frequency was positively correlated with human population growth prior to the fire suppression era beginning in 1920. This study determined that sampled stands contained mean fire intervals of 4.6-16 years during Native American inhabitation (1680-1820), jumping to 2.0-3.1 years during early European settlement (1821-1880) and 1.4-5.0 years during the regional development era (1881-1920), but declining substantially during the suppression era (1920-2000) to 62 to 80 years.

The natural fire regime of oak-hickory forests maintains favorable conditions for the regeneration and persistence of the xerophytic vegetation that is prevalent within these communities (Abrams 1992). Fires that occur within oak-hickory forests are typically of low intensity, with fine fuels such as leaf litter and herbaceous matter being the primary carrying fuels (Scott and Burgan 2005). The possibility of ensuring active fire behavior within oak-hickory forests is dependant on the abundance and condition of flammable fuels and favorable weather conditions (Abrams 2005, Nowacki and Abrams 2008).

Historic Landscapes and Disturbance History of Southern Illinois

Historical accounts provided by early travelers and surveyors depict the region as possessing high landscape diversity, with descriptions of oak-hickory woodlands (Fralish et al. 1991, Fralish et al. 2002, Ruffner et al. 2003) and vast areas of grassland and savanna in the early 1800s (Anderson and Anderson 1975, Olson 1996). The maintenance of these vegetation types was regulated by the historic disturbance regime developed over the past 8,000 years governed by a blend of abiotic and biotic disturbances, with extensive human manipulation (Parker and Ruffner 2004, Lorimer 2001). Notable abiotic disturbances that occur within the region include tornadoes (Henry 1925), earthquakes (Davis 2003), windsheer events (Ruffner et al. 2003), glaze ice storms (Davis 2003), as well as lightning ignited wildfires (Crist 2009). Historic biotic disturbances include widespread anthropogenic manipulation (Robertson and Heikens 1994, Conrad 1978), passenger pigeon flocks (Ellsworth and McComb 2003), herbivory (Conrad 1978), and pathogens such as chestnut blight and Dutch elm disease

(Parker and Leopold 1982).

Fire scarred timber provides researchers with clues to ascertain historic fire frequency, however southern Illinois forests are devoid of stems which regenerated during presettlement times due to past timber harvesting practices and rapid wood decomposition rates (Robertson and Heikens 1994). Therefore, presettlement fire history records currently do not exist for southern Illinois, however fire is widely accepted as a common disturbance during presettlement times (Abrams 1992, Parker and Ruffner 2004). Supporters of this argument rely on accounts of fire adapted vegetation types (Heikens and Robertson 1995, Fralish 1991) as well as observations of vast tracts of burned areas and smoke filled skies (Olson 1996) to suggest that the area was fire prone.

As previously mentioned, an ignition source is necessary for wildland fires to occur, with lightning and humans being the probable ignition sources in southern Illinois. However, lightning caused fires are rare within the Shawnee National Forest, with only 8 recorded ignitions within the past 20 years (Crist 2009). In Pennsylvania hardwood forests, lightning fires occur with greatest frequency during the late summer, primarily on dry ridges which would slowly spread through the landscape (Ruffner and Abrams1998). Anthropogenic fire use practices therefore are believed to be the primary ignition source for wildland fires in the Central Hardwoods Region, with ignitions occurring whenever conditions were suitable for fires to burn until natural fire breaks were encountered (Robertson and Heikens 1994, Parker and Ruffner 2004).

The reasons for anthropogenic fire use are obvious, with fire being the least energy intensive method available to prepare agricultural plots, clear traveling paths, and to stimulate populations of edible vegetation and game mammals (Delcourt and Delcourt 1997, Delcourt et al. 1998, Abrams and Nowacki 2008). Although presettlement fire records have yet to be developed for southern Illinois, numerous authors have documented evidence of Native American caused fires throughout the Central Hardwoods Region, with increasing fire frequency observed within forests within close proximity of high human population centers (Batek et al. 1999, Ruffner and Abrams 2002, Guyette et al. 2003, Abrams and Nowacki 2008). Well-distributed Native American settlements across southern Illinois provides reason to believe that prehistoric forests of this province were likely impacted by Native American burning practices (Parker and Ruffner 2004).

Native American inhabitation of southern Illinois first occurred nearly 12,000 years ago, with different patterns of inhabitation and resource utilization. Population increases with subsequent sedentary lifestyles developed during the Middle and Late Archaic time periods (3000-1000 B.C.), expanding into greater resource utilization with the development of plant cultivation during the Early and Middle Woodland time periods (1000 B.C.-400 A.D) (Jeffries 1987Jefferies 1987). Higher intensities in resource utilization occurred during the Late Woodland time period (A.D. 400-900), reaching peak utilization during the Mississippian era (A.D. 900-1600), where southern Illinois was a resource gathering site for the metropolises of Cahokia and Kincaid (Jefferies 1987, Dye and Cox 1990). Resource depletion and the introduction of European diseases led to population declines during the 15th century, with Mississippian occupation nearly disappearing with the exception of scattered settlements (Dye and Cox 1990). Southern Illinois was largely uninhabited during the 16th and 17th centuries, until eastern tribes such as the Shawnee were driven to the area following European expansion into their home territories (Alvord 1920, Dye and Cox 1990).

European settlement of southern Illinois uplands began during the late 18th century, with a large influx of primarily Scotch-Irish immigrants taking the place of the remaining Native American population who were subsequently driven west through land treaties (Alvord 1920). European land use practices included widespread clearing of forested uplands to provide pasture for livestock as well as row cropping (Conrad 1978). Fire frequency was increased following European settlement due to the use of fire in conjunction with land clearing and enhancement of pasture (Miller 1920, Robertson and Heikens 1994, Nelson et al. 2008b). Commercial logging was also heavily practiced to support the developing railroads, charcoal-iron industry, mining industry, and growing human populations of the region (Conrad 1978). The amount of land cleared for agriculture peaked in the early 1900s, when it became apparent that many cleared areas were unsuitable for agriculture with subsequent exploitation of their natural resources leading to land degradation and erosion (Conrad 1978). Social efforts to restore the integrity and sustainability of southern Illinois landscapes ultimately led to the creation of the Shawnee National Forest during 1933 (USDA 2000).

Land management policies and objectives of the Shawnee National Forest were assigned to the USDA Forest Service, an agency largely interested in timber management and reforestation during this era. At the time, foresters suggested that fire control was essential for maintaining forest health and integrity, therefore numerous local bans on fires were initiated with the aid of the 1924 Clarke-McNary Act, significantly reducing human ignitions after 1940 (Miller 1920, Conrad 1978, Pyne 1982). Thus, the long-term effects of periodic fire in maintaining healthy oak-hickory forests were removed, and many recent authors cite subsequent significant changes in forest structure across much of the region (Weaver and Ashby 1971, Fralish et al. 1991).

As the forest communities of the Shawnee National Forest continued to mature, management practices aiming to regenerate oaks and hickories with where employed with variable success. Late 20th century silvicultural practices within southern Illinois public lands included group selection (Nelson et al. 1973), clearcutting (Groninger and Long 2008) and selective harvesting treatments (Ozier et al. 2006) which provided mixed results due to competition from mesophytic tree species. Prescribed fires were implemented in the 1980's, although it's popularity as a management tool did not persist within management of the Shawnee National Forest, and without continued support the program ceased (Richard Johnson *personal communication* 2009). The spawning of a local environmentalist movement opposed to active forest management during late 20th century resulted in the cessation of timber harvesting within the Shawnee National Forest following a controversial 1995 court decision, with the last timber harvests occurring in the early 1990's (Clevenger *personal communication* 2009).

Threats to the Persistence of Oak-Hickory Forests

Oak-hickory dominance within the Shawnee National Forest uplands has continued into the present, although widespread reports of significant changes in forest structure have been documented (Anderson and Anderson 1975, Fralish et al. 1991, Weaver and Ashby 1971, Shotola et al. 1992, Rentch et al. 2003, Rentch and Hicks 2005). The present overstory of shade intolerant oaks and hickories largely regenerated during the turn of the 20th century following active burning and timber harvesting practices, however the advent of fire suppression resulted in declines in oak-hickory regeneration (Zaczek et al. 2002, Van de Gavel et al. 2003, Ozier et al. 2006). Further decreasing prospects for oak dominance, it is believed that many of these oaks will not survive much longer in the canopy, especially shorter-lived species of red oaks which are vulnerable to numerous pathogens including *Armillaria* root rot (Bruhn et al. 2000).

Although previously reported as a minor component of upland oak-hickory communities, a large mesophytic tree species component has become established underneath a dense oak-hickory overstory (Fralish et al. 1991, Fralish et al. 2002), creating problems for the sustainability of oak-hickory forests (Lorimer et al. 1994, Larsen et al. 1997, Rebertus and Burns 1997, Nowacki and Abrams 2008). Mixed mesophytic tree species such as sugar maple (*Acer saccharum* Marsh.) and American beech (*Fagus grandifolia* Ehrh.) thrive underneath these protected conditions, and are capable of claiming canopy dominance during the creations of overstory gaps (Canham 1985, Shotola et al. 1992, Taylor and Lorimer 2003, Nowacki and Abrams 2008). Mesophytic species also tend to have a rapid decomposition rate of their leaves when compared to the lignin rich oak leaves, which alters fire behavior and renders oak-hickory forests less likely to burn with desired effects (Rebertus and Burns 1997, Abrams 2005, Nowacki and Abrams 2008). Due to a high foliar nitrogen content, mesophytic species such as sugar maple are also linked to higher nitrogen availability within forest soils, with further potential impacts on species composition (Hutchinson et al. 1999).

Albeit early and mid-successional species are disturbance dependent, some areas have been exposed to irresponsible timber harvesting practices of the past, which have decreased oak-hickory dominance (Abrams and Nowacki 1992, Jenkins and Parker 1998). In many areas of the eastern deciduous forests, harvesting practices have focused on single tree selection methods consisting of the removal of mature oaks, which has accelerated succession and the replacement of oaks by mesophytic species (Abrams and Nowacki 1992, Jenkins and Parker 1998). Where harvesting practices have removed a sufficient portion of the overstory, oak regeneration has failed without sufficient competition controls (Hannah 1987, Crow 1988), pre-harvest root development, and on nutrient rich sites (Larsen and Johnson 1998, Groninger and Long 2008). Clearcutting results in dramatic increases in light aiding oak regeneration, however this boost can lead to greater influxes of other mesophytic pioneer species such as tulip-poplar (*Liriodendron tulipifera* L.) on mesic sites (Groninger and Long 2008, Jenkins and Parker 1998).

Alterations in forest and landscape structure also pose numerous threats to the health of oak-hickory ecosystem as a whole. Not only have mature oak-hickory uplands changed in structure, the diversity of forest cover types across the landscape has also decreased (Parker and Ruffner 2004), with substantial declines in early successional habitat (Thompson and Dessecker 1997). Oak-hickory forests with a dense mesophytic component have been found to hold lower levels of species richness within avian (Rodewald and Abrams 2002) and herbaceous communities (Fralish 1997). Invasive species have become established throughout areas of the Shawnee National Forest (Olson et al. 2004, USDA 2006), which are capable of becoming readily established on sites subjected to long periods of site facilitation leading to low levels of native species richness (Shea and Chesson 2002). Exotic vegetation poses many threats to native ecosystems and natural fire regimes (Brooks et al. 2004) by altering decomposition rates (Ashton et al. 2005), fuel loading (Dibble and Rees 2005), fuel continuity, and fire seasonality.

CHAPTER 3

METHODS

Study Area Description

The Shawnee National Forest of southern Illinois is comprised of 277,506 acres within the Central Hardwood Forest Region of the United States (Fralish 2003, Parker and Ruffner 2004) (Figures 1 and 2). Due to geologic variability, the Shawnee National Forest can be divided into various ecological subsections that have unique vegetation associations (Figure 3). Oak-hickory uplands are the dominant vegetation type throughout the majority of the Shawnee, while other unique communities exist throughout the region on more edaphically distinct settings (Anderson and Anderson 1975, Olson et al. 2004). The local vegetation type was classified as being mixed mesophytic by Braun (1950), while the potential vegetation type was classified as oak-hickory by Küchler (1964).

The Shawnee National Forest lies within the Humid Temperate Domain/Hot Continental Division, which experiences hot summers and moderate winters (Bailey 1996). The average annual precipitation is approximately 44-46 inches, with the driest month of the growing season being July (Bailey 1996). The location of southern Illinois provides extreme variability in temperatures, humidity, and wind direction due the ability of northern frontal systems to mix with southern warm moist air masses (Bailey 1996). The landscape of southern Illinois remained unglaciated following the last ice age, providing topographic relief not frequently observed within the majority of northern Illinois (Schwegman

1973). Soils throughout the Shawnee are primarily classified as alfisols with some ultisols, with soil textures being predominantly silt, silt loam, and silt clay loam which possess moderate drainage and water retention capacities (Fehrenbacher 1984). Soil profiles contain a deeper loess cap within the western portions of southern Illinois due to the closer proximity of the Mississippi River which provides sandy soil easily transported by prevailing westerly winds (Fehrenbacher 1984).

The Illinois Ozarks (546,060 ac) are found within the southwestern portion of the Shawnee National Forest (Figure 3), characterized by rugged, dissected topography capped with loess deposits and underlain with cherty limestone providing rich growing conditions which support mesophytic species (Fralish 1997, Parker and Ruffner 2004). Ridgetop sites lie on narrow spur ridges capped with loess above steep slopes of colluvial materials descending to narrow riparian zones comprised of alluvial soils (Fehrenbacher 1984). The landscape dissection of the Illinois Ozarks poses challenges to the spread of large, landscape level fires (Stambaugh and Guyette 2008) typical with homogenous topography, thereby favoring fire intolerant mesophytes.

The Greater Shawnee Hills (466,741 ac) lies within the Interior Low Plateau physiographic province, which extends into parts of northern Alabama, southern Indiana, central Tennessee, and the majority of Kentucky (Figure 2) (Fralish et al. 2002). Soils within the Greater Shawnee Hills are primarily composed of a silty loess cap which lies upon a massive bedrock sheet of Pennsylvanian sandstone (Fehrenbacher 1984). Soil profiles are often mixed with scattered sandstone fragments and sandstone bluffs and rock outcrops are also common throughout the region (Fenneman 1938). The Greater Shawnee Hills contain gently rolling hills and extensive uplands, favorable to large fire spread and a recurring fire regime with a 15-25 year return interval (Fralish 1988, Fralish 1997). Presettlement forests of this region were dominated by xerophytic species such as white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), and post oak (*Quercus stellata* Wangenh.), with mesophytic species restricted to mesic sites having lower overall importance (Fralish 1997, Fralish et al. 2002).

The Lesser Shawnee Hills (483,754 ac) runs parallel with the Greater Shawnee Hills on an east-west transect throughout southern Illinois and is also included within the Interior Low Plateau physiographic province (Figure 2) (Fehrenbacher 1984). The Lesser Shawnee Hills are classified as gently rolling hills underlain with variable bedrock types, with parent material primarily composed of limestone, with scattered bedrock composed of sandstone and shale (Fenneman 1938). Tree species composition is relatively similar to the Greater Shawnee Hills, with presettlement forests primarily dominated by oak-hickory species (Fralish 1997, Fralish et al. 2002).

The Cretaceous Hills subsection (23, 685 ac) lies within the Gulf Coastal Plain region which extends north along the Mississippi River from the Gulf of Mexico (Figure 2) (Fehrenbacher 1984). The rolling hills and knobs of the Cretaceous Hills soils are underlain with unconsolidated sand, gravel, and clay, topped with loess deposits (Fenneman 1938). The Cretaceous Hills attain the lowest elevations of any of the subsections contained within the Shawnee

National Forest, with elevations ranging from 340 to 450 feet (Fralish et al. 2002).

Landscape diversity throughout the region is enhanced by the presence of barrens communities and mesophytic coves. While many barrens communities may be edaphically influenced, there is ample evidence suggesting that fire is an important factor in controlling woody encroachment on these sites (Heikens and Robertson 1995, Anderson et al. 2000). Mesophytic cove sites support a variety of mesophytic tree species which thrive within moist and rich sites conditions (Fralish 1988).

Southern Illinois has a rich cultural history, extending from long periods of Native American inhabitation to eventual European settlement during the 16th century (Parker and Ruffner 2004). Poor land management practices of early European settlers created numerous negative ecological impacts, which continued until resource exhaustion led to a period of widespread land abandonment during the early 20th century (Conrad 1978). Many of these lands were acquired by the federal government, and included in the Shawnee National Forest, which was created in 1933 (Conrad 1978). Although the forest boundaries are extensive, a large component of private ownership is scattered throughout the purchase unit, creating a highly fragmented landscape (Parker and Ruffner 2004).

Site Selection

Due to the high amount of private ownership and the fragmented nature of the Shawnee National Forest, strict site selection criteria had to be employed to ensure quality of sites. Geographic information systems (GIS) data describing stand characteristics were provided by the Shawnee National Forest, and analyzed with ArcView GIS 3.2 to develop a list of potential stands. Eligible stands were dominated by upland oak-hickory species with an overstory comprised of stems >20” diameter at breast height, greater than 250 acres in size, and accessible by public roadways. To account for diversity of ecological subsections and landscape heterogeneity, as well as stand independence, stand selection was distributed evenly across the Shawnee National Forest (Figure 4). Plots located within sampled stands within the Greater Shawnee Hills subsection included the Williams Hill (n=17) and Bay Creek (n=16) sites. Plots within Lesser Shawnee Hills were distributed throughout the Cache Creek (n=18), Cedar Lake (n=16), Cobden (n=16), and Kaskaskia (n=17) sites. Plots within the Burke Branch stand (n=18) was sampled to represent the Cretaceous Hills subsection. The Illinois Ozarks was sampled through plots within the Bean Ridge (n=19), Cripps Bend (n=17), and Viney Ridge (n=16) stands.

Plot Sampling Procedures

Forest inventories were conducted during the summer of 2006 (June, July, August, September) for this project. A systematic grid pattern was utilized for determining plot locations to account for an equal distribution of site conditions amidst variable landscape conditions throughout the upland communities. Once plot locations were determined, variable radius plot centers and range pole placement were located at a standard distance of 6.05 m in the direction of the sampling plane. Sampling plane directions were determined at random for each site to prevent bias for plot sampling transects.

Variable radius plots were conducted using a 10 basal area factor (BAF) prism to sample present tree species. The diameter at breast height (DBH) of sampled trees were then measured with diameter tapes. Stand age was determined by using an increment borer to obtain core samples from dominant and co-dominant overstory trees. Stand age was determined by analyzing core samples from codominant and dominant overstory trees of *Quercus* spp. since the regeneration of this species group is largely a result of stand initiating disturbance and the reliability of core sample readings performed on oaks.

Fire Regime Condition Class values were assigned to each plot sampled during the forest inventory period. The criteria utilized for the sampling followed guidelines presented by Schmidt and others (2002) and the Interagency Fire Regime Condition Class Guidebook version 1.2.0 (Hann et al. 2004). In accordance to the goals of the Shawnee National Forest (USDA 2006), the ability of land managers to sustain oak-hickory forests by restoring the historic fire regime served as the driving factor for determining Fire Regime Condition Class values.

Unfortunately, fire history records for the Shawnee National Forest have not been maintained, thereby limiting the ability to determine accurate estimates of how long each stand has been excluded from fire. Although it is clear that fire has been aggressively suppressed throughout the management area since the late 1930's, assumptions cannot be made regarding the fire history of each stand due to the possibility of these stands being exposed to an undocumented wildfire. Therefore FRCC classification was determined through analyzing current forest structure parameters such as species composition and density within the overstory, midstory, sapling, and seedling layers. Additional FRCC determinants included observed herbaceous cover and the presence of invasive species as well as assessing historic disturbance regimes and management possibilities.

Photo plots were established for both growing season and dormant season photographs to capture visual representations of stand structure, with guidance from the procedures of Ottmar and Vihnanek (1999). A range pole with the height of 2.42 m was placed at the plot centers and was utilized to establish a constant scale of reference. Growing season photographs were taken during the summer of 2006 (June, July, August, September), whereas dormant season photos were taken during the winter of 2006 (December) and 2007 (January, February, March).

Fuel loading measurements were calculated according to Brown's Handbook for Inventorying Downed Woody Material (Brown 1974). Reported aspects of fuel depth included measuring the depths of the duff layer, leaf litter, and total surface fuels. Fuel loading calculations expressed in tons/ac were calculated for stands by inventorying 1 hour time lag fuels (0-0.24" diameter), 10 hour time lag fuels (0.25-0.99" diameter), 100 hour time lag fuels (1-2.99" diameter), as well as rotten and sound 1000 hour time lag fuels ($\geq$3" diameter).

Data Analyses

Records of the frequency of trees by diameter at breast height were used to calculate forest structure parameters, including stand density (trees/ac) and basal area per acre (ft^2 BA/ac). Species groups were compared by forming three tree species groups including xerophytes, mesophytes, and midstory tree species (Table 2). Relative values were determined for each stand, including stand level relative species density (relative trees/ac), relative species dominance (relative basal area/ac), and relative importance value. Stand level relative importance values were determined by combining stand level species relative density and species relative dominance. Stand relative importance values were then averaged within each ecological subsection to provide a comparison with reference conditions (Fralish et al. 2002).

Relative importance values (RIV) were calculated by the following formula:

[(Species relative trees/ac) + (Species relative basal area/ac)]/(100)= RIV..

Reference conditions were based on surveyor records described in the 1806-1810 General Land Office (GLO) surveys of southern Illinois township boundary location (Fralish et al. 2002). Surveyors of the GLO recorded descriptions of witness trees and landscape features to identify township boundaries which were later analyzed to develop presettlement conditions. During the initial surveys, witness trees served as township boundaries, with notes taken on their respective diameter and species. Additional surveyor measurements included distances between witness trees and their nearest tree neighbors, which were analyzed by Fralish et al. (2002) to determine past density and basal area/ac for each subsection as well as relative importance values for species groups and individual species.

Descriptions of species relative importance values and forest structure characteristics described within the reported reference conditions were utilized to provide a comparison of current trends in species relative importance values and forest structure. However, plot locations sampled in this study were not the same as those sampled during the GLO survey. Although the reference conditions that were analyzed in this study are the most reliable resource currently available, caution must be exercised when using the data as a perfect example of past conditions due to the possibility of human error during the GLO surveys (Black and Abrams 2001).

Current estimates of tree density (trees/ac) and basal area/ac for upland oak-hickory forests were compared with observations described in reference conditions (Fralish et al. 2002). One-way tests for analysis of variance (alpha= 0.05) performed with Microsoft Office Excel were used to compare differences in tree density and basal area/ac for reference and current conditions.

Fire Regime Condition Class values assigned during site inventories were compared with forest structure ratios to assess their reliability and to determine thresholds of FRCC values. The forest structure ratios were developed through the calculation of density (trees/ac) and basal area estimates for each species within each plot. These species specific calculations of density and dominance were then separated into three distinct groups (oaks, mesophytes, xerophytes) by adding total density and dominance measures for each group within each plot. These ratios included oak:mesophyte density (OMDE), oak:mesophyte dominance (OMDO), xerophyte:mesopyte density (XMDE), and xerophyte:mesophyte dominance (XMDO).

Forest structure ratios were calculated by the following formulas:

[(Oak trees/ac)]/[(Mesophytic trees/ac) + 1]= OMDE

[(Oak basal area)]/[(Mesophytic basal area) + 1]= OMDO

[(Xerophytic trees/ac)]/[(Mesophytic trees/ac) + 1]= XMDE

[(Xerophytic basal area)]/[(Mesophytic basal area) + 1]= XMDO..

Since mesophytes were not sampled in each plot, mesophytic density and dominance was added by 1 to ensure that all calculated ratios had values above 0.1. Analyzing the validity of FRCC values was performed through utilizing the computer statistical analysis program SAS 9.1 with the mixed procedure (alpha= 0.05). Log transformation was used in FRCC values to increase normality. Physiographic region and stand location were random variables, with Fire Regime Condition Class values as a fixed variable.

Plot level fuel loading calculations (tons/ac) were also assessed for their use as determinants of Fire Regime Condition Class values. Plots assigned as FRCC 2 and 3 were compared with their corresponding fuel loading characteristics (tons/ac) by using SAS 9.1 with the mixed procedure (alpha= 0.05). Physiographic region and stand location were random variables, with Fire Regime Condition Class values as a fixed variable.

CHAPTER 4

RESULTS

Current Forest Structure

Greater Shawnee Hills

Oaks and hickories were clearly the dominant species group throughout the Greater Shawnee Hills due to their overwhelming presence in the 9-16” and 16-25” diameter classes (Tables 3 and 4, Figures 4 and 5). Xerophytic species comprised 83% of the basal area/ac, with mesophytes restricted to the smaller diameter classes (Table 4, Figure 5). White oak (*Quercus alba* L.) had the highest density (56.4 trees/ac) (Table 3) and was the most dominant overstory tree (37.8 ft^2 BA/ac), representing 38% of the basal area/ac (Table 4). Pignut hickory (*Carya glabra* Mill.) was the second densest species, representing 35.8 trees/ac (Table 3), and was sub-dominant in the 9-16” size class with 11.2 ft^2 BA/ac (Table 4). Black oak (*Quercus velutina* Lam.) was well distributed throughout all of the size classes and the third most dominant species, with most of its dominance found in the 16-25” size class with 6.8 ft^2 BA/ac (Table 4).

Although mesophytes comprised a smaller portion of the overstory trees, their presence dominated the smaller diameter classes (Tables 3 and 4). Their density within the 1-4” size class (38.2 trees/ac) was higher than that of the xerophytes (32 trees/ac) (Table 3). Blackgum (*Nyssa sylvatica* Marsh.) was very dense in the 1-4” diameter class, representing 17.1 trees/ac (Table 3). Midcanopy species, primarily eastern hophornbeam (*Ostrya virginiana* Mill.) also were common within the understory, representing 28.8 trees/ac within the 1-4" size class (Table 3). Throughout all size classes xerophytic species comprised 125 trees/ac, with a highest representation of smaller diameter stems when compared to the other ecological subsections (Table 3). The majority of the sampled stems were within the 9-16" size class representing 43.5 ft^2 BA/ac out of total 99.8 ft^2 BA/ac (Table 4).

Lesser Shawnee Hills

Although xerophytes were still the dominant overstory species group (69.3 ft^2 BA/ac) within the Lesser Shawnee Hills, mesophytes represented a high proportion of the basal area/ac (36.7 ft^2 BA/ac) (Table 6). Mesophytic species were well distributed throughout the diameter classes, subsequently leading to higher levels of density (93.1 trees/ac) than xerophytes (87.0 trees/ac) (Table 5). Midcanopy species were also very abundant (51.2 trees/ac), predominately populated by 1-4" flowering dogwood (*Cornus florida* L.) and eastern hophornbeam (*Ostrya virginiana* Mill.) stems in the understory (Table 5). Sugar maple (*Acer saccharum* Marsh.) had the highest density of any of the tree species (46.1 trees/ac), and was found within all size classes except the 25-35" size class (Table 5). It was notable that xerophytic species were mostly confined to larger diameters, primarily the 16-25" class, and no oaks were sampled in the 1-4" size class (Tables 5 and 6).

White oak comprised 26% of the total basal area/ac, representing 34.4 ft^2 BA/ac of the total 113.1 ft^2 BA/ac for the Lesser Shawnee Hills (Table 6). Black cherry (*Prunus serotina* Ehrh.), sugar maple, and tulip-poplar (*Liriodendron* *tulipifera* L.) were common in the larger diameter classes, boosting their basal area/ac within the overstory and their overall dominance (Table 5). Mesophytic species such as sugar maple and sassafras (*Sassafras albidum* Nutt.) comprised a high amount of the basal area/ac within the smaller diameter classes (Table 6).

Cretaceous Hills

Xerophytes were the clear dominant within the Cretaceous Hills, with the overstory comprised of numerous large diameter oaks. White oak (46.1 ft^2 BA/ac) and black oak (27.8 ft^2 BA/ac) stems were the most dominant species within the ecological subsection (Table 8). Mesophytic stems were not very common in the overstory, although large diameter tulip-poplar stems were the third most dominant species sampled (7.0 ft^2 BA/ac) (Table 8). Hickories (*Carya spp.*) exhibited less dominance in the overstory than the other ecological subsections, representing only 7.8 ft^2 BA/ac (Table 8).

Tree species density consisted mostly of mesophytes, with high amounts of sassafras (44.5 trees/ac), red maple (*Acer rubrum* L.) (29.0 trees/ac), and tulip-poplar (28.8 trees/ac) (Table 7). Flowering dogwood was common within the 1-4” size class, representing 12.7 trees/ac (Table 7). Xerophytes, primarily white oak (17.9 trees/ac) and shagbark hickory (*Carya ovata* Mill.) (11.3 trees/ac) had a small but comparatively large component of stems within the 1-4” diameter class (Table 7). However, no red oak species were sampled in the 1-4” or 4-9” size classes (Tables 7 and 8).

Illinois Ozarks

Xerophytes in the Illinois Ozarks were clearly the dominant species group when analyzing total basal area/ac (80.1 ft^2 BA/ac) (Table 10), although the high density of mesophytes (131.6 trees/ac) (Table 9) was due to their constant presence throughout all size classes except the 25-45" class. Sugar maple stems within the 4-9" class were very common (17.8 trees/ac) (Table 9), with the highest basal area/ac (5 ft^2 BA/ac) within this size class than any other species throughout the study area (Table 10). Xerophytic density was limited to the larger diameter classes (Table 9), with red oak species entirely absent in the smaller diameter classes (Tables 9 and 10). White oak was the most dominant tree species, with numerous stems in both the 9-16" and 16-25" classes (Tables 9 and 10).

Sugar maple density within the 1-4" diameter class (28.1 trees/ac) and the 4-9" diameter class (17.8 trees/ac) boosted the overall density of this species to the highest overall density within the ecological subsection (Table 9). American beech (*Fagus grandifolia* Ehrh.) saplings were very common within this subsection, with 30 trees/ac represented in the 1-4" size class (Table 9). Sassafras stems within the 1-4" diameter class were also very common (20.0 trees/ac) (Table 9). Winged elm (*Ulmus alata* Michx.) (14.3 trees/ac) and serviceberry (*Amelanchier arborea* Michx. F.) (10.1 trees/ac) were also very common in the 1-4" diameter class (Table 9).

Current vs. Reference Conditions

Greater Shawnee Hills

Tree density increased significantly ($F_{1, 32}$= 16.66, p= 0.0001) (Table 15) within the Greater Shawnee Hills ecological subsection, with trees/ac expanding from 78 trees/ac to 216 ± 33.91 SE trees/ac (Table 15). Significant declines in basal area/ac were observed ($F_{1, 32}$=14.52, p=0.0003) (Table 16), dropping from 105 ft² BA/ac to 91.52 ± 3.54 SE ft² BA/ac (Table 16). Alterations in species composition within the Greater Shawnee Hills were also observed (Table 11).

Xerophytes retained their status as having the highest average relative importance values (72.9%), although oaks (*Quercus spp.*) decreased in importance from 66.8% to 52.8%, as hickories (*Carya spp.*) increased in importance from 7.8% to 20.1% (Table 11). Red oak species such as northern red oak (*Quercus rubra* L.) and black oak (*Quercus velutina* Lam.) decreased in importance, which was a similar trend throughout the study (Table 11). Although white oak (*Quercus alba* L.) was the clear dominant species throughout the Greater Shawnee Hills, the species was more dominant in the past with a relative importance value of 45.5%, as opposed to its current position of 33.5% (Table 11).

Mesophytic species as a whole slightly decreased in importance, and within this species group there were changes in the dominance of individual species. Sugar maple (*Acer saccharum* Marsh.) became the most dominant mesophyte, with an increase in importance from 1.9% to 5.1% (Table 11). Ash (*Fraxinus spp.*) and overstory species of elm (*Ulmus spp.*) were a significant component in historic forests (4.2%), although this species had an unremarkable presence in current forests (Table 11).

Tree species typical within the midstory increased substantially from 5.9% to 9.7% (Table 11). Remarkably, eastern hophornbeam (*Ostrya virginiana* Mill.) experienced a large increase in dominance, with a current relative importance value of 7.2%, whereas in the past this species was not mentioned (Table 11). Flowering dogwood (*Cornus florida* L.) dropped from being the most dominant midstory species with a historic relative importance value of 4.3%, declining in importance to 1.7% (Table 11).

Lesser Shawnee Hills

The Lesser Shawnee Hills has experienced dramatic deviations in forest structure when comparing conditions described in reference conditions. Tree density increased significantly within the Lesser Shawnee Hills ecological subsection ($F_{1,65}$=72.16, p<0.0001) (Table 15), with trees/ac increasing from 52 trees/ac to 215.00 ± 19.19 SE trees/ac (Table 15). Significant increases in basal area/ac were also observed for the Lesser Shawnee Hills ($F_{1,65}$=80.49, p<0.0001) (Table 16), with basal area/ac increased considerably from 73 ft^2 BA/ac to 104.55 ± 3.52 ft^2 SE BA/ac (Table 16).

Relative importance values of xerophytic species dropped from 76% to 56%, with large declines in the dominance of oaks. Hickories did however double in importance from 6.1% to 12.3% (Table 12). Previously the two most dominant species throughout the Lesser Shawnee Hills, white oak and black oak both experienced large declines in importance (Table 12).

Relative importance values of mesophytes increased significantly, with the species group jumping from 15.6% to 30.6% (Table 12). Sugar maple became the most dominant mesophyte, increasing in importance from 1.9% to 13.9% (Table 12). Notable increases in importance were also observed in the populations of tulip-poplar (*Liriodendron tulipifera* L.), sassafras (*Sassafras albidum* Nutt.), and red maple (*Acer rubrum* L.) (Table 12).

Large increases in the importance of the midcanopy species group were observed, with previous estimates of relative importance values of 4.7% and current estimates are13.7% (Table 12). This increase is due to a substantial cohort of eastern hophornbeam (3.5%) and winged elm (*Ulmus alata* Michx.) (2.6%), as well as a slight increase in flowering dogwood (4.8%) which remained the overall dominant (Table 12).

Cretaceous Hills

The Cretaceous Hills ecological subsection experienced the most substantial changes in tree density and basal area/ac than any other sampled area. Significant increases in tree density occurred within the Cretaceous Hills ecological subsection ($F_{1,17}$=13.39, p=0.0008) (Table 15), with trees/ac increasing from 16 trees/ac to 237.99 ± SE 60.54 trees/ac (Table15). Basal area/ac increased significantly ($F_{1,17}$=117.03, p<0.0001) (Table 16) from 14 ft^2 BA/ac to 113.33 ± 9.28 SE ft^2 BA/ac (Table 16).

Xerophytes still dominate the forest structure, although their overall importance dropped from 86.6% to 62.5% (Table 13). Historically nearly half of the basal area/acre was comprised of white oak, a species that has now dropped to 30% of the stand (Table 13). Black oak also dropped in importance, with the species relative importance values declining from 28.3% to 15.3% (Table 13).

Remarkable increases in importance were reported for the mesophytic species group. Historically an insignificant component of the forest structure, sassafras became the most dominant mesophyte sampled in this study, with a present relative importance value of 10.5% (Table 13). Although individual maple species (*Acer spp.*) were unreported in reference conditions, red maple was found to have a relative importance value of 8% within current forests (Table 13). Tulip-poplar also was found to be a significant part of the current forest, with a relative importance value of 7.2%, whereas in the past it was reported as having a relative importance value of 1.4% (Table 13).

The midstory species group also increased in importance, with previous estimates of 1.7% increasing to 6.3% (Table 13). Flowering dogwood remained the most dominant midstory species, with a substantial boost in importance from 1.4% to 4.5% (Table 13). Winged elm also increased in importance, from a previously unreported value to a relative importance value of 1.8% (Table 13).

Illinois Ozarks

Tree density increased significantly within the Illinois Ozarks ecological subsection ($F_{1,51}$=21.99, p<0.0001), with trees/ac increasing from 87 trees/ac to 263.30 ± 37.59 SE trees/ac (Table 15). Significant declines in basal area/ac occurred within the Illinois Ozarks ($F_{1,51}$=15.35, p=0.0002) with basal area/ac declining from 120 ft^2 BA/ac to 105.96 ± 3.58 SE ft^2 BA/ac (Table 16). Deviations in species composition were also observed for the Illinois Ozarks (Table 14).

The large presence of oaks (36.3%) within the overstory earned the xerophytes a place as the most dominant species group (48.1%) (Table 14). Relative importance values for the xerophytic species group unexpectedly increased slightly, with few notable changes in importance within this species group (Table 14). Although xerophytes increased in importance overall, white oak remained the most dominant species while decreasing in importance from 26.4% to 21.2% (Table 14).

Previously the most dominant species group, mesophytes unexpectedly declined in importance from 50.3% to 43.3% (Table 14). Sugar maple became the most dominant mesophyte, increasing in importance from 3.6% to 15.8%, filling a void created by a decline in the previous dominant, American beech which dropped in importance from 25.8% to 8.3% (Table 14). Previously unreported, sassafras became the third most dominant mesophyte with a relative importance value of 7.3% (Table 14).

The establishment of midcanopy species increased the relative importance value of this species group from 2.2% to 8.5% (Table 14). Flowering dogwood remained the most dominant species, slightly increasing in importance from 1.3% to 3.7% (Table 14). Winged elm (2.3%) and serviceberry (*Amelanchier arborea* Michx. F.) (1.5%) also increased in importance and were two of the most abundant midstory species, whereas their presence was unreported within reference conditions (Table 14).

Fire Regime Condition Class Value Determination

Fire Regime Condition Class values were found to be influenced by density and dominance ratios, with distinct differences between FRCC 2 and FRCC 3 (Table 17, Figure 12). The relationship between FRCC values and forest structure ratios were statistically highly significant at the 0.05 significance level for each of the tested analyses. Density ratios for oak:mesophyte density ($F_{1,167}$=35.09, p< 0.0001) and xerophyte:mesophyte density ($F_{1,167}$=35.09, p< 0.0001) were determined to adequate measures of FRCC, therefore accepting the null hypothesis that density ratios were valid criterion for FRCC determination. Dominance ratios for oak:mesophyte dominance ($F_{1,167}$=55.26, p<0.0001) and xerophyte:mesophyte dominance ($F_{1,167}$=43.76, p< 0.0001) were determined to satisfactory measures of FRCC, therefore accepting the null hypothesis that dominance ratios were valid criterion for FRCC determination.

Plots classified as Fire Regime Condition Class values of 2 were found to contain sufficient levels of oak-hickory vegetation without a large component of mesophytes. These plots contained a higher density of oaks than mesophytes (46.65:1 ± 5.33 SE) as well as a higher oak:mesophyte basal area ratio (11.03:1 ± 0.54 SE) (Table 17). The xerophyte:mesophyte density ratio (62.04:1 ± 7.75 SE) was also higher within plots determined to represent FRCC 2, as well as the xerophyte:mesophyte basal area ratio (12.25:1 ± 0.55 SE) (Table 17).

Plots designated with Fire Regime Condition Class 3 values contained a much higher proportion of mesophytes. While oaks and xerophytes were still commonly found within these plots, their overall density and dominance ratios were less substantial. Plots ranked as FRCC 3 possessed a lower oak:mesophyte density ratio (5.12:1 ± 1.88 SE), as well as a decreased oak:mesophyte basal area ratio (4.74:1 ± 0.53 SE) (Table 17). The xerophyte:mesophyte density ratio (5.93:1 ± 1.98 SE) decreased in FRCC 3 plots, as well as the xerophyte:mesophyte basal area ratio (5.72:1 ± 0.53 SE) (Table 17).

Fuel loading (tons/ac) was not found to be a statistically significant determinant of FRCC at the 0.05 significance level ($F_{1,167}$=1.12, p= 0.2929) (Table 17). Therefore the null hypothesis that fuel loading was a valid determinant of FRCC was rejected. Average fuel loading (tons/ac) characteristics for stands classified as FRCC 2 (6.19 ± 0.68 SE) were found to be similar to stands classified as FRCC 3 (7.61 ± 0.91 SE) (Table 17).

Stand Age

Tree ring analyses of codominant and dominant overstory trees sampled through increment boring provided interesting data pertinent to stand age (Figure 13). Core samples from dominant and codominant oaks suggest that the oak overstory within these uplands regenerated nearly 102.92 ± 3.26 SE years ago. Species level analysis reported average ages for white oak (*Quercus alba* L.) (104.89 ± 3.86 SE) (n=61), southern red oak (*Quercus falcata* Michx.) (112.5 ± 12.5 SE) (n=2), northern red oak (*Quercus rubra* L.) (89 ± 2.08 SE) (n=3), post oak (*Quercus stellata* Wangenh.) (124.33 ± 12.93 SE) (n=15), and black oak (*Quercus velutina* Lam.) (85.42 ± 4.95 SE) (n=24).

CHAPTER 5

DISCUSSION

Departure from Historic Forest Structure

Current estimates of tree density within mature oak-hickory uplands of the Shawnee National Forest were found to have increased substantially in each of the ecological subsections (Table 15). Reference conditions suggest that density for the upland forests of each of the ecological subsections ranged from 16-87 trees/ac, whereas current estimates were found to be between 216-263 trees/ac (Table 15). The development of dense, closed canopy forests has facilitated the expansion of a dense component of fire-intolerant mesophytic tree species which favor the moist, protected microenvironments (Burns and Honkala 1990, Fralish et al. 1991). Since reductions in tree density are found following fire entries within oak-hickory forests (Abrams 1992, Brose et al. 2006), these large increases in tree density are most likely a result of fire suppression and altered disturbance regimes within the upland oak-hickory communities (Robertson and Heikens 1994, Fralish et al. 2002, Schmidt et al. 2002).

Substantial increases in basal area/ac occurred within the Cretaceous Hills and Lesser Shawnee Hills ecological subsections (Table 16). These ecological subsections also possessed lower estimates of tree density during reference conditions (Table 16) therefore these areas must have been comprised of open woodland and savanna communities with scattered oaks and hickories being the dominant trees (Anderson and Anderson 1975, Fralish et al. 2002).

Current estimates of basal area/ac within these ecological subsections are similar to those described in the Greater Shawnee Hills and the Illinois Ozarks (Table 16), consequently the woodland communities that historically dominated the landscape have developed into closed canopy forest communities which have reached their carrying capacity (Bormann and Likens 1979).

Current estimates of basal area/ac within the Greater Shawnee Hills and the Illinois Ozarks declined slightly, although they were fairly similar to those described in reference conditions (Table 16). Although these ecological subsections have experienced significant increases in tree density (Table 15), the amount of basal area/ac did not increase since these stands have most likely reached their carrying capacity and can only support so much biomass (Bormann and Likens 1979). Within these ecological subsections, upland oak-hickory communities were most likely comprised of large diameter oaks and hickories representing high amounts of basal area/ac (Fralish et al. 2002), although these large trees probably lost following logging practices during early settlement (Robertson and Heikens 1994, Parker and Ruffner 2004). Therefore large increases in tree density (Table 15) have filled the void created by historic logging practices, resulting in similar estimates of basal area/ac within these upland communities (Table 16).

Changes in Species Composition

Within the sampled upland oak-hickory communities relative importance values for xerophytic species vary upon ecological subsection and site. The Greater Shawnee Hills and surprisingly the Illinois Ozarks retained a high overall presence of overstory xerophytes, although variability existed between individual species of oaks and hickories (Tables 11 and 14). However, xerophytic tree species are not well represented within the smaller diameter classes (Tables 11, 12, 13, 14), leading to possible changes in their competitive stature for future forests (Fralish et al. 2002). Where xerophytes are dominant in the overstory, their relative basal area/ac values are maintaining their overall relative importance values and status as the dominant species group.

Within the xerophytic species group, variability in importance values exists between individual species (Tables 11, 12, 13, 14). Species within the red oak (*Erythrobalanus*) group such as black oak and northern red oak appear to be on the decline (Tables 11, 12, 13, 14), which may be a result of overmaturity and their inability to regenerate underneath dense forest canopies (Burns and Honkala 1990). White oak (*Quercus alba* L.) retained its status as the overall dominant species, although the relative importance values for this species as well as the white oak species group (*Leucobalanus*) have declined as other tree species are becoming more common (Tables 11, 12, 13, 14). Although the relative importance values of most oak species are declining, the ability of the xerophytic species group to retain high relative importance is due to increases in the importance of hickories (*Carya spp.*), which tend to be more shade tolerant and less fire tolerant than oaks (Burns and Honkala 1990).

Mesophytic species also displayed variability within site location for their relative importance values (Tables 11, 12, 13, 14). The Greater Shawnee Hills had similar mesophytic relative importance values (Table 11), whereas the

Lesser Shawnee Hills (Table 12) and the Cretaceous Hills (Table 13) had large increases in mesophytic presence. Surprisingly, relative importance values of mesophytic tree species actually declined within the Illinois Ozarks ecological subsection (Table 14), although the encroachment of a well developed mesophytic understory (Table 9) will most likely result in increased mesophytic importance within future forests (Fralish et al. 2002). The large influx of mesophytic stems in the smaller diameter classes (Tables 3, 5, 7, 9) was responsible for their high relative trees/ac values, although their presence in the overstory was restricted to degraded stands within the Lesser Shawnee Hills (Table 5) and the historically mesophytic Illinois Ozarks (Tables 9 and 14).

Previously not well represented in oak-hickory uplands, sugar maple (*Acer saccharum* Marsh.) has increased substantially with greater relative importance values throughout the Greater Shawnee Hills, Lesser Shawnee Hills, and the Illinois Ozarks (Tables 11, 12, 13, 14). Being a shade tolerant species (Burns and Honkala 1990, Shotola et al. 1992), sugar maple was found to be thriving underneath dense canopies of mature oak-hickory forest, as well as becoming overstory trees within degraded stands (Tables 3, 5, 9). Tulip-poplar (*Liriodendron tulipifera* L.) was observed growing as an overstory tree within stands that experienced obvious land-use practices such as selective logging and farm abandonment, as well in recently created gaps where light resources were plentiful (Orwig and Abrams 1994) (Tables 3, 5, 7, 9) . Previously possessing the highest mesophytic importance values for the Illinois Ozarks, American beech (*Fagus grandifolia* Ehrh.) declined in importance due to low numbers of overstory stems (Table 14).

Throughout each of the ecological subsections, midstory species increased considerably (Tables 11, 12, 13, 14). Due to their small stature and fire intolerance (Dey and Hartman 2005), their past relative importance values were relatively low although the progressive succession within oak-hickory forests and the absence of fire has allowed species such as eastern hophornbeam (*Ostrya virginiana* Mill.) and flowering dogwood (*Cornus florida* L.) to proliferate. However, flowering dogwood declined within the Greater Shawnee Hills, possibly due to the presence of a devastating fungus (*Discula destructiva* Redlin.) causing dogwood anthracnose to proliferate following fire suppression within fire-prone areas (Holzmueller 2006) (Table 11). These midstory species are providing additional challenges to xerophytic regeneration, as are cable of increasing the amount of shade on the forest floor reducing xerophytic regeneration success (Lorimer et al. 1994).

Future Oak-Hickory Ecosystems and Landscapes

Although xerophytes are the clear dominant in the overstory, their eventual demise is imminent as they continue to age with inevitable losses in vigor and seed-production capabilities (Table 14) (Downs 1944). Adding insult to injury, a strong cohort of regenerating oaks and hickories has yet to be developed to replace the aging overstory (Tables 3, 5, 7, 9). While the average life expectancy of oaks varies, those grown in a wildland setting face numerous challenges to their survival which lowers their life expectancy (Bruhn et al. 2000, Spetich 2004) and their ability to successfully regenerate as they become over mature (Downs 1944). Black oak (*Quercus velutina* Lam.) may be the most threatened, due to the species shorter life span (Burns and Honkala 1990) and vulnerability to pathogens (Bruhn et al. 2000, Spetich 2004). Without the continuation of a local seed source within these stands, it is apparent that the oak-hickory vegetation type is a transitional sere of the forest due to the small amount of surviving stems in the smaller diameter classes and large increases in mesophytic competitors (Weaver and Ashby 1971, Fralish 1991, Zaczek et al. 2002, Groninger et al. 2003, Ozier et al 2006).

Although a dominant oak-hickory overstory presence is widespread within non-degraded stands, their dominance is ephemeral due to their increasing age and declining vigor (Abrams 1996, Bruhn et al.2000, Spetich 2004). Declines in relative importance values can be attributed to the weak numbers of oak-hickory stems in the 1-4" and 4-9" diameter classes, which lowers their values for relative trees/ac (Tables 3, 5, 7, 9). Low numbers of the xerophytic regeneration suggests that present oak-hickory forests are even-aged (Figures 4, 6, 8, and 10), with their future persistence in jeopardy due to a weak regeneration class (Weaver and Ashby 1971, Fralish et al. 1991, Zaczek et al.2002, Aldrich et al. 2005). The absence in advance regeneration of oaks and hickories limits the possibility of retaining oak-hickory dominance within future stands which may lead to negative impacts on the oak-hickory ecosystem (Fralish 2004).

The conversion of a historically dominated oak-hickory forest into a mesophytic forest will lead to dramatic changes within the ecosystem as a whole (Brawn et al. 2001, Rodewald and Abrams 2002, Fralish 2004). Native herbaceous diversity associated with oak-hickory forests will no longer be able to survive underneath dense mesophytic canopies, with negative implications for plant and animal biodiversity (Fralish 2004). The loss of production of hard mast by mature oaks and hickories will also reduce populations of obligate wildlife species (Lacher and Mares 1996, Ostfeld et al. 1996, McShea et al. 2007).

Although stand level reference conditions are unavailable, it is notable that most of the regenerating oak-hickory stems were found growing within small inclusions of early successional habitats. This poses a threat to the current early successional vegetation, which will eventually not be able to persist on these sites due to the sites progressive succession into a closed canopy forest (Anderson et al. 2000, Perkins 2002). Populations of early successional obligate wildlife species are already declining (Thompson and Dessecker 1997), with the additional loss of quality habitat leading to their eventual extirpation (Brawn et al. 2001).

Fire Regime Condition Class Values for Oak-Hickory Uplands

The forest structure parameter ratios outlined in this study (Table 17) can be applied during the data analysis stage following a forest inventory. The ratios serve as estimates of forest structure parameters of FRCC 2 and 3 within oak-hickory upland forests that are to be managed for the sustainability of oak-hickory dominated forests. Therefore these ratios should not be utilized for FRCC determination on sites with different management objectives such as grasslands and mesophytic coves where the regeneration of a dominant oak-hickory component is not desirable. Although numerous ecological dissimilarities exist, the development of similar stand level determination criterion for FRCC values may be created for other fire adapted forest ecosystems.

Fire Regime Condition Class 1

Comparisons of current forest structure with reference conditions suggests that Fire Regime Condition Class values of 1 could not be assigned to any of the sampled oak-hickory uplands of the Shawnee National Forest (Tables 11, 12, 13, 14, 15,16, 18). With the advent of fire suppression and changes in land use practices, serious deviations in the historic disturbance regime have occurred (Parker and Ruffner 2004, Ruffner and Groninger 2006). As a result, key attributes of the vegetation type are no longer intact and functioning within the historic range of variability. Large increases in tree density were observed within each of the ecological subsections (Table 15), an aspect of forest structure that poses significant risks to the sustainability of the key ecosystem components (Schmidt et al. 2002).

Due to the prolonged neglect and a lack of maintenance of oak-hickory uplands of the Shawnee National Forest, management options must be more intensive than an oak-hickory forest reminiscent of Fire Regime Condition Class 1 (Table 18). Although fire use will probably not be detrimental to overstocked oak-hickory forests, fire alone will not restore the ecological integrity of these forests due to the high density of trees able to withstand mild surface fires (Hutchinson et al. 2005, Brose et al. 2006). More rigorous management practices must be employed such as timber harvesting and thinning from below to maintain or restore key ecosystem attributes (Brose et al. 2006).

Fire Regime Condition Class 2

Most of the sampled oak-hickory uplands were congruent with the aspects necessary for Fire Regime Condition Class 2 (Table 18), which have experienced moderate deviations in their disturbance regime and forest structure. Although fire has been excluded from much of the upland oak-hickory communities of the Shawnee National Forest for approximately 70 years (Parker and Ruffner 2004), one can conclude that a moderate risk of losing key ecosystem components exists. A large component of oaks and hickories still dominate the overstory of these upland forests (Tables 3, 5, 7, 9, 17) , complemented with a minor oak-hickory regeneration and xerophytic herb component that proves a viable seed source is still present. Current oak-hickory dominance provides land managers a chance to rely on natural regeneration following prescribed fire treatments (Brose et al. 2006) as well as silvicultural treatments such as shelterwood-burn treatments (Brose et al. 1999) and thinning from below (Carril 2009).

Land managers within oak-hickory forests have experienced mixed results when using prescribed fire alone to reduce tree density and encourage xerophytic regeneration (Iverson et al. 2004, Abrams 2005). The ineffectiveness of prescribed fire to reduce tree density is largely due to the overwhelming presence of mesophytic competitors that have become resistant to low intensity fires (Signell et al. 2005, Carril 2009). Silvicultural treatments such as shelterwood harvests (Brose and Van Lear 1999) and thinning from below (Rebbeck et al. 2004, Carril 2009) have been found to be very effective at stimulating oak regeneration, especially in when used in tandem with prescribed fire.

Fire Regime Condition Class 3

Although the majority of sampled uplands of Shawnee National Forest have experienced moderate deviations in their disturbance regime, numerous uplands have been subjected to severe deviations that are similar to those outlined in Fire Regime Condition Class 3 (Tables 17, 18). Instead of being excluded from fire and beneficial silvicultural practices, many stands throughout southern Illinois have been subjected to disturbances with negative outcomes such as selective timber harvesting (Ozier et al. 2006) and introduced invasive species (Olson et al. 2004). Throughout many upland forests previously dominated by oak-hickory stands, the removal of an oak-hickory overstory results in the subsequent loss of a viable seed source for natural regeneration (Abrams and Nowacki 1992).

The effectiveness of prescribed fire and silvicultural treatments is reduced within in these stands due to the widespread invasion of exotic vegetation and mesophytic species, which alter natural successional trajectories (Abrams 2005, Nowacki and Abrams 2008). Intensive management practices are required to restore key ecosystem attributes, which include artificial regeneration methods and intensive silvicultural treatments (Schmidt et al. 2002). Although restoring these stands seems unfeasible to many, it is important to manage them in an attempt to remove non-native seed resources (Brooks et al. 2004) and restore ecosystem integrity (Thompson and Dessecker 1997, Fralish 2004).

Management Implications

Current resource management objectives of the Shawnee National Forest focus on sustaining ecological and landscape integrity throughout the management boundaries, with a strong emphasis on sustaining oak-hickory forests for the future (USDA 2006). Maintaining oak-hickory forests is dependent on the regeneration of oak-hickory species, which has proven to be unsuccessful within numerous stands that have been excluded from fire and beneficial silvicultural practices (Zaczek et al. 2002, Aldrich et al. 2005, Rentch and Hicks 2005). However, with the majority of the upland forests of the Shawnee National Forest dominated by a mature oak-hickory overstory, the feasibility of stimulating xerophytic regeneration and sustaining oak-hickory ecosystems through active management practices is possible (Brose et al. 1999, Ruffner and Groninger 2005, Brose et al. 2006). Guidance as to what restoration tool to choose is largely dependent on the management objectives, current conditions of forest structure, sustainability of key ecosystem components, and available resources (Schmidt et al. 2002).

Fire Use Applications

Due to the individualistic nature of each upland oak-hickory stand, standard thresholds for determining appropriate fire use practices have not, and probably will never be developed. Consequently, management objectives are largely the most critical governing element of the development of successful and appropriate fire use applications. When stimulating oak regeneration has been a primary management objective, prescribed fire has been widely used as a management tool to achieve objectives although there is much to consider when prescribed fire is being viewed as an appropriate management tool (Brose et al. 2006).

The timing of fire use applications within oak-hickory forests is a crucial for land managers to consider when aiming to achieve management objectives. Within oak-hickory forests of southern Ohio, post fire reductions in floor litter depth and increases in understory light intensity were found to be the most important criteria for successful white oak regeneration, therefore prescribed fires should be conducted following periods of adequate drying of forest fuels and when understory competitors are vulnerable to fire (Hutchinson et al. 2005, Wang et al. 2005). Increasing the chances of oak seedlings to resprout with greater vigor than their competitors following a topkilling prescribed fire has been found to be related to the root collar diameter of oak seedlings, consequently stands with abundant oak seedlings should be allowed to adequately mature prior to prescribed fires (Brose and Van Lear 2004). Oak regeneration may also be optimized when prescribed fires are conducted prior to a heavy acorn crop, since fire has been found to expose mineral soil for acorn germination (Wang et al. 2005).

When prescribed fire is utilized to increase available resources for oak regeneration, success also depends on the ability of the fire to induce mortality of competing mesophytic tree species (Signell et al. 2005, Brose et al. 2006). Dey and Hartman (2005) reported that dormant season prescribed fires in the Ozarks of Missouri can been effective at reducing mesophytic competitors, although mortality was limited to stems less than 7.6 cm in diameter. Prescribed fires conducted during the winter within eastern Kentucky were found to only topkill stems of mesophytic tree species less than 3.8 cm in diameter, suggesting that additional treatments are necessary to reduce mesophytic dominance (Franklin et al. 2003).

Within sites where available resources and policies do not allow for additional silvicultural treatments to be utilized, prescribed fires must be conducted numerous times in order to sufficiently reduce competition from mesophytic tree species (Hutchinson et al. 2005). However burning when oak seedlings have yet to become well developed limits their ability to resprout following fire induced topkilling (Brose and Van Lear 2004), as well as restricts their development into overstory trees (Abrams 1996). Although overstory oaks have many ecophysiological adaptations which increases their chances of surviving fires (Abrams 1996, Smith and Sutherland 1999), repeated prescribed fires may lead to increased cambial damage and eventual stem decline (Burns and Honkala 1990, Brose and Van Lear 1999).

Silvicultural Practices

Since oak-hickory regeneration was found to be sparse throughout the study area, silvicultural practices may be necessary to stimulate oak regeneration. Although prescribed fires may temporarily increase oak regeneration, the ability of oaks to eventually become dominant overstory trees requires more drastic increases in available resources (Brose et al. 2006). Although many silvicultural practices have been attempted to stimulate oak regeneration within oak-hickory uplands of southern Illinois (Nelson et al. 1973, Ozier et al. 2006, Groninger and Long 2008), shelterwood harvests and thinning from below may be the best options to achieve management objectives on a wide variety of site conditions.

Shelterwood harvests can be used successfully as a timber harvesting practice by increasing necessary resources for oak regeneration such as increased light resources reaching the forest floor as well as increasing the vigor of residual overstory oaks which provide acorn production (Loftis 1990). However, shelterwood harvests conducted on productive sites may stimulate populations of mesophytic tree species where post treatment competition controls are not implemented (Brose and Van Lear 1998, Brose and Van Lear 1999). This problem can be solved by conducting prescribed fires within stands that have received shelterwood harvests to improve the competitive status of oak seedlings by reducing mesophytic competition (Brose and Van Lear 1998, Brose and Van Lear 1999). The timing of these post shelterwood prescribed fires should be conducted at least 3-5 years following the initial shelterwood entry to allow for the development of oak seedlings, potentially increasing the chances of oak seedlings to resprout vigorously after being topkilled (Brose et al. 1999).

Thinning from below may be beneficial for the regeneration of oak-hickory ecosystems, although numerous studies suggest that thinning should be practiced in tandem with prescribed fire to increase oak-hickory regeneration (Iverson et al. 2004, Rebbeck et al. 2004). Carril (2009) reported that thinning from below within southern Illinois oak-hickory forests increased available resources necessary for the stimulation of oak seedling growth, however the competitive status of mesophytic tree species was enhanced with the use of prescribed fire following thinning treatments. Stimulating populations of herbaceous species within oak-hickory forests can also be effectively accomplished when both thinning from below and prescribed fires are used to increase available light resources to reach the forest floor (Phillips et al. 2007). The possibility of fire damage to residual overstory trees should also be considered when prescribed fires are implemented following shelterwood harvests (Brose and Van Lear 1999) and thinning treatments (Kolaks et al. 2004) due to increases in fuel loading from these silvicultural practices.

Fuel Loading

Brown's Handbook for Inventorying Downed Woody Material (Brown 1974) has long served as the most popular method of measuring fuel loading within forests however its applicability is questionable for determining fire behavior within oak-hickory forests (Table 18) since fire behavior within undisturbed mature oak-hickory forests is largely regulated by the abundance of flammable leaf litter (Scott and Burgan 2005). Although Brown's method provides accurate estimates of fuel loading (tons/ac) and fuel depth, it does not account for variability within the leaf litter regarding contributions of various tree species. The relationship between the species-specific litter attributes and fire behavior has been documented throughout eastern deciduous forests (Brooks et al. 2004, Ashton et al. 2005, Dibble and Rees 2005, Nowacki and Abrams 2008), therefore this may be an important measurement that should be included in future fuel loading assessments.

CHAPTER 7

CONCLUSION

This study provides an example of how the forest structure of mature oak-hickory uplands of southern Illinois has deviated from reference conditions. Maintaining a dominant oak-hickory component is being jeopardized by numerous threats, with time running out on successful restoration efforts (Abrams 2005, Nowacki and Abrams 2008). Maintaining the ecological integrity of oak-hickory forests is crucial for the ecosystems of the Central Hardwoods Region, and should remain the top priority for resource managers of the Shawnee National Forest.

Stand level FRCC values will be helpful for land managers, as opposed to limiting the scope of the values to the landscape level. Fragmentation and the lack of large contiguous blocks of upland oak-hickory forests within the Shawnee National Forest limit the ability of landscape level data to assess FRCC values within stands and subsequent stand-level management implications. However, management practices applied on a landscape level across stands should still be considered to achieve management objectives.

The diameter distribution of trees found within mature oak-hickory uplands is similar to trends discovered in previous studies (Weaver 1971, Zaczek et al. 2002, Groninger et al. 2003), with oak-hickory stems mostly limited to the larger diameter classes. A strong cohort of young mesophytic stems has become well established underneath the mature oaks, preventing shade intolerant xerophytes from successfully regenerating. Since mature oaks and hickories are reaching the latter stages of maturity while failing to regenerate, utilizing natural regeneration techniques favoring a strong, genetically diverse regeneration class should be stressed (Glaubitz et al. 2004). Due to many challenges facing the management of the Shawnee National Forest, restoration techniques should be employed on a landscape level (Schmidt et al. 2002), with treated areas scattered throughout the Shawnee to maximize the diversity of successional seres.

Sustaining oak-hickory forests through the restoration of the natural disturbance regime is complicated by numerous ecological and social challenges. Management goals may be harder to achieve due to changes in post treatment successional trajectories caused by the presence of invasive species and an overwhelming presence of well developed mesophytes. Limitations imposed on the USDA Forest Service regarding prescribed fire and timber harvesting within the Shawnee National Forest have created management additional challenges, and restrict the ability of the agency to accomplish management goals. The environmentalist movement that began during the latter part of the 20th century which subsequently altered the management policies of the Shawnee National Forest still lives on to this day, creating further roadblocks to accomplishing management objectives. Many studies assessing the effectiveness of restoration treatments within Central Hardwood Forests have proven numerous returns may be necessary to achieve success, therefore restoration efforts must be considered as a long-term process instead of a quick fix. Thus land managers must demonstrate patience when attempting to developing management strategies to ensure that management objectives are achieved.

This study focused on upland forests currently dominated by mature oak-hickory forest cover, neglecting a large portion of forested uplands previously covered by mature oak-hickory stands. Although this study found that mature oak-hickory upland stands have a viable seed source securing a chance for the persistence of the vegetation type, numerous stands exist that have since been converted to pine forests and mesophytic uplands with a large component of invasive exotic vegetation (Olson et al. 2004). Therefore a landscape level Fire Regime Condition Class assessment cannot be derived from this report, subsequently necessitating further assessments of additional forest cover types and landscape level analyses.

Future research into the historical disturbance ecology of the Shawnee National Forest would also greatly enhance our comprehension how historic and current landscapes have developed under variable disturbance regimes. Maintaining adequate records of future disturbances as well as applied management practices will prevent future misunderstandings about the local disturbance history, and provide us with invaluable clues regarding the effects of variable disturbance effects. Continual monitoring and landscape level vegetation surveys are also highly recommended to assess successional trends in both treated and untreated stands.

The reliability of this study is limited due to the small number of mature oak-hickory stands that were visited within the Shawnee National Forest.

Employing variable radius plots using a 10 BAF prism may have underrepresented smaller diameter stems that variable radius plots using a 5 BAF prism or fixed radius plots would have sampled more accurately and would have provided a better representation of the seedling and sapling layer. Stand level vegetation data provided by the USDA Forest Service was not always accurate, suggesting additional forest mensuration is required to generate accurate forest wide mapping and treatment projects. Another possible variable of Fire Regime Condition Class that was not tested during this study was stand acquisition date, which may be an important factor considering the developmental history of the Shawnee National Forest purchase area.

TABLES

Table 1- Stand locations described by latitude and longitude and USDA Forest Service Stand ID numbers for each ecological subsection.

Sampled Stands by Ecological Subsection			
Greater Shawnee Hills			
	Latitude	**Longitude**	**USFS Stand ID #**
Bay Creek	N 37°33'39"	W 88° 37'49"	15009
Williams Hill	N 37°35'57"	W 88° 28'40"	13010
Illinois Ozarks			
	Latitude	**Longitude**	**USFS Stand ID #**
Bean Ridge	N 37°14'34"	W 89° 21'56"	57001
Cripps Bend	N 37°38'02"	W 89° 24'35"	30005
Viney Ridge	N 37°40'57"	W 89° 24'03"	42010
Lesser Shawnee Hills			
	Latitude	**Longitude**	**USFS Stand ID #**
Cache Creek	N 37°29'54"	W 88° 52'04"	88046
Cedar Lake	N 37°37'45"	W 89° 16'55"	50001
Cobden	N 37°32'12"	W 89° 12'25"	57001
Kaskaskia	N 37°29'57"	W 88° 19'06"	51023
Cretaceous Hills			
	Latitude	**Longitude**	**USFS Stand ID #**
Burke Branch	N 37°12'01"	W 88° 32'16"	82008

Table 2- List of reported tree species separated by species groups.

Xerophytic Tree Species		Mesophytic Tree Species	
Scientific Name	**Common Name**	**Scientific Name**	**Common Name**
Carya cordiformis	Bitternut hickory	*Acer saccharum*	Sugar maple
Carya glabra	Pignut hickory	*Acer negundo*	Boxelder
Carya ovata	Shagbark hickory	*Acer rubrum*	Red maple
Carya texana	Black hickory	*Celtis occidentalis*	Hackberry
Carya tomentosa	Mockernut hickory	*Fagus grandifolia*	American beech
Quercus alba	White oak	*Fraxinus americana*	White ash
Quercus coccinea	Scarlet oak	*Fraxinus pennsylvanica*	Green ash
Quercus falcata	Southern red oak	*Juglans nigra*	Black walnut
Quercus imbricaria	Shingle oak	*Liquidambar styraciflua*	Sweetgum
Quercus marilandica	Blackjack oak	*Liriodendron tulipifera*	Tulip poplar
Quercus muhlenbergii	Chinkapin oak	*Nyssa sylvatica*	Black tupelo
Quercus pagoda	Cherrybark oak	*Prunus serotina*	Black cherry
Quercus rubra	Northern red oak	*Sassafras albidum*	Sassafras
Quercus stellata	Post oak	*Ulmus americana*	American elm
Quercus velutina	Black oak	*Ulmus rubra*	Slippery elm
Midcanopy Tree Species			
Scientific Name	**Common Name**		
Amelanchier arborea	Serviceberry		
Cornus florida	Flowering dogwood		
Diospyros virginiana	Persimmon		
Gleditsia triancanthos	Honey locust		
Juniperus virginiana	Eastern redcedar		
Morus rubra	Red mulberry		
Ostrya virginiana	Eastern hophornbeam		

Table 3- Stand table displaying trees/ac by diameter size class (1-4”, 4-9”, 9-16”, 16-25”, 25-30”) for dominant species of each species group for the Greater Shawnee Hills ecological subsection.

Greater Shawnee Hills						
Trees/ac						
Xerophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-30"**	**TOTAL**
Quercus alba	19.3	10.8	18.3	7.7	0.3	**56.4**
Carya glabra	6.0	13.9	14.0	2.0	0.0	**35.8**
Quercus velutina	6.7	3.5	3.0	3.5	0.2	**17.0**
Quercus stellata	0.0	0.0	6.2	0.4	0.0	**6.6**
Carya ovata	0.0	3.5	1.2	0.2	0.0	**4.9**
Other *Quercus spp.*	0.0	0.7	2.1	1.5	0.1	**4.4**
Other *Carya spp.*	0.0	0.0	0.0	0.3	0.0	**0.3**
SUBTOTAL	**32.0**	**32.3**	**44.9**	**15.4**	**0.6**	**125.3**
Mesophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-30"**	**TOTAL**
Nyssa sylvatica	17.1	0.8	0.0	0.0	0.1	**18.0**
Acer saccharum	9.4	7.1	1.0	0.0	0.0	**17.4**
Acer rubrum	9.0	0.0	0.0	0.0	0.0	**9.0**
Sassafras albidum	3.4	2.6	1.4	0.0	0.0	**7.3**
Liriodendron tulipifera	0.0	0.7	1.0	0.2	0.0	**1.9**
Other Mesophytes	0.0	2.7	0.2	0.1	0.0	**3.1**
SUBTOTAL	**38.8**	**13.9**	**3.6**	**0.3**	**0.1**	**56.8**
Midcanopy Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-30"**	**TOTAL**
Ostrya virginiana	25.5	3.2	0.0	0.0	0.0	**28.6**
Cornus florida	3.4	2.8	0.0	0.0	0.0	**6.2**
Ulmus alata	0.0	2.3	0.0	0.0	0.0	**2.3**
Other Midcanopy	0.0	0.0	0.0	0.0	0.0	**0.0**
SUBTOTAL	**28.8**	**8.3**	**0.0**	**0.0**	**0.0**	**93.9**
TOTAL	**99.7**	**54.5**	**48.5**	**15.7**	**0.7**	**219.2**

Table 4- Stand table displaying basal area/ac (ft^2 BA/ac) by diameter size class (1-4", 4-9", 9-16", 16-25", 25-30") for dominant species of each species group for the Greater Shawnee Hills ecological subsection.

Greater Shawnee Hills						
Basal Area/ac						
Xerophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-30"**	**TOTAL**
Quercus alba	1.2	3.3	17.1	15.7	0.6	**37.8**
Carya glabra	0.3	3.0	11.2	3.6	0.0	**18.1**
Quercus velutina	0.6	0.3	2.9	6.8	0.9	**11.5**
Quercus stellata	0.0	0.0	5.4	0.8	0.0	**6.1**
Quercus coccinea	0.0	0.3	1.7	2.1	0.5	**4.6**
Other *Quercus spp.*	0.0	0.0	1.3	1.1	0.0	**2.4**
Other *Carya spp.*	0.0	0.6	0.9	0.9	0.0	**2.4**
SUBTOTAL	**2.1**	**7.5**	**40.4**	**30.9**	**2.0**	**82.9**
Mesophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-30"**	**TOTAL**
Sassafras albidum	0.3	1.4	1.2	1.0	0.0	**3.9**
Prunus serotina	0.0	0.5	0.0	0.0	3.0	**3.5**
Acer saccharum	0.6	1.4	0.9	0.0	0.0	**2.9**
Liriodendron tulipifera	0.0	0.5	0.8	0.6	0.0	**1.9**
Nyssa sylvatica	0.8	0.3	0.0	0.0	0.5	**1.6**
Other Mesophytes	0.5	0.3	0.3	0.3	0.0	**1.4**
SUBTOTAL	**2.2**	**4.4**	**3.1**	**1.9**	**3.5**	**15.1**
Midcanopy Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-30"**	**TOTAL**
Ostrya virginiana	0.5	0.5	0.0	0.0	0.0	**1.0**
Ulmus alata	0.0	0.5	0.0	0.0	0.0	**0.5**
Cornus florida	0.3	0.0	0.0	0.0	0.0	**0.3**
Other Midcanopy	0.0	0.0	0.0	0.0	0.0	**0.0**
SUBTOTAL	**0.8**	**1.0**	**0.0**	**0.0**	**0.0**	**1.8**
TOTAL	**5.1**	**12.9**	**43.5**	**32.8**	**5.5**	**99.8**

Table 5- Stand table displaying trees/ac by diameter size class (1-4”, 4-9”, 9-16”, 16-25”, 25-35”) for dominant species of each species group for the Lesser Shawnee Hills ecological subsection.

Lesser Shawnee Hills						
Trees/ac						
Xerophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-35"**	**TOTAL**
Quercus alba	0.0	12.4	15.3	9.6	0.5	**37.7**
Carya glabra	2.8	3.3	6.1	1.6	0.0	**13.8**
Carya ovata	7.6	0.0	1.7	0.3	0.0	**9.7**
Quercus stellata	0.0	1.7	5.8	0.6	0.0	**8.1**
Quercus velutina	0.0	1.8	2.9	3.1	0.2	**8.0**
Other *Quercus spp.*	0.0	2.3	3.6	1.8	0.2	**8.0**
Other *Carya spp.*	0.0	0.0	1.1	0.5	0.0	**1.7**
SUBTOTAL	**10.5**	**21.5**	**36.5**	**17.6**	**0.9**	**87.0**
Mesophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-35"**	**TOTAL**
Acer saccharum	24.7	17.4	3.4	0.7	0.0	**46.1**
Sassafras albidum	6.9	3.2	0.6	0.0	0.0	**10.6**
Liriodendron tulipifera	0.0	4.4	3.1	1.6	0.2	**9.4**
Ulmus americana	2.8	5.8	0.3	0.0	0.0	**8.9**
Acer rubrum	7.2	0.4	0.0	0.0	0.0	**7.6**
Other Mesophytes	0.0	7.4	2.1	0.8	0.1	**10.4**
SUBTOTAL	**41.5**	**38.6**	**9.5**	**3.2**	**0.3**	**93.1**
Midcanopy Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-35"**	**TOTAL**
Cornus florida	16.2	1.5	0.0	0.0	0.0	**17.7**
Ostrya virginiana	14.4	0.8	0.0	0.0	0.0	**15.2**
Ulmus alata	2.8	5.8	0.3	0.0	0.0	**8.9**
Other Midcanopy	3.7	4.2	1.5	0.1	0.0	**9.4**
SUBTOTAL	**37.1**	**12.3**	**1.8**	**0.1**	**0.0**	**51.2**
TOTAL	**89.1**	**72.4**	**47.8**	**20.8**	**1.2**	**231.3**

Table 6- Stand table displaying basal area/ac (ft^2 BA/ac) by diameter size class (1-4”, 4-9”, 9-16”, 16-25”, 25-35”) for dominant species of each species group for the Lesser Shawnee Hills ecological subsection.

Lesser Shawnee Hills						
Basal Area/ac						
Xerophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-35"**	**TOTAL**
Quercus alba	0.0	2.9	8.7	15.6	1.3	**28.5**
Quercus velutina	0.0	0.8	2.8	6.6	0.8	**11.0**
Carya glabra	0.1	0.9	5.7	3.4	0.0	**10.2**
Quercus stellata	0.0	0.6	4.7	1.3	0.0	**6.7**
Quercus coccinea	0.0	0.8	1.9	1.5	0.1	**4.4**
Other *Quercus spp.*	0.0	0.1	1.3	2.0	0.7	**4.2**
Other *Carya spp.*	0.2	0.1	2.3	1.7	0.2	**4.4**
SUBTOTAL	**0.3**	**6.3**	**27.4**	**32.2**	**3.1**	69.3
Mesophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-35"**	**TOTAL**
Prunus serotina	0.0	1.0	4.7	4.5	0.6	**10.7**
Acer saccharum	1.3	3.7	2.8	1.6	0.0	**9.4**
Liriodendron tulipifera	0.0	1.2	2.7	3.6	0.9	**8.5**
Sassafras albidum	0.6	0.9	0.5	0.0	0.0	**2.0**
Fraxinus americana	0.0	0.9	0.3	0.6	0.2	**2.0**
Other Mesophytes	0.5	0.9	1.7	1.1	0.1	**4.2**
SUBTOTAL	**2.4**	**8.7**	**12.6**	**11.3**	**1.8**	36.7
Midcanopy Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-35"**	**TOTAL**
Juniperus virginiana	0.3	1.0	0.8	0.1	0.0	**2.2**
Ulmus alata	0.1	1.4	0.1	0.0	0.0	**1.6**
Cornus florida	0.5	0.3	0.0	0.0	0.0	**0.8**
Other Midcanopy	0.5	0.4	0.0	0.0	0.0	**0.9**
SUBTOTAL	**1.3**	**3.1**	**1.0**	**0.1**	**0.0**	5.5
TOTAL	4.0	18.0	40.9	43.7	4.9	111.6

Table 7- Stand table displaying trees/ac by diameter size class (1-4", 4-9", 9-16", 16-25", 25-45") for dominant species of each species group for the Cretaceous Hills ecological subsection.

Cretaceous Hills						
Trees/ac						
Xerophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-45"**	**TOTAL**
Quercus alba	17.7	10.9	5.6	10.1	3.1	**47.4**
Carya ovata	11.3	5.7	0.0	0.0	0.0	**17.0**
Quercus velutina	0.0	0.0	8.6	6.9	1.0	**16.5**
Quercus stellata	0.0	1.3	1.5	0.8	0.0	**3.5**
Quercus falcata	0.0	0.0	1.7	1.5	0.0	**3.2**
Other *Quercus spp.*	0.0	0.0	1.0	2.5	0.6	**4.1**
Other *Carya spp.*	0.0	0.0	1.6	1.8	0.3	**3.6**
SUBTOTAL	**29.0**	**17.9**	**19.8**	**23.6**	**5.0**	**95.3**
Mesophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-45"**	**TOTAL**
Sassafras albidum	36.8	7.7	0.0	0.0	0.0	**44.5**
Acer rubrum	25.5	1.3	2.3	0.0	0.0	**29.0**
Liriodendron tulipifera	25.5	2.1	1.1	0.2	0.0	**28.8**
Nyssa sylvatica	0.0	9.0	0.8	0.0	0.0	**9.8**
Acer saccharum	0.0	5.7	0.0	0.0	0.0	**5.7**
Other Mesophytes	0.0	1.3	0.5	0.2	0.0	**1.9**
SUBTOTAL	**87.7**	**27.0**	**4.5**	**0.4**	**0.0**	**119.7**
Midcanopy Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-45"**	**TOTAL**
Cornus florida	12.7	4.2	0.0	0.0	0.0	**16.9**
Ulmus alata	0.0	6.2	0.0	0.0	0.0	**6.2**
Other Midcanopy	0.0	0.0	0.0	0.0	0.0	**0.0**
SUBTOTAL	**12.7**	**10.3**	**0.0**	**0.0**	**0.0**	**23.0**
TOTAL	**129.4**	**55.2**	**24.4**	**24.0**	**5.0**	**238.0**

Table 8- Stand table displaying basal area/ac (ft^2 BA/ac) by diameter size class (1-4", 4-9", 9-16", 16-25", 25-45") for dominant species of each species group for the Cretaceous Hills ecological subsection.

Cretaceous Hills						
Basal Area/ac						
Xerophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-45"**	**TOTAL**
Quercus alba	1.1	2.8	5.6	22.8	13.9	**46.1**
Quercus velutina	0.0	0.0	8.9	14.4	4.4	**27.8**
Quercus coccinea	0.0	0.0	0.6	3.3	2.2	**6.1**
Quercus falcata	0.0	0.0	1.7	2.8	0.0	**4.4**
Quercus stellata	0.0	0.6	1.7	1.7	0.0	**3.9**
Other *Quercus spp.*	0.0	0.0	0.6	2.8	0.6	**3.9**
Other *Carya spp.*	0.6	1.1	1.7	3.3	1.1	**7.8**
SUBTOTAL	**1.7**	**4.4**	**20.6**	**51.1**	**22.2**	**100.0**
Mesophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-45"**	**TOTAL**
Liriodendron tulipifera	0.6	0.3	0.1	1.8	4.1	**7.0**
Acer rubrum	0.6	0.6	2.2	0.0	0.0	**3.3**
Nyssa sylvatica	0.0	2.2	0.6	0.0	0.0	**2.8**
Sassafras albidum	1.1	1.7	0.0	0.0	0.0	**2.8**
Acer saccharum	0.0	1.1	0.0	0.0	0.0	**1.1**
Other Mesophytes	0.0	0.6	0.6	0.6	0.0	**1.7**
SUBTOTAL	**2.3**	**6.4**	**3.5**	**2.4**	**4.1**	**18.7**
Midcanopy Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-45"**	**TOTAL**
Cornus florida	1.1	1.1	0.0	0.0	0.0	**2.2**
Ulmus alata	0.0	1.1	0.0	0.0	0.0	**1.1**
Other Midcanopy	0.0	0.0	0.0	0.0	0.0	**0.0**
SUBTOTAL	1.1	2.2	0.0	0.0	0.0	**3.3**
TOTAL	**5.1**	**13.1**	**24.0**	**53.5**	**26.4**	**122.0**

Table 9- Stand table displaying trees/ac by diameter size class (1-4”, 4-9”, 9-16”, 16-25”, 25-45”) for dominant species of each species group for the Illinois Ozarks ecological subsection.

Illinois Ozarks						
Trees/ac						
Xerophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-45"**	**TOTAL**
Quercus alba	3.6	4.6	11.9	18.5	1.6	**40.1**
Carya glabra	2.0	7.4	4.2	0.8	0.0	**14.5**
Quercus velutina	0.0	1.0	5.4	4.1	0.6	**11.1**
Carya ovata	2.6	2.4	0.6	0.1	0.0	**5.7**
Quercus rubra	0.0	0.4	0.7	1.1	0.4	**2.6**
Other *Quercus spp.*	0.0	0.6	2.2	0.7	0.1	**3.6**
Other *Carya spp.*	0.0	1.5	0.7	0.2	0.0	**2.5**
SUBTOTAL	**8.2**	**17.9**	**25.8**	**25.5**	**2.7**	**80.1**
Mesophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-45"**	**TOTAL**
Acer saccharum	28.1	17.8	4.5	0.4	0.0	**50.9**
Fagus grandifolia	30.5	3.0	0.0	0.3	0.1	**33.9**
Sassafras albidum	20.0	7.1	2.0	0.0	0.0	**29.2**
Fraxinus americana	3.6	0.4	1.4	0.4	0.1	**5.9**
Liriodendron tulipifera	0.0	0.6	1.7	2.0	0.5	**4.8**
Other Mesophytes	2.0	2.5	1.6	0.8	0.1	**7.0**
SUBTOTAL	**84.2**	**31.5**	**11.2**	**3.9**	**0.9**	**131.6**
Midcanopy Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-45"**	**TOTAL**
Ulmus alata	14.3	2.3	0.0	0.0	0.0	**16.6**
Amelanchier arborea	10.1	0.0	0.0	0.0	0.0	**10.1**
Cornus florida	8.6	3.6	0.0	0.0	0.0	**12.3**
Other Midcanopy	8.0	0.0	0.2	0.0	0.0	**8.3**
SUBTOTAL	**41.0**	**6.0**	**0.2**	**0.0**	**0.0**	**47.2**
TOTAL	**133.5**	**55.3**	**37.3**	**29.4**	**3.6**	**259.0**

Table 10- Stand table displaying basal area/ac (ft^2 BA/ac) by diameter size class (1-4", 4-9", 9-16", 16-25", 25-45") for dominant species of each species group for the Illinois Ozarks ecological subsection.

Illinois Ozarks						
Basal Area/ac						
Xerophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-45"**	**TOTAL**
Quercus alba	0.2	1.8	8.6	20.0	3.8	**34.4**
Quercus velutina	0.0	0.4	5.5	8.7	2.5	**17.1**
Carya glabra	0.2	2.0	5.2	5.2	0.0	**12.5**
Quercus rubra	0.0	0.2	0.7	2.6	2.0	**5.5**
Carya ovata	0.2	0.5	0.7	0.6	0.2	**2.3**
Other *Quercus spp.*	0.0	0.2	2.0	1.4	0.6	**4.2**
Other *Carya spp.*	0.0	0.2	0.4	0.0	0.0	**0.6**
SUBTOTAL	**0.5**	**5.2**	**23.2**	**38.5**	**9.1**	76.6
Mesophytic Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-45"**	**TOTAL**
Acer saccharum	1.6	5.0	3.1	1.0	0.0	**10.7**
Liriodendron tulipifera	0.0	0.2	1.6	4.8	2.5	**9.0**
Sassafras albidum	0.9	1.7	1.2	0.0	0.0	**3.8**
Fraxinus americana	0.2	0.2	1.2	0.8	0.6	**3.0**
Fagus grandifolia	0.8	0.6	0.0	0.6	0.8	**2.8**
Other Mesophytes	0.2	0.6	1.8	1.8	0.2	**4.6**
SUBTOTAL	**3.7**	**8.3**	**8.9**	**9.0**	**4.0**	33.9
Midcanopy Species	**1-4"**	**4-9"**	**9-16"**	**16-25"**	**25-45"**	**TOTAL**
Cornus florida	0.6	0.6	0.0	0.0	0.0	**1.2**
Ulmus alata	0.2	0.4	0.0	0.0	0.0	**0.6**
Amelanchier arborea	0.4	0.2	0.0	0.0	0.0	**0.5**
Other Midcanopy	0.2	0.0	0.2	0.0	0.0	**0.4**
SUBTOTAL	**1.3**	**1.2**	**0.2**	**0.0**	**0.0**	2.7
TOTAL	5.5	14.7	32.3	47.4	13.1	113.1

Table 11- Table comparing reference conditions (1806-1810) (Fralish et al. 2002) with current (2006) relative importance values (IV) for species groups and individual species within the Greater Shawnee Hills ecological subsection.

Reference Conditions		**Current Conditions**	
Greater Shawnee Hills		**Greater Shawnee Hills**	
Xerophytic Species	**IV**	**Xerophytic Species**	**IV**
Quercus alba	45.5	*Quercus alba*	33.5
Quercus velutina	16.8	*Carya Spp.*	20.1
Carya Spp.	7.8	*Quercus velutina*	10.1
Quercus rubra	2.8	*Quercus stellata*	4.8
Other *Quercus spp.*	1.7	Other *Quercus spp.*	4.4
SUBTOTAL	**74.6**	**SUBTOTAL**	**72.9**
Mesophytic Species	**IV**	**Mesophytic Species**	**IV**
Fraxinus spp.	4.1	*Acer saccharum*	5.1
Ulmus spp.	4.2	*Nyssa sylvatica*	4.6
Liriodendron tulipifera	2.7	*Sassafras albidum*	2.7
Nyssa sylvatica	2.0	*Acer rubrum*	2.4
Acer saccharum	1.9	*Liriodendron tulipifera*	1.2
Other Mesophytes	4.4	Other Mesophytes	1.3
SUBTOTAL	**19.3**	**SUBTOTAL**	**17.5**
Midcanopy Species	**IV**	**Midcanopy Species**	**IV**
Cornus spp.	4.3	*Ostrya virginiana*	7.2
Morus rubra	0.7	*Cornus florida*	1.7
Gleditsia triacanthos	0.4	*Ulmus alata*	0.7
Other Midcanopy	0.4	Other Midcanopy	0.0
SUBTOTAL	**5.9**	**SUBTOTAL**	**9.7**

Table 12- Table comparing reference conditions (1806-1810) (Fralish et al. 2002) with current (2006) relative importance values (IV) for species groups and individual species within the Lesser Shawnee Hills ecological subsection.

Reference Conditions		Current Conditions	
Lesser Shawnee Hills		**Lesser Shawnee Hills**	
Xerophytic Species	**IV**	**Xerophytic Species**	**IV**
Quercus alba	45.6	*Quercus alba*	25.8
Quercus velutina	19.2	*Carya spp.*	12.3
Carya spp.	6.1	*Quercus velutina*	6.8
Quercus rubra	3.2	*Quercus stellata*	4.9
Quercus stellata	1.6	*Quercus coccinea*	3.4
Other *Quercus spp.*	0.6	Other *Quercus spp.*	2.5
SUBTOTAL	**76.3**	**SUBTOTAL**	**55.7**
Mesophytic Species	**IV**	**Mesophytic Species**	**IV**
Liriodendron tulipifera	3.7	*Acer saccharum*	13.9
Fraxinus spp.	2.6	*Liriodendron tulipifera*	5.8
Ulmus spp.	2.2	*Sassafras albidum*	3.6
Nyssa sylvatica	2.1	*Acer rubrum*	2.1
Acer saccharum	1.9	*Fraxinus americana*	2.0
Other Mesophytes	3.1	Other Mesophytes	3.2
SUBTOTAL	**15.6**	**SUBTOTAL**	**30.6**
Midcanopy Species	**IV**	**Midcanopy Species**	**IV**
Cornus florida	3.7	*Cornus florida*	4.8
Morus rubra	0.5	*Ostrya virginiana*	3.5
Ostrya virginiana	0.2	*Ulmus alata*	2.6
Other Midcanopy	0.3	Other Midcanopy	2.7
SUBTOTAL	**4.7**	**SUBTOTAL**	**13.7**

Table 13- Table comparing reference conditions (1806-1810) (Fralish et al. 2002) with current (2006) relative importance values (IV) for species groups and individual species within the Cretaceous Hills ecological subsection.

Reference Conditions		**Current Conditions**	
Cretaceous Hills		**Cretaceous Hills**	
Xerophytic Species	**IV**	**Xerophytic Species**	**IV**
Quercus alba	49.8	*Quercus alba*	29.5
Quercus velutina	28.3	*Quercus velutina*	15.3
Carya spp.	5.9	*Carya spp.*	7.6
Quercus falcata	1.1	*Quercus coccinea*	3.1
Quercus marilandica	0.7	*Quercus falcata*	2.6
Other *Quercus spp.*	0.7	Other *Quercus spp.*	4.4
SUBTOTAL	**86.6**	**SUBTOTAL**	**62.5**
Mesophytic Species	**IV**	**Mesophytic Species**	**IV**
Liquidambar styraciflua	2.1	*Sassafras albidum*	10.5
Nyssa sylvatica	2.0	*Acer rubrum*	7.5
Acer spp.	1.6	*Liriodendron tulipifera*	7.2
Liriodendron tulipifera	1.4	*Nyssa sylvatica*	3.2
Ulmus spp.	1.0	*Acer saccharum*	1.7
Other Mesophytes	1.3	Other Mesophytes	1.1
SUBTOTAL	**9.4**	**SUBTOTAL**	**31.3**
Midcanopy Species	**IV**	**Midcanopy Species**	**IV**
Cornus florida	1.4	*Cornus florida*	4.5
Morus rubra	0.3	*Ulmus alata*	1.8
Other Midcanopy	0.0	Other Midcanopy	0.0
SUBTOTAL	**1.7**	**SUBTOTAL**	**6.3**

Table 14- Table comparing reference conditions (1806-1810) (Fralish et al. 2002) with current (2006) relative importance values (IV) for species groups and individual species within the Illinois Ozarks ecological subsection.

Reference Conditions		**Current Conditions**	
Illinois Ozarks		**Illinois Ozarks**	
Xerophytic Species	**IV**	**Xerophytic Species**	**IV**
Quercus alba	26.4	*Quercus alba*	21.2
Quercus velutina	9.5	*Carya spp.*	11.8
Carya spp.	7.3	*Quercus velutina*	9.8
Quercus rubra	3.5	*Quercus rubra*	2.9
Quercus falcata	0.7	*Quercus stellata*	1.2
Other *Quercus spp.*	0.2	Other *Quercus spp.*	1.2
SUBTOTAL	**47.6**	**SUBTOTAL**	**48.1**
Mesophytic Species	**IV**	**Mesophytic Species**	**IV**
Fagus grandifolia	25.8	*Acer saccharum*	15.8
Liquidambar styraciflua	6.6	*Fagus grandifolia*	8.3
Liriodendron tulipifera	5.6	*Sassafras albidum*	7.3
Acer saccharum	3.6	*Liriodendron tulipifera*	5.7
Fraxinus spp.	3.5	*Fraxinus americana*	2.2
Other Mesophytes	5.2	Other Mesophytes	3.8
SUBTOTAL	**50.2**	**SUBTOTAL**	**43.3**
Midcanopy Species	***IV***	***Midcanopy Species***	***IV***
Cornus florida	1.3	*Cornus florida*	3.7
Ostrya virginiana	0.6	*Ulmus alata*	2.3
Morus rubra	0.2	*Amelanchier arborea*	1.5
Other Midcanopy	0.1	Other Midcanopy	1.1
SUBTOTAL	**2.2**	**SUBTOTAL**	**8.5**

Table 15- Comparison of tree density for each ecological subsection described in reference conditions (Ref. Cond.) (Fralish et al. 2002) and representative project data for trees/ac (mean ± SE) for each ecological subsection and site with corresponding n, df, F, and p values for one-way ANOVA tests.

			Ref. Cond.	Project Data			
Ecological Subsection	Site	n	Trees/ac	Trees/ac	df	F	P
Greater Shawnee Hills		33	78	216.41 ± 33.91	1	16.7	0.0001
	Bay Creek	16	-	209.07 ± 52.52	-	-	-
	Williams Hill	17	-	223.32 ± 45.00	-	-	-
Lesser Shawnee Hills		66	52	215.00 ± 19.19	1	72.2	<0.0001
	Cache Creek	18	-	298.75 ± 46.06	-	-	-
	Cedar Lake	15	-	196.13 ± 37.89	-	-	-
	Cobden	16	-	177.85 ± 27.59	-	-	-
	Kaskaskia	17	-	177.96 ± 31.46	-	-	-
Cretaceous Hills		18	16	237.99 ± 60.64	1	13.4	0.0008
	Burke Branch	18	-	237.99 ± 60.65	-	-	-
Illinois Ozarks		52	87	263.30 ± 37.59	1	22	<0.0001
	Bean Ridge	19	-	452.21 ± 80.92	-	-	-
	Cripps Bend	17	-	129.19 ± 17.59	-	-	-
	Viney Ridge	16	-	181.47 ± 37.24	-	-	-
Project Total		169	-	214.72 ± 16.52	-	-	-

Table 16- Comparison of basal area/ac for each ecological subsection described in reference conditions (Ref. Cond.) (Fralish et al. 2002) and representative project data for trees/ac (mean ± SE) for each ecological subsection and site with corresponding n, df, F, and p values for one-way ANOVA tests.

			Ref. Cond.	Project Data			
Ecological Subsection	Site	n	Basal Area/ac	Basal Area/ac	df	F	P
Greater Shawnee Hills		33	105	91.52 ± 3.54	1	14.52	0.0003
	Bay Creek	16	-	86.88 ± 5.38	-	-	-
	Williams Hill	17	-	95.88 ± 4.54	-	-	-
Lesser Shawnee Hills		66	73	104.55 ± 3.52	1	80.49	<0.0001
	Cache Creek	18	-	92.78 ± 7.53	-	-	-
	Cedar Lake	15	-	103.33 ± 7.73	-	-	-
	Cobden	16	-	106.88 ± 6.75	-	-	-
	Kaskaskia	17	-	115.88 ± 5.22	-	-	-
Cretaceous Hills		18	14	113.33 ± 9.28	1	117.03	<0.0001
	Burke Branch	18	-	113.33 ± 9.28	-	-	-
Illinois Ozarks		52	120	105.96 ± 3.58	1	15.35	0.0002
	Bean Ridge	19	-	115.26 ± 6.77	-	-	-
	Cripps Bend	17	-	100.00 ± 5.14	-	-	-
	Viney Ridge	16	-	101.25 ± 5.98	-	-	-
Project Total		169	-	103.37 ± 2.16	-	-	-

Table 17- Forest structure parameter ratios (mean ± SE) comparing density (TPA) and dominance (BA) of *Quercus* spp. : mesophytics and xerophytics : mesophytics and fuel loading (tons/ac) (mean ± SE) for plots classified as FRCC 2 and 3. Ratios and fuel loading were analyzed on a plot level basis with FRCC as a fixed variable.

Forest Structure Parameter Ratio	FRCC 2	FRCC 3	df	F	P
Quercus spp./Mesophytic spp. TPA	43.65 ± 5.33	5.12 ± 1.88	1	35.09	<0.0001
Quercus spp./Mesophytic spp. BA	11.03 ± 0.54	4.74 ± 0.53	1	55.26	<0.0001
Xerophytic spp./Mesophytic spp. TPA	62.04 ± 7.75	5.93 ± 1.98	1	35.09	<0.0001
Xerophytic spp./Mesophytic spp. BA	12.25 ± 0.55	5.72 ± 0.53	1	43.76	<0.0001
Fuel Loading	**FRCC 2**	**FRCC 3**	**df**	**F**	**P**
Tons/ac	6.19 ± 0.68	7.61 ± 0.90	1	1.12	0.2929

Table 18- Fire Regime Condition Class guidelines as described by Schmidt et al. 2002.

Fire Regime Condition Class Guidelines
Fire Regime Condition Class 1 (FRCC 1)
Description
Fires are within the historic range of variability, and the risk of losing key ecosystem components are low.
Vegetation attributes (species composition and structure) are intact and functioning within the historic range of variability.
Appropriate Management Response
Where appropriate, these areas can be maintained with the historic fire regime by treatments such as fire use.
Fire Regime Condition Class 2 (FRCC 2)
Description
Fire regimes have been moderately altered from their historic range of variability.
The risk of losing key ecosystem components is moderate.
Fire frequencies have departed from their historic frequencies by one or more intervals (either increased or decreased).
This results in moderate changes to one or more of the following: fire size, intensity and severity, and landscape patterns.
Vegetation attributes have been moderately altered from their historic range of variability.
Appropriate Management Response
Where appropriate, these areas may need moderate levels of restoration treatments to restore the historic fire regime.
Appropriate treatment options include fire use and hand or mechanical treatments.
Fire Regime Condition Class 3 (FRCC 3)
Description
Fire regimes have been significantly altered from their historic range of variability.
The risk of losing key ecosystem components is high.
Fire frequencies have departed from their historic frequencies by multiple return intervals (either increased or decreased).
This results in a dramatic change to one or more of the following: fire size, intensity and severity, and landscape patterns.
Vegetation attributes have been significantly altered from their historic range of variability.
Appropriate Management Response
Where appropriate, these areas may need high levels of restoration treatments such as hand or mechanical thinning.
Restoration treatments may need to take place before fire is used to restore the historic fire regime.

FIGURES

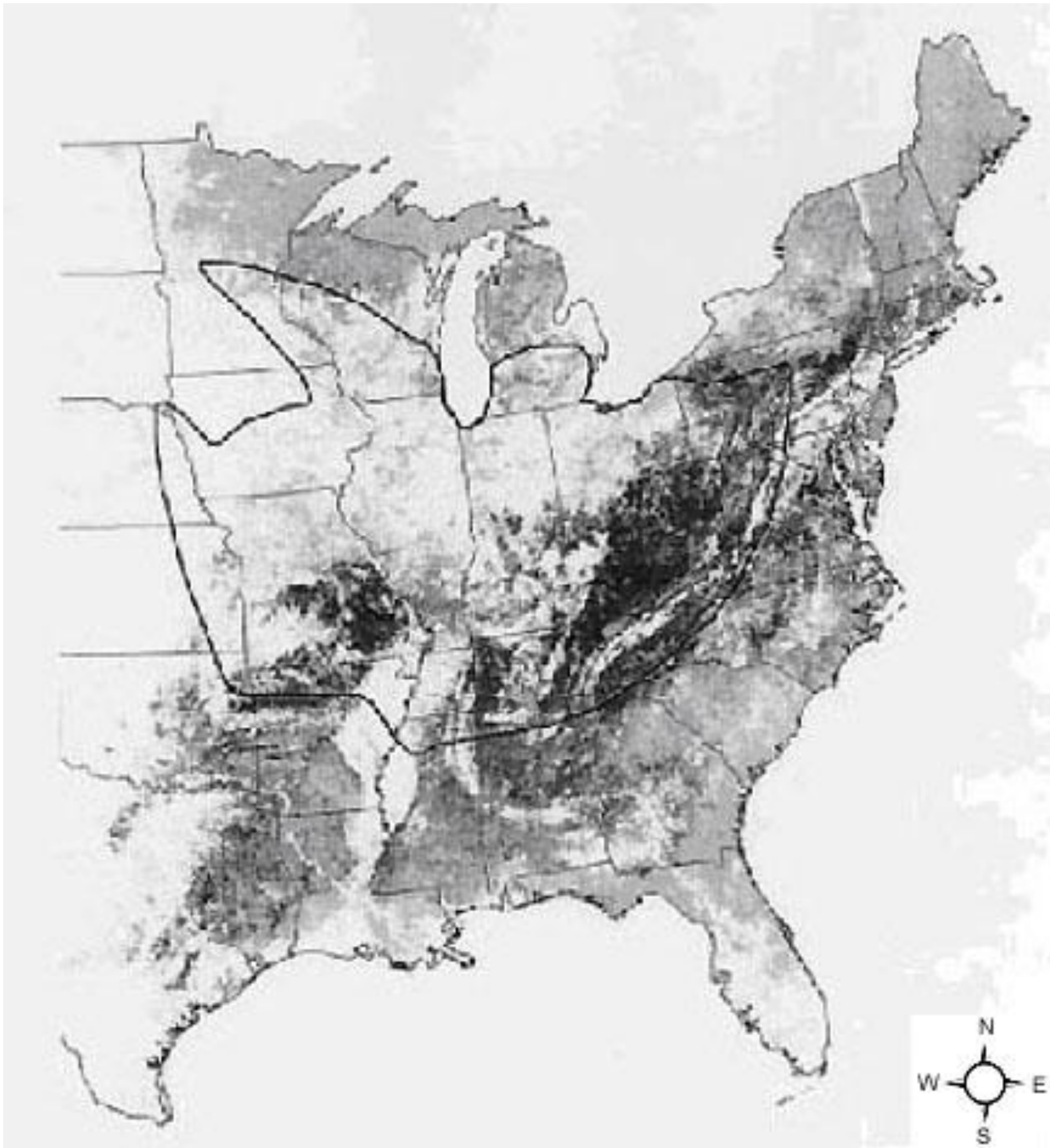


Figure 1- Location of Central Hardwoods Forest Region (outlined in black) as described in text (Thompson and Dessecker 1997).

Figure 2- Map of the state of Illinois with the Shawnee National Forest Purchase Unit (shaded green) (USDA 2009).

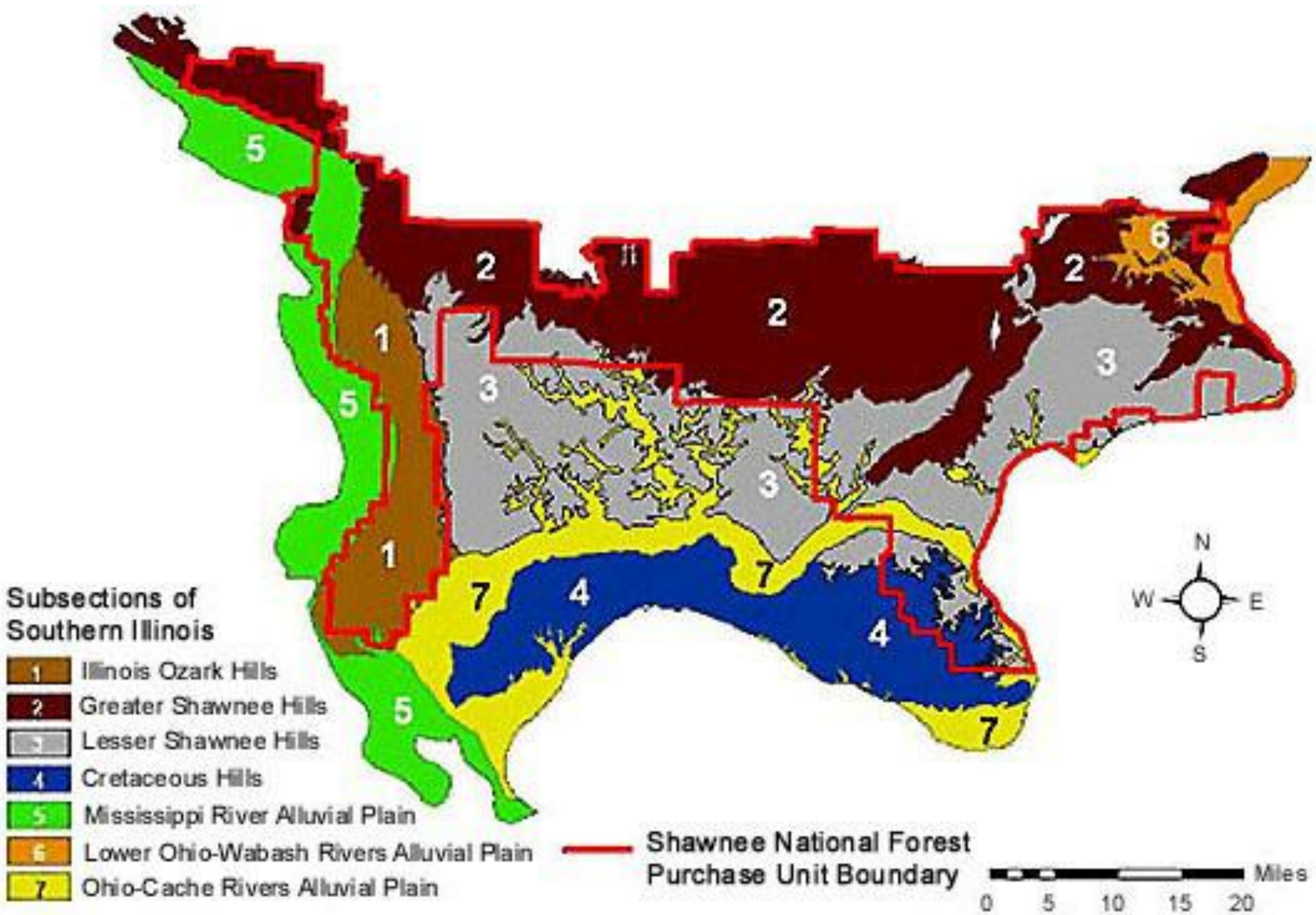


Figure 3- Ecological subsections of southern Illinois described in text (Fralish et al. 2002).

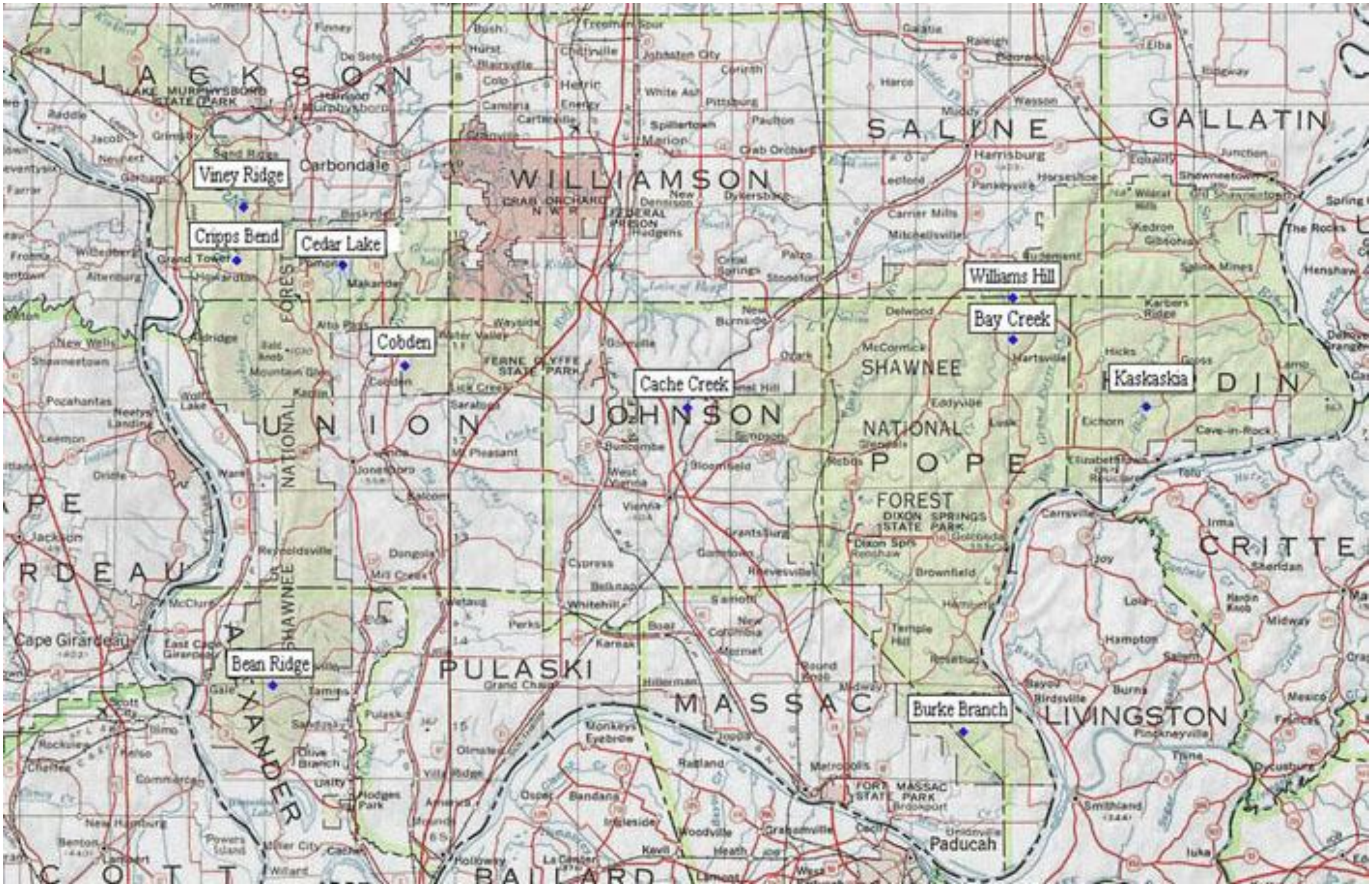
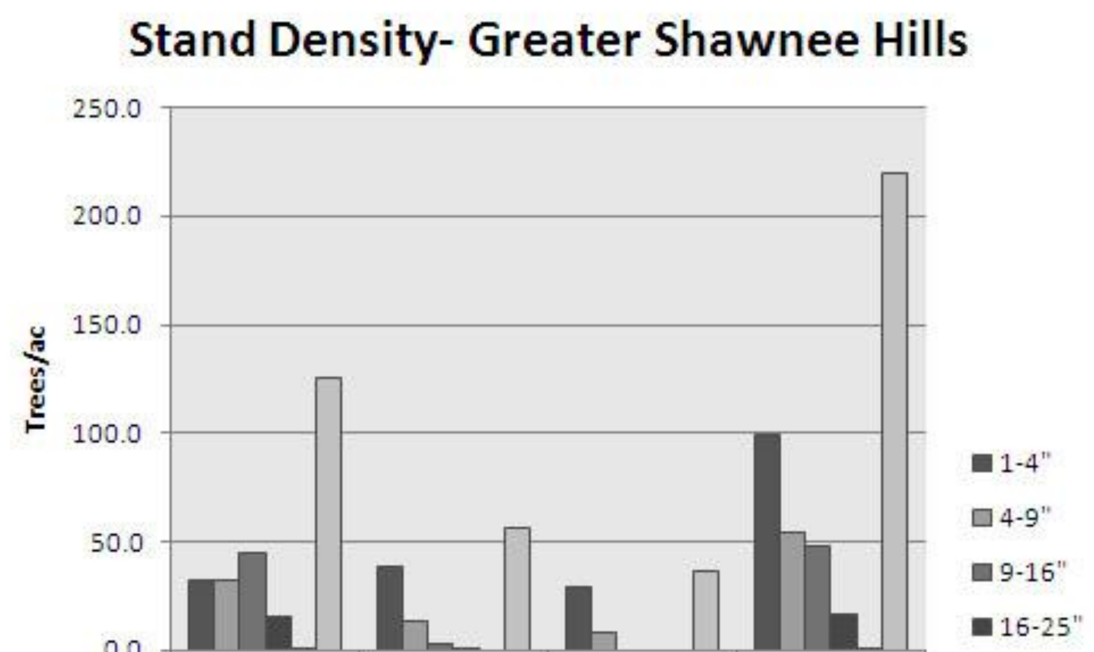


Figure 4- Location of research plots within the Shawnee National Forest Purchase Unit (shaded green) throughout southern Illinois.



	Xerophytic Species	Mesophytic Species	Midcanopy Species	TOTAL
1-4"	32.0	38.8	28.8	99.7
4-9"	32.3	13.9	8.3	54.5
9-16"	44.9	3.6	0.0	48.5
16-25"	15.4	0.3	0.0	15.7
25-30"	0.6	0.1	0.0	0.7
TOTALS	125.3	56.8	37.1	219.2

Figure 4- Diameter distribution of stand density (trees/ac) for each species group within the Greater Shawnee Hills ecological subsection.

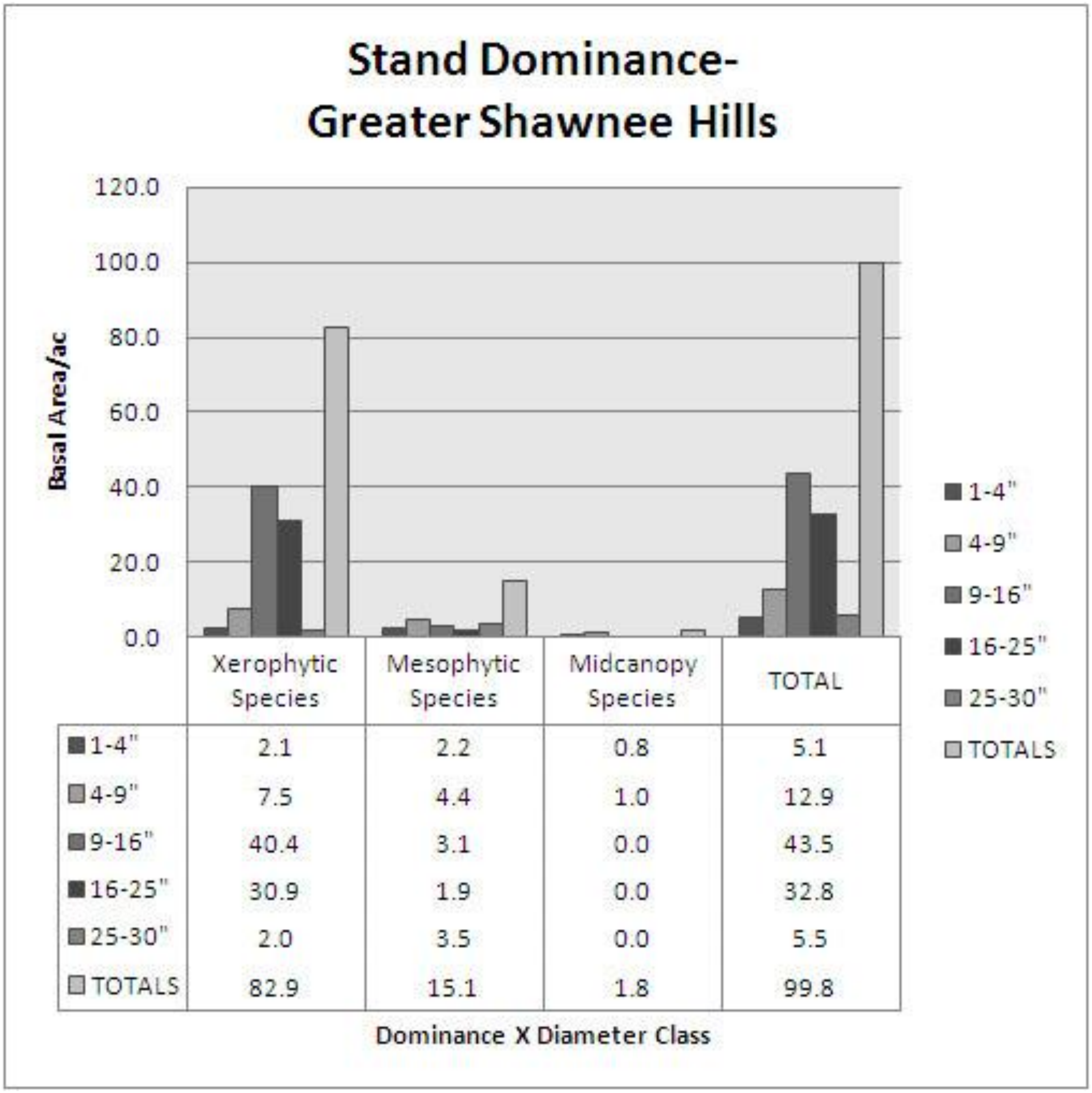
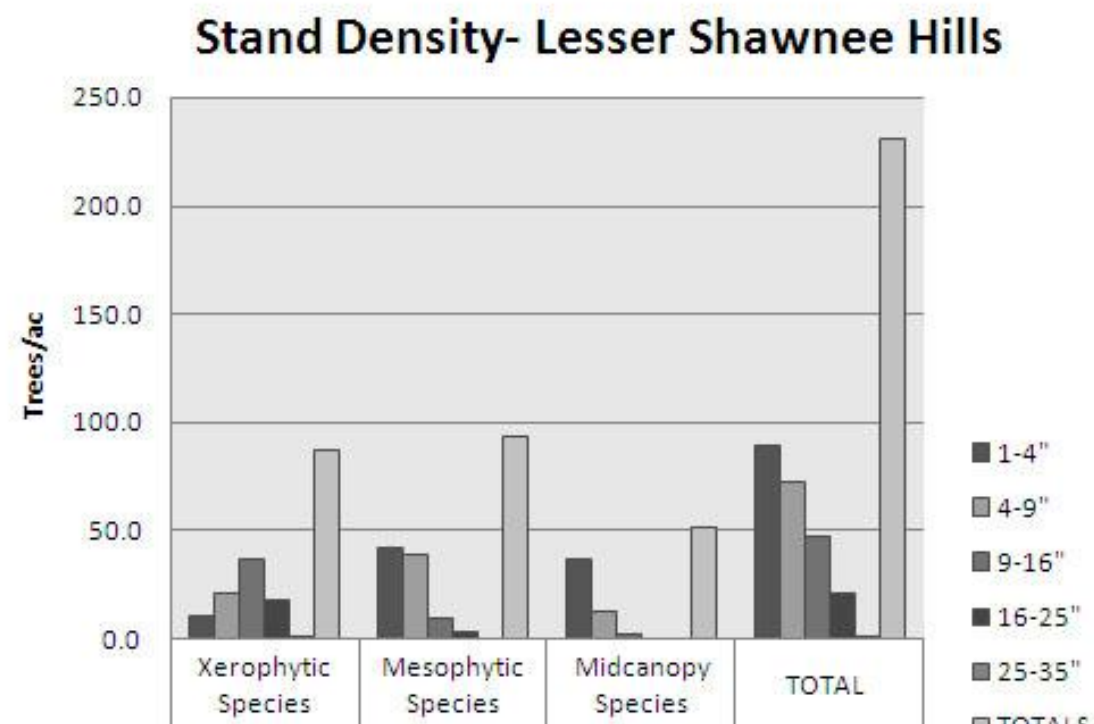


Figure 5- Diameter distribution of stand dominance (ft^2 BA/ac) for each species group within the Greater Shawnee Hills ecological subsection.



	Xerophytic Species	Mesophytic Species	Midcanopy Species	TOTAL
1-4"	10.5	41.5	37.1	89.1
4-9"	21.5	38.6	12.3	72.4
9-16"	36.5	9.5	1.8	47.8
16-25"	17.6	3.2	0.1	20.8
25-35"	0.9	0.3	0.0	1.2
TOTALS	87.0	93.1	51.2	231.3

Figure 6- Diameter distribution of stand density (trees/ac) for each species group within the Lesser Shawnee Hills ecological subsection.

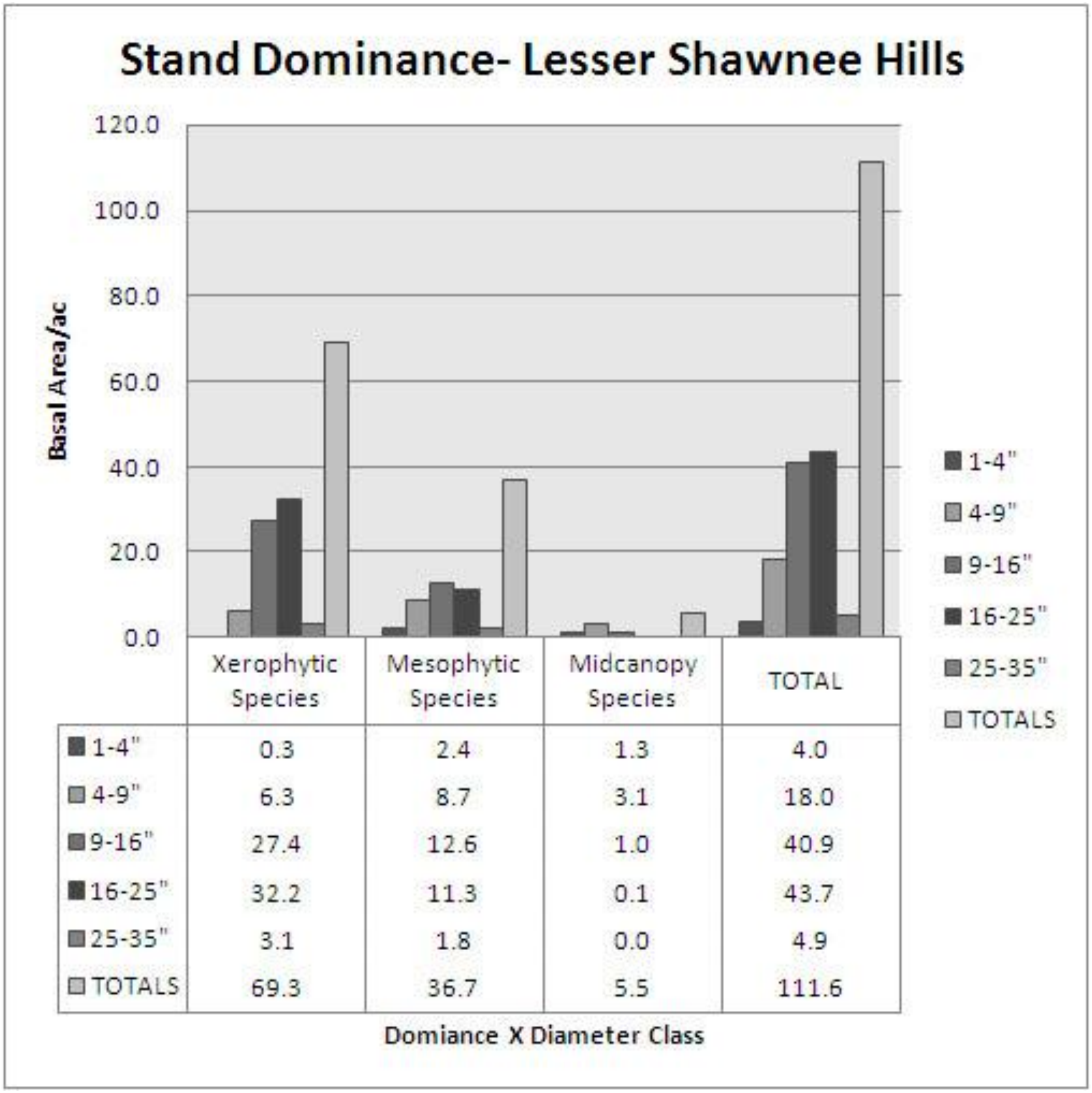
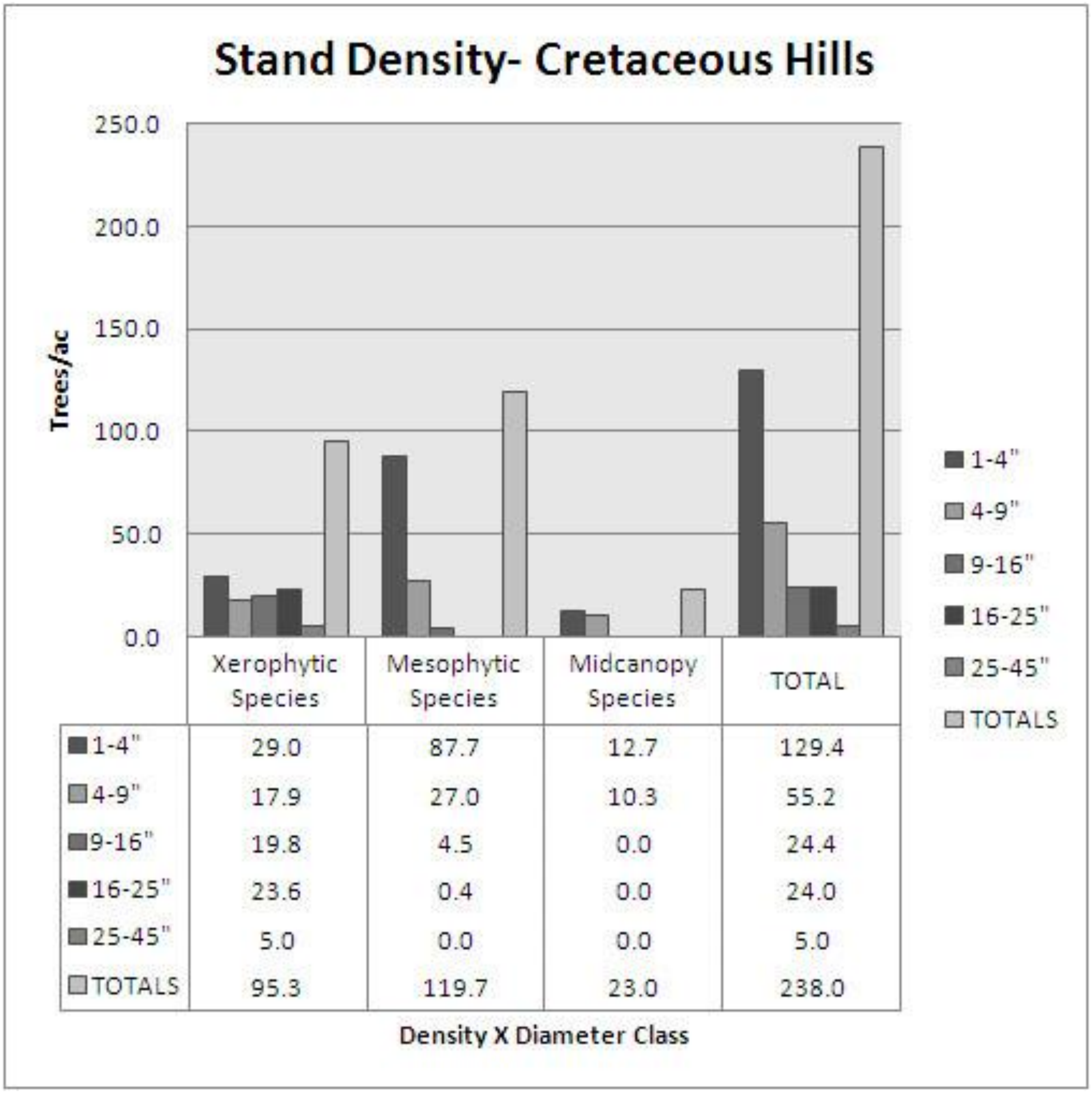
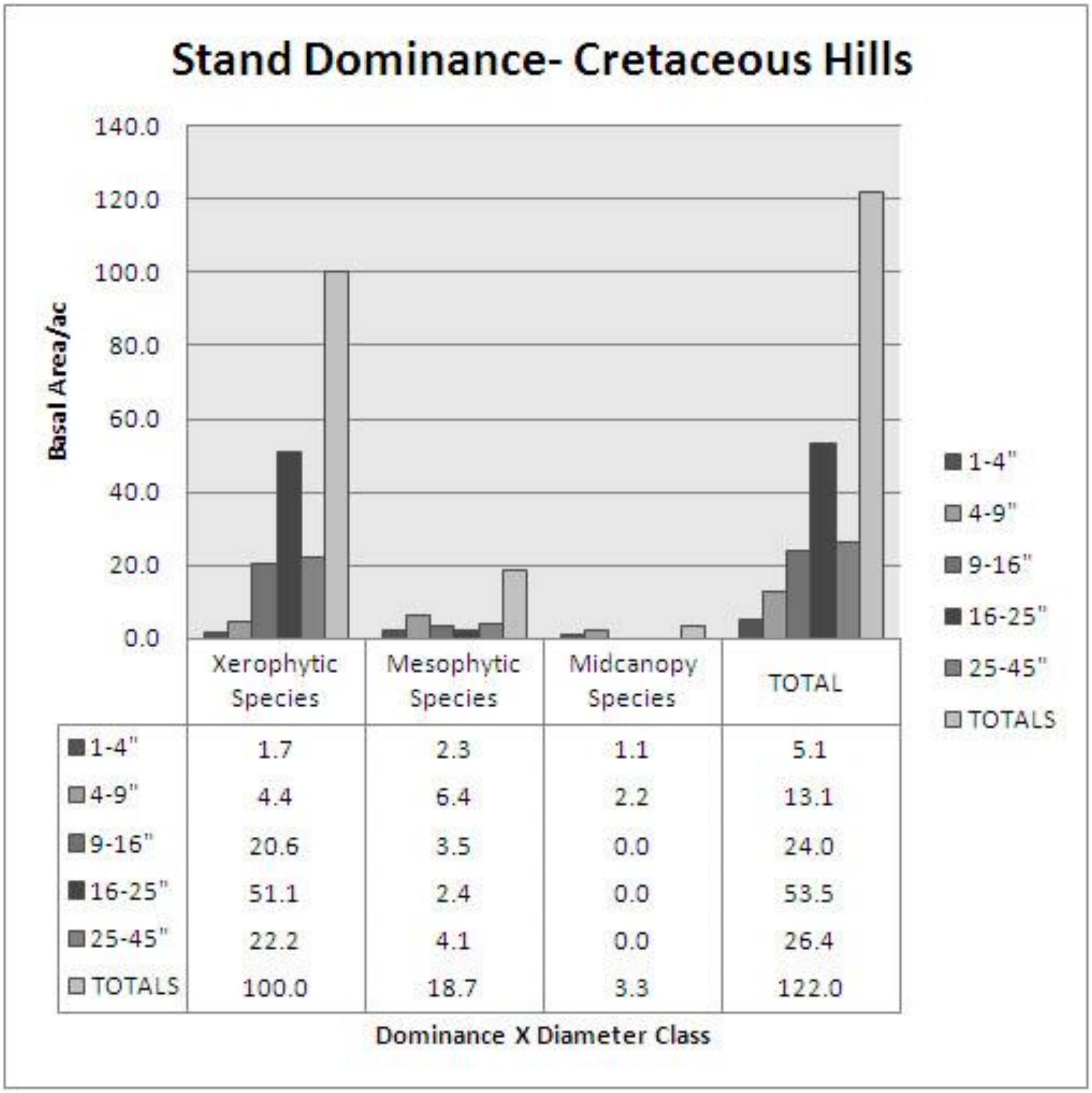


Figure 7- Diameter distribution of stand dominance (ft^2 BA/ac) for each species group within the Lesser Shawnee Hills ecological subsection.



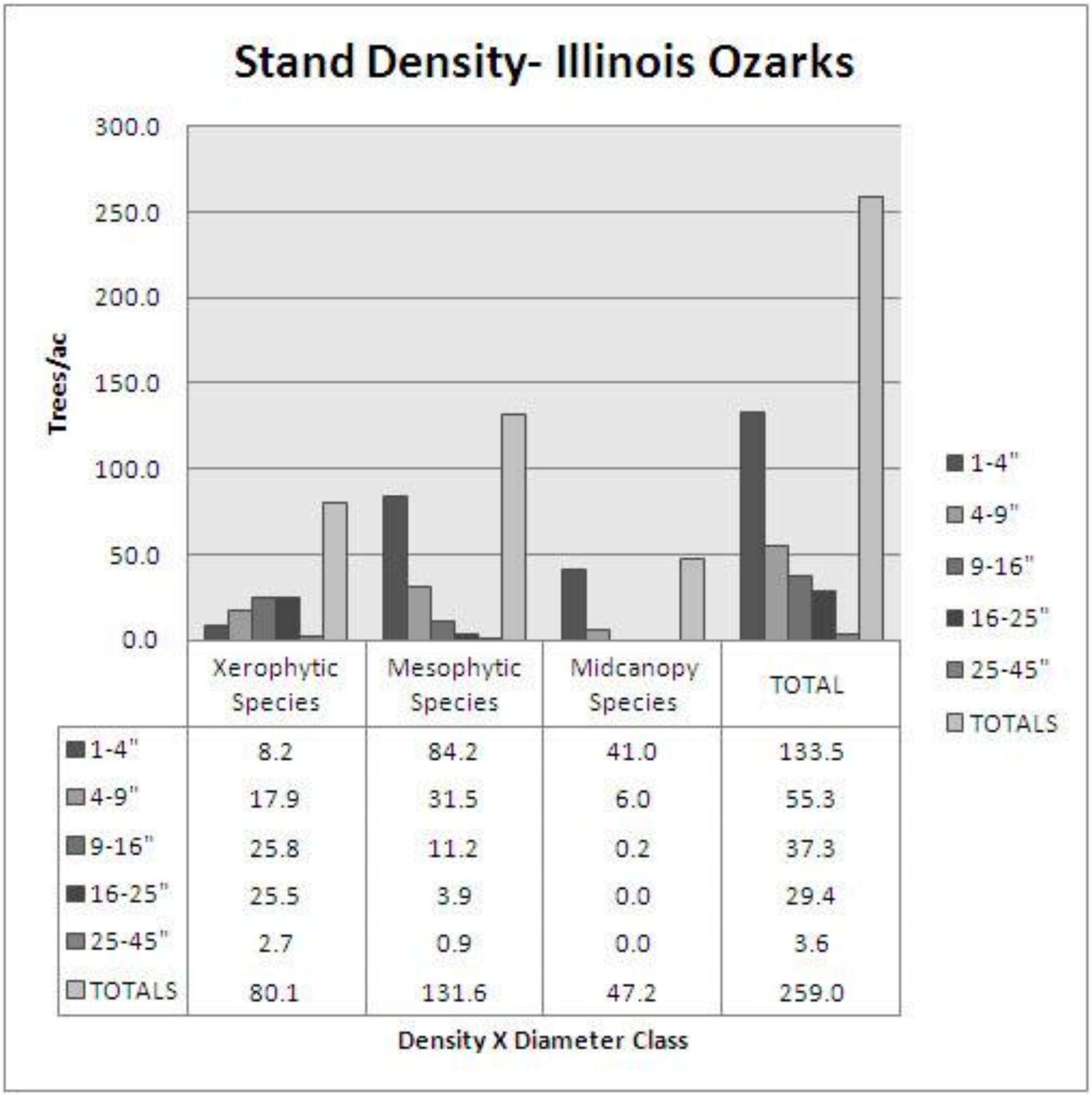
	Xerophytic Species	Mesophytic Species	Midcanopy Species	TOTAL
1-4"	29.0	87.7	12.7	129.4
4-9"	17.9	27.0	10.3	55.2
9-16"	19.8	4.5	0.0	24.4
16-25"	23.6	0.4	0.0	24.0
25-45"	5.0	0.0	0.0	5.0
TOTALS	95.3	119.7	23.0	238.0

Figure 8- Diameter distribution of stand density (trees/ac) for each species group within the Cretaceous Hills ecological subsection.



	Xerophytic Species	Mesophytic Species	Midcanopy Species	TOTAL
1-4"	1.7	2.3	1.1	5.1
4-9"	4.4	6.4	2.2	13.1
9-16"	20.6	3.5	0.0	24.0
16-25"	51.1	2.4	0.0	53.5
25-45"	22.2	4.1	0.0	26.4
TOTALS	100.0	18.7	3.3	122.0

Figure 9- Diameter distribution of stand dominance (ft^2 BA/ac) for each species group within the Cretaceous Hills ecological subsection.



	Xerophytic Species	Mesophytic Species	Midcanopy Species	TOTAL
1-4"	8.2	84.2	41.0	133.5
4-9"	17.9	31.5	6.0	55.3
9-16"	25.8	11.2	0.2	37.3
16-25"	25.5	3.9	0.0	29.4
25-45"	2.7	0.9	0.0	3.6
TOTALS	80.1	131.6	47.2	259.0

Figure 10- Diameter distribution of stand density (trees/ac) for each species group within the Illinois Ozarks ecological subsection.

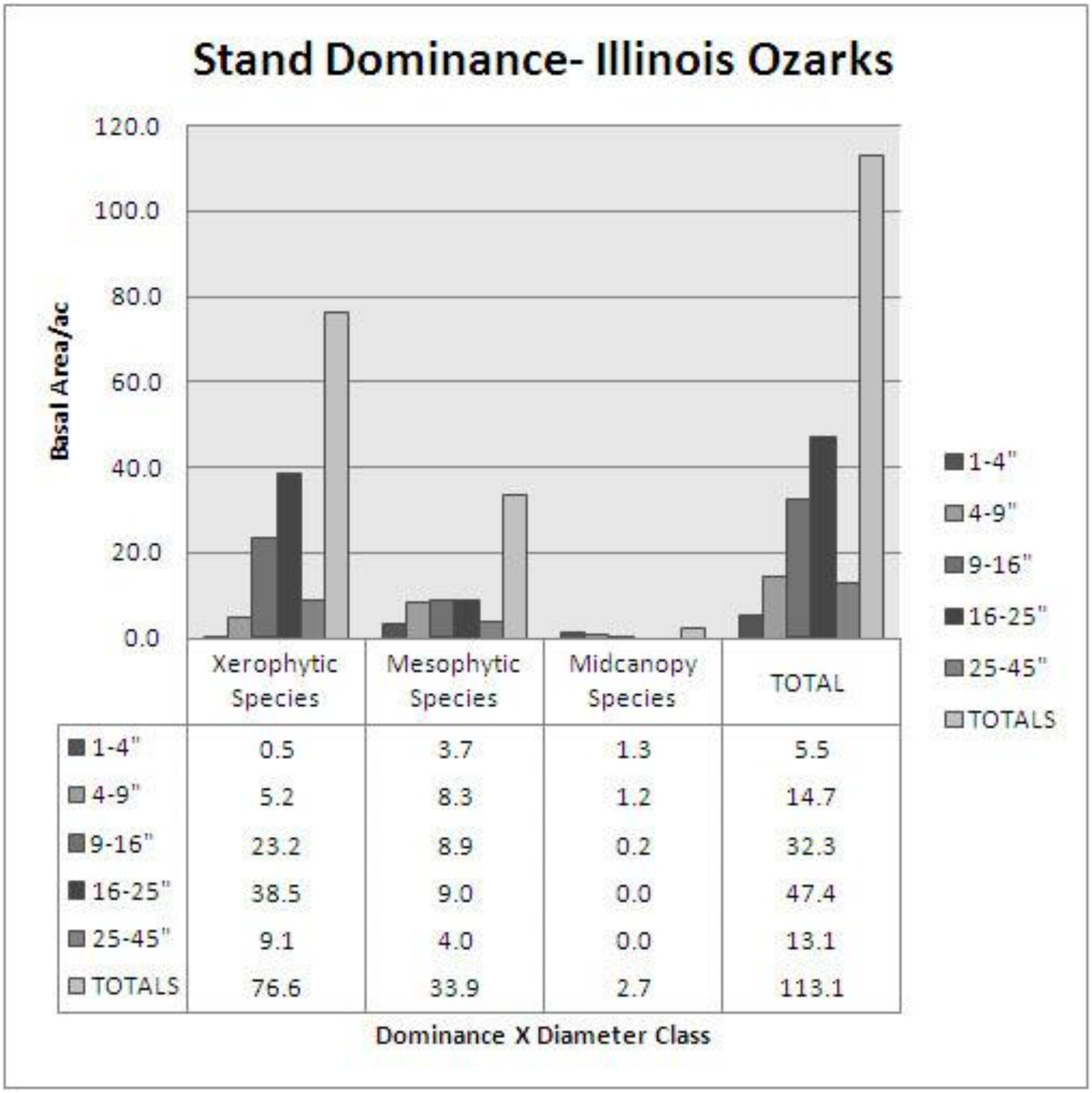
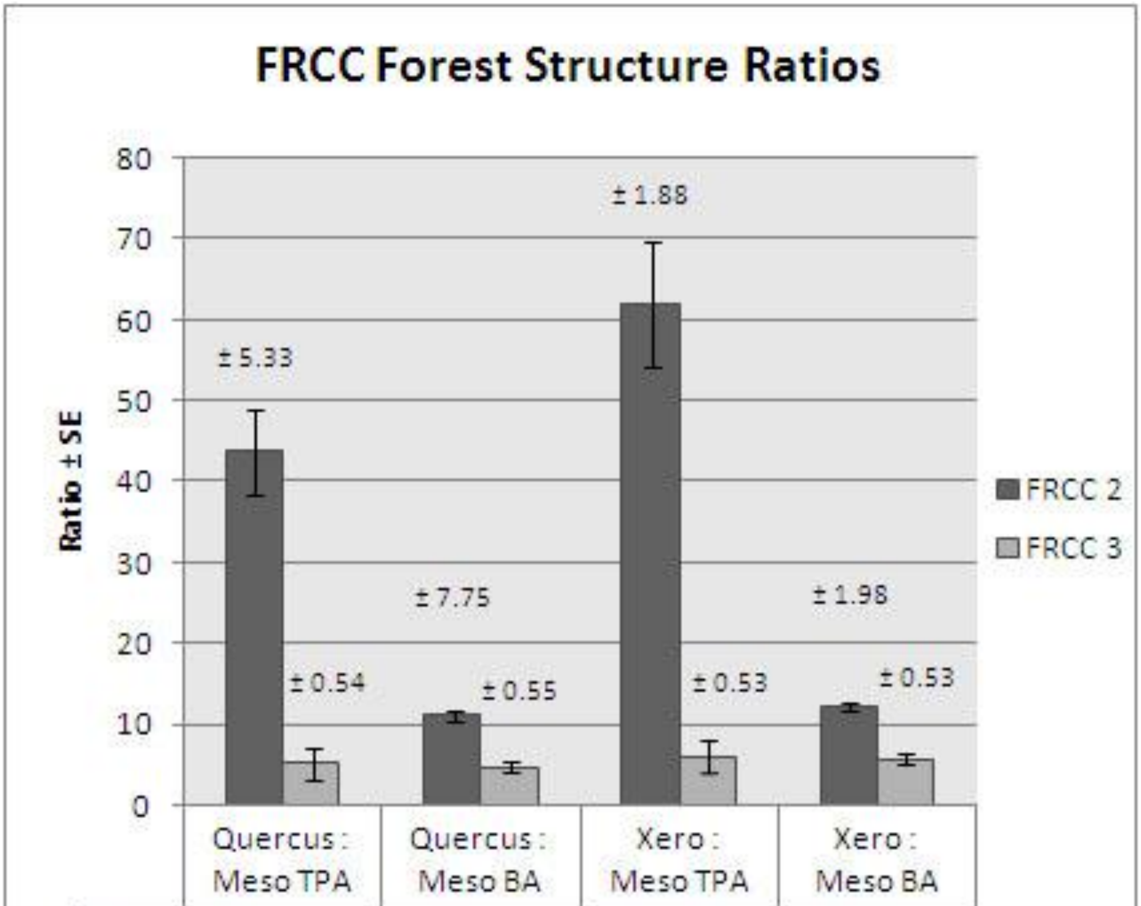


Figure 11- Diameter distribution of stand dominance (ft^2 BA/ac) for each species group within the Illinois Ozarks ecological subsection.



	Quercus : Meso TPA	Quercus : Meso BA	Xero : Meso TPA	Xero : Meso BA
FRCC 2	43.65	11.03	62.04	12.25
FRCC 3	5.12	4.74	5.93	5.72

Figure 12- Forest structure parameter ratios (mean) for FRCC 2 and 3 comparing density (TPA) and dominance (BA) of *Quercus* spp. : mesophytics and Xerophytics : mesophytics. Standard error bars are included with standard error values (mean ± SE).

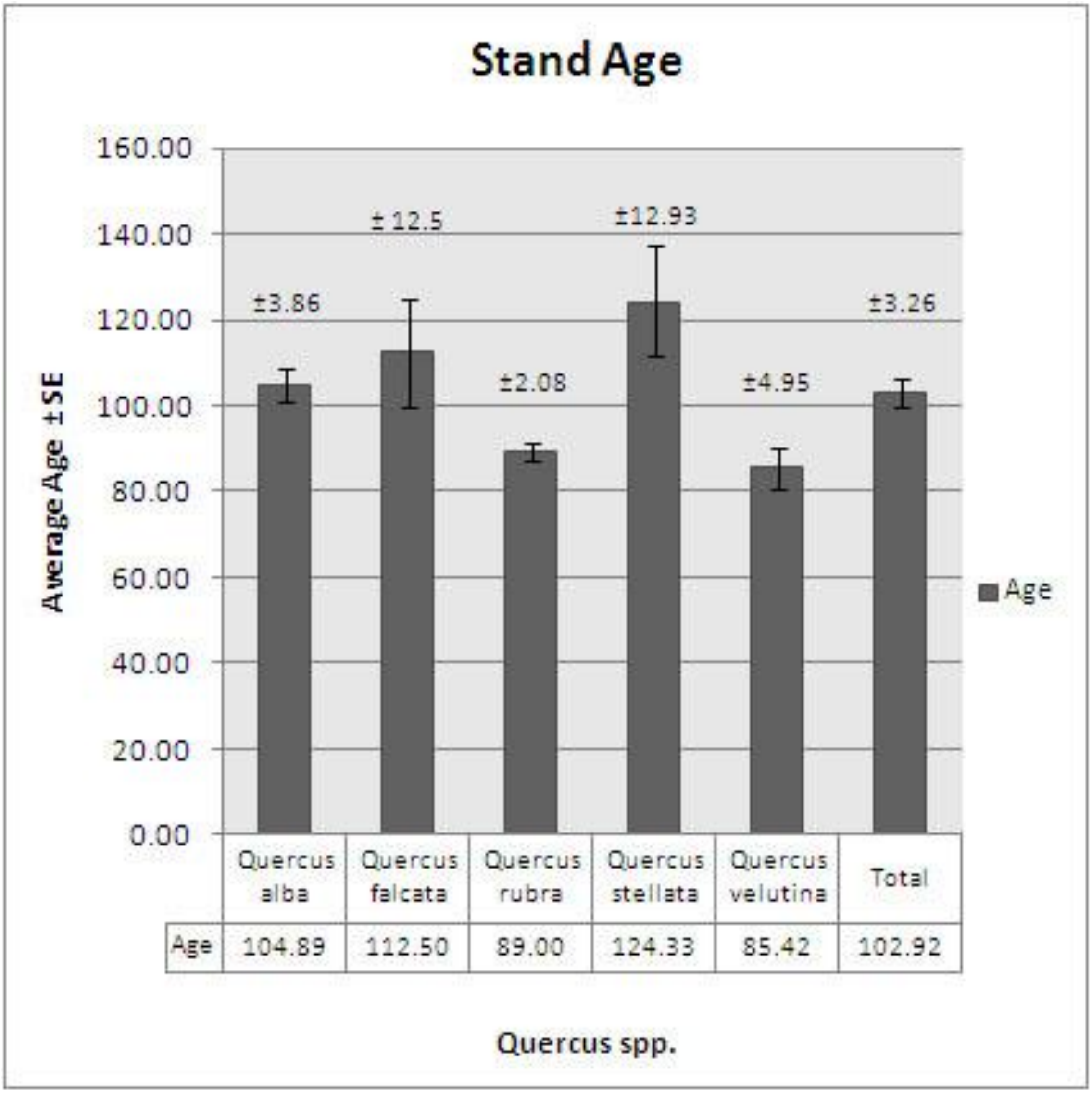


Figure 13- Average age of codominant and dominant stems of *Quercus* spp. sampled within each ecological subsection. Standard error bars are included with standard error values (mean ± SE).

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APPENDICES

APPENDIX A

FRCC 2- Mature upland forest with dominant oak-hickory overstory and midstory with numerous oak seedlings. Also note fire scarred trunks.

FRCC 3- Tulip-poplar and red maple overstory replacing oak-hickory following a past selective harvesting operation. Notice stumps from harvesting.

APPENDIX B

Bay Creek									
Plot	Latitude					Longitude			
1	N	37°	33'	39"		W	88°	37'	49"
2	N	37°	33'	34"		W	88°	37'	45"
3	N	37°	33'	33"		W	88°	37'	42"
4	N	37°	33'	28"		W	88°	37'	42"
5	N	37°	33'	23"		W	88°	37'	45"
6	N	37°	33'	24"		W	88°	37'	48"
7	N	37°	33'	26"		W	88°	37'	52"
8	N	37°	33'	33"		W	88°	37'	50"
9	N	37°	33'	09"		W	88°	38'	00"
10	N	37°	33'	13"		W	88°	37'	59"
11	N	37°	33'	15"		W	88°	37'	54"
12	N	37°	33'	17"		W	88°	37'	48"
13	N	37°	33'	11"		W	88°	37'	49"
14	N	37°	33'	06"		W	88°	37'	52"
15	N	37°	33'	07"		W	88°	37'	56"
16	N	37°	33'	04"		W	88°	37'	53"

Plot locations by latitude and longitude (degrees, minutes, seconds) for the Bay Creek stand.

Bean Ridge									
Plot	**Latitude**					**Longitude**			
1	N	37°	14'	34"		W	89°	21'	56"
2	N	37°	14'	36"		W	89°	21'	49"
3	N	37°	14'	37"		W	89°	21'	46"
4	N	37°	14'	37"		W	89°	21'	43"
5	N	37°	14'	39"		W	89°	21'	39"
6	N	37°	14'	41"		W	89°	21'	36"
7	N	37°	14'	41"		W	89°	21'	33"
8	N	37°	14'	43"		W	89°	21'	30"
9	N	37°	14'	43"		W	89°	21'	26"
10	N	37°	14'	45"		W	89°	21'	25"
11	N	37°	14'	53"		W	89°	21'	41"
12	N	37°	14'	53"		W	89°	21'	43"
13	N	37°	14'	54"		W	89°	21'	48"
14	N	37°	14'	53"		W	89°	21'	50"
15	N	37°	14'	53"		W	89°	21'	53"
16	N	37°	14'	54"		W	89°	21'	55"
17	N	37°	14'	54"		W	89°	21'	58"
18	N	37°	14'	52"		W	89°	22'	02"
19	N	37°	14'	47"		W	89°	22'	08"

Plot locations by latitude and longitude (degrees, minutes, seconds) for the Bean Ridge stand.

Burke Branch								
Plot	Latitude				Longitude			
1	N	37°	12'	01"	W	88°	32'	16"
2	N	37°	12'	06"	W	88°	32'	13"
3	N	37°	12'	07"	W	88°	32'	12"
4	N	37°	12'	08"	W	88°	32'	11"
5	N	37°	12'	09"	W	88°	32'	10"
6	N	37°	12'	10"	W	88°	32'	10"
7	N	37°	12'	11"	W	88°	32'	09"
8	N	37°	12'	12"	W	88°	32'	07"
9	N	37°	12'	13"	W	88°	32'	07"
10	N	37°	12'	14"	W	88°	32'	05"
11	N	37°	12'	51"	W	88°	32'	05"
12	N	37°	12'	51"	W	88°	32'	03"
13	N	37°	12'	49"	W	88°	32'	03"
14	N	37°	12'	48"	W	88°	32'	01"
15	N	37°	12'	46"	W	88°	32'	00"
16	N	37°	12'	45"	W	88°	31'	58"
17	N	37°	12'	43"	W	88°	31'	56"
18	N	37°	12'	43"	W	88°	31'	55"

Plot locations by latitude and longitude (degrees, minutes, seconds) for the Burke Branch stand.

Cache Creek									
Plot	Latitude					Longitude			
1	N	37°	29'	54"		W	88°	52'	04"
2	N	37°	29'	52"		W	88°	52'	11"
3	N	37°	29'	51"		W	88°	52'	15"
4	N	37°	29'	50"		W	88°	52'	18"
5	N	37°	29'	25"		W	88°	52'	10"
6	N	37°	29'	28"		W	88°	52'	09"
7	N	37°	29'	33"		W	88°	52'	05"
8	N	37°	29'	37"		W	88°	52'	04"
9	N	37°	29'	28"		W	88°	51'	55"
10	N	37°	29'	25"		W	88°	51'	53"
11	N	37°	29'	20"		W	88°	51'	50"
12	N	37°	29'	17"		W	88°	51'	47"
13	N	37°	29'	18"		W	88°	51'	43"
14	N	37°	29'	20"		W	88°	51'	45"
15	N	37°	29'	29"		W	88°	51'	49"
16	N	37°	29'	32"		W	88°	51'	51"
17	N	37°	29'	36"		W	88°	51'	52"
18	N	37°	29'	41"		W	88°	51'	51"

Plot locations by latitude and longitude (degrees, minutes, seconds) for the Cache Creek stand.

Cedar Lake									
Plot	Latitude					Longitude			
1	N	37°	37'	45"		W	89°	16'	55"
2	N	37°	37'	41"		W	89°	17'	00"
3	N	37°	37'	38"		W	89°	17'	07"
4	N	37°	37'	33"		W	89°	17'	11"
5	N	37°	37'	25"		W	89°	17'	13"
6	N	37°	37'	21"		W	89°	17'	18"
7	N	37°	37'	24"		W	89°	17'	26"
8	N	37°	37'	27"		W	89°	17'	22"
9	N	37°	37'	29"		W	89°	17'	19"
10	N	37°	37'	30"		W	89°	17'	16"
11	N	37°	37'	07"		W	89°	16'	15"
12	N	37°	37'	02"		W	89°	16'	53"
13	N	37°	36'	59"		W	89°	17'	00"
14	N	37°	36'	55"		W	89°	17'	06"
15	N	37°	36'	53"		W	89°	17'	14"

Plot locations by latitude and longitude (degrees, minutes, seconds) for the Cedar Lake stand.

Cobden									
Plot	Latitude					Longitude			
1	N	37°	32'	12"		W	89°	12'	25"
2	N	37°	32'	12"		W	89°	12'	28"
3	N	37°	32'	10"		W	89°	12'	30"
4	N	37°	32'	08"		W	89°	12'	34"
5	N	37°	32'	06"		W	89°	12'	38"
6	N	37°	32'	06"		W	89°	12'	40"
7	N	37°	32'	05"		W	89°	12'	42"
8	N	37°	32'	04"		W	89°	12'	45"
9	N	37°	32'	10"		W	89°	12'	42"
10	N	37°	32'	12"		W	89°	12'	38"
11	N	37°	32'	13"		W	89°	12'	35"
12	N	37°	32'	16"		W	89°	12'	34"
13	N	37°	32'	18"		W	89°	12'	32"
14	N	37°	32'	19"		W	89°	12'	29"
15	N	37°	32'	21"		W	89°	12'	25"
16	N	37°	32'	25"		W	89°	12'	23"

Plot locations by latitude and longitude (degrees, minutes, seconds) for the Cobden stand.

Cripps Bend									
Plot	Latitude					Longitude			
1	N	37°	38'	02"		W	89°	24'	35"
2	N	37°	38'	01"		W	89°	24'	38"
3	N	37°	38'	00"		W	89°	24'	41"
4	N	37°	37'	55"		W	89°	24'	47"
5	N	37°	37'	55"		W	89°	24'	52"
6	N	37°	37'	54"		W	89°	24'	55"
7	N	37°	37'	52"		W	89°	24'	59"
8	N	37°	37'	50"		W	89°	25'	02"
9	N	37°	37'	48"		W	89°	25'	05"
10	N	37°	37'	54"		W	89°	24'	31"
11	N	37°	37'	51"		W	89°	24'	31"
12	N	37°	37'	46"		W	89°	24'	31"
13	N	37°	37'	43"		W	89°	24'	31"
14	N	37°	37'	39"		W	89°	24'	31"
15	N	37°	37'	36"		W	89°	24'	31"
16	N	37°	37'	33"		W	89°	24'	33"
17	N	37°	37'	29"		W	89°	24'	36"

Plot locations by latitude and longitude (degrees, minutes, seconds) for the Cripps Bend stand.

Kaskaskia									
Plot	Latitude					Longitude			
1	N	37°	29'	57"		W	88°	19'	06"
2	N	37°	30'	01"		W	88°	19'	06"
3	N	37°	30'	05"		W	88°	19'	07"
4	N	37°	30'	07"		W	88°	19'	07"
5	N	37°	30'	10"		W	88°	19'	07"
6	N	37°	30'	14"		W	88°	19'	07"
7	N	37°	30'	21"		W	88°	19'	06"
8	N	37°	30'	26"		W	88°	19'	08"
9	N	37°	30'	29"		W	88°	19'	08"
10	N	37°	30'	27"		W	88°	18'	46"
11	N	37°	30'	33"		W	88°	18'	47"
12	N	37°	30'	28"		W	88°	18'	46"
13	N	37°	30'	24"		W	88°	18'	47"
14	N	37°	30'	21"		W	88°	18'	47"
15	N	37°	30'	18"		W	88°	18'	45"
16	N	37°	30'	13"		W	88°	18'	48"
17	N	37°	30'	09"		W	88°	18'	47"

Plot locations by latitude and longitude (degrees, minutes, seconds) for the Kaskaskia stand.

Viney Ridge									
Plot	Latitude					Longitude			
1	N	37°	40'	57"		W	89°	24'	3"
2	N	37°	40'	56"		W	89°	24'	4"
3	N	37°	40'	56"		W	89°	24'	6"
4	N	37°	40'	57"		W	89°	24'	09"
5	N	37°	40'	56"		W	89°	24'	11"
6	N	37°	40'	57"		W	89°	24'	13"
7	N	37°	40'	57"		W	89°	24'	15"
8	N	37°	40'	59"		W	89°	24'	17"
9	N	37°	40'	39"		W	89°	23'	59"
10	N	37°	40'	37"		W	89°	23'	59"
11	N	37°	40'	37"		W	89°	24'	00"
12	N	37°	40'	36"		W	89°	24'	03"
13	N	37°	40'	35"		W	89°	24'	05"
14	N	37°	40'	35"		W	89°	24'	07"
15	N	37°	40'	34"		W	89°	24'	09"
16	N	37°	40'	34"		W	89°	24'	10"

Plot locations by latitude and longitude (degrees, minutes, seconds) for the Viney Ridge stand.

Williams Hill									
Plot	Latitude					Longitude			
1	N	37°	35'	57"		W	88°	28'	40"
2	N	37°	35'	58"		W	88°	28'	47"
3	N	37°	35'	57"		W	88°	28'	53"
4	N	37°	35'	57"		W	88°	28'	58"
5	N	37°	35'	57"		W	88°	29'	03"
6	N	37°	35'	56"		W	88°	29'	07"
7	N	37°	35'	44"		W	88°	29'	08"
8	N	37°	35'	45"		W	88°	29'	03"
9	N	37°	35'	36"		W	88°	28'	41"
10	N	37°	35'	36"		W	88°	28'	47"
11	N	37°	35'	36"		W	88°	28'	52"
12	N	37°	35'	36"		W	88°	28'	58"
13	N	37°	35'	36"		W	88°	29'	04"
14	N	37°	35'	36"		W	88°	29'	09"
15	N	37°	35'	46"		W	88°	28'	58"
16	N	37°	35'	46"		W	88°	28'	52"
17	N	37°	35'	47"		W	88°	28'	48"

Plot locations by latitude and longitude (degrees, minutes, seconds) for the Williams Hill stand.

			Tons/ac					Fuel Depth (inches)		
Ecological Subsection	Site	n	1 hr	10 hr	100 hr	1000 hr	Total	Duff	Leaf Litter	Surface Fuels
Greater Shawnee Hills		33	0.17 ± 0.01	0.36 ± 0.05	2.42 ± 0.39	4.88 ± 1.57	7.83 ± 1.64	0.33 ± 0.04	1.81 ± 0.15	6.29 ± 0.53
	Bay Creek	16	0.18 ± 0.01	0.27 ± 0.05	2.04 ± 0.50	3.61 ± 0.86	6.10 ± 0.83	0.43 ± 0.08	2.31 ± 0.20	7.38 ± 0.80
	Williams Hill	17	0.15 ± 0.01	0.45 ± 0.09	2.78 ± 0.59	6.08 ± 2.95	9.46 ± 3.07	0.24 ± 0.01	1.33 ± 0.15	5.26 ± 0.63
Lesser Shawnee Hills		66	0.14 ± 0.01	0.49 ± 0.03	1.91 ± 0.21	3.79 ± 0.72	6.33 ± 0.73	0.25 ± 0.01	1.34 ± 0.08	6.42 ± 0.43
	Cache Creek	18	0.14 ± 0.01	0.48 ± 0.06	1.82 ± 0.39	4.31 ± 2.07	6.75 ± 2.04	0.20 ± 0.01	1.56 ± 0.13	7.93 ± 0.82
	Cedar Lake	15	0.12 ± 0.01	0.49 ± 0.07	1.45 ± 0.38	2.59 ± 1.08	4.65 ± 1.10	0.28 ± 0.01	1.50 ± 0.13	5.86 ± 0.71
	Cobden	16	0.16 ± 0.02	0.52 ± 0.05	2.42 ± 0.38	2.35 ± 0.70	5.46 ± 0.75	0.23 ± 0.02	0.87 ± 0.10	3.30 ± 0.23
	Kaskaskia	17	0.15 ± 0.02	0.46 ± 0.07	2.14 ± 0.52	5.42 ± 1.26	8.17 ± 1.35	0.28 ± 0.01	1.39 ± 0.18	8.24 ± 0.86
Cretaceous Hills		18	0.15 ± 0.01	0.50 ± 0.09	2.42 ± 0.57	2.40 ± 0.42	5.47 ± 0.82	0.24 ± 0.04	1.57 ± 0.10	7.15 ± 0.86
	Burke Branch	18	0.15 ± 0.01	0.50 ± 0.09	2.42 ± 0.57	2.40 ± 0.42	5.47 ± 0.82	0.24 ± 0.04	1.57 ± 0.10	7.15 ± 0.86
Illinois Ozarks		52	0.17 ± 0.01	0.50 ± 0.05	1.75 ± 0.33	4.47 ± 1.00	6.89 ± 1.08	0.26 ± 0.03	2.02 ± 0.13	7.10 ± 0.53
	Bean Ridge	19	0.18 ± 0.02	0.48 ± 0.06	1.02 ± 0.25	3.26 ± 1.91	4.94 ± 1.87	0.24 ± 0.03	1.82 ± 0.19	5.79 ± 0.47
	Cripps Bend	17	0.16 ± 0.01	0.54 ± 0.10	1.85 ± 0.44	5.56 ± 1.94	8.81 ± 2.01	0.30 ± 0.07	1.66 ± 0.17	6.73 ± 0.81
	Viney Ridge	16	0.16 ± 0.02	0.50 ± 0.09	2.50 ± 0.92	4.75 ± 1.18	7.90 ± 1.66	0.23 ± 0.02	2.65 ± 0.28	9.04 ± 1.26
Project Total		169	0.16 ± 0.005	0.47 ± 0.02	2.03 ± 0.16	4.04 ± 0.52	6.70 ± 0.55	0.27 ± 0.01	1.66 ± 0.06	6.68 ± 0.27

Appendix 13- Fuel loading characteristics (tons/ac) separated by time lag fuel classes and fuel depth measurements (mean +- SE) for each ecological subsection (n=169).

VITA

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Classifying the Fire Regime Condition Class for Upland Oak-Hickory Forests of the Shawnee National Forest

Major Professor: Charles M. Ruffner