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Oak Savanna Restoration and Management in the Mid-South

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To the Graduate Council:

I am submitting herewith a thesis written by Seth A. Barrioz entitled "Oak Savanna Restoration and Management in the Mid-South." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

Patrick D. Keyser, Major Professor

We have read this thesis and recommend its acceptance:

David S. Buckley, David A. Buehler, Craig A. Harper

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Oak Savanna Restoration and Management in the Mid-South

A thesis presented
for the
Master of Science Degree
The University of Tennessee

Seth Adam Barrioz
May 2010

Dedication

I dedicate this thesis to my family and friends who have always encouraged me to follow my dreams with a career in wildlife management. Without my parents pushing me to always do my best and never questioning my overwhelming love for the outdoors, I could not have done this.

"To such the Kansas plains are tedious. They see the endless corn, but not the heave and grunt of ox teams breaking the prairie. History, for them, grows on campuses. They look at the low horizon, but they cannot see it, as de Vaca did, under the bellies of the buffalo."
-Aldo Leopold, A Sand County Almanac

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I appreciate my major professor, Dr. Patrick Keyser, for providing me with this opportunity to work with early successional habitat restoration and management. He has provided me with much needed guidance and the encouragement to complete this thesis. The hurdles and laughs that I have shared along the way will never be forgotten. I would also like to thank my committee members, Drs. Craig Harper, David Buehler, David Buckley, and Mr. Roger Applegate, for their guidance and support during my time here at the university.

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Preface

My objectives for this study were to document key factors that influence herbaceous and woody plant communities where fire and overstory mechanical thinning were used during restoration of oak savannas in the mid-South. In Chapter One, I describe savannas and previous research. In Chapter Two, I report on the influence of site, and canopy retention, with respect to cover of grass, forbs, legumes and woody plants with increasing disturbance of the overstory and understory vegetation, associated with oak savanna restoration. Also discussed in this chapter is the response of avian species associated with the oak savanna restoration. Chapter Three documents the effects of drum-chopping as a tool for savanna restoration.

Abstract

Oak savannas are among the most imperiled ecosystems in the United States as a result of habitat degradation and consequently, associated vegetation and wildlife communities have also declined. I evaluated savanna restoration strategies on twelve case studies in Tennessee and Kentucky. These case studies represented a broad range of disturbances and the most advanced savanna restoration sites within the region. I evaluated vegetation and breeding bird responses to landscape and overstory conditions across sites through a meta-analysis. Total grass and forb cover were influenced by overstory metrics but not by topography ($P > 0.05$). Oak regeneration density was influenced by canopy cover, while oak competitor regeneration density was influenced by percent slope and sapling density ($P < 0.05$). With respect to breeding birds, I found forest species persisted within case studies despite substantial disturbance; shrub/scrub birds were common on disturbed sites. Only three obligate grassland bird species, *Tyrannus tyrannus*, *Aimophila aestivalis*, *Spiza americana*, were observed on my sites. Relative abundance of *Passerina cyanea* was positively related to the groundlayer development; whereas that of *Melanerpes erythrocephalus* was positively related to basal area of dead trees ($P < 0.05$). Based on my results, canopy reduction and growing-season burns may both be critical for the restoration of savannas within the region.

Drum-chopping is a tool that may expedite oak savanna restoration through improved woody competition control, however, its effectiveness has not been investigated. Therefore, I evaluated drum-chopping effects on vegetative structure at Catoosa Wildlife Management Area, Tennessee, during 2008 and 2009 using two adjacent sites with similar fire and overstory removal histories. One site was subjected to drum-chopping in September of 2007, while an adjacent site (control) was not chopped. Drum-chopping reduced grass and forb cover, and oak seedling density, but increased bare ground and density of vines and shrubs versus the control ($P < 0.05$). Except for bare ground, differences were no longer apparent in the second year. Based on my results, drum chopping may reduce midstory vegetation too thick to be effectively controlled by fire, but otherwise has limited utility as a restoration tool.

TABLE OF CONTENTS

LIST OF TABLES

List of Figures

I INTRODUCTION

Background

Native Americans' use of fire for hunting, wildlife management, and agriculture, played a crucial part in the development of woodlands in the southeast (Van Lear and Waldrop, 1989; Elliot et al., 1999). Frequent fire helped to develop and maintain regional prairies and savannas by stimulating grasses and forbs, while reducing woody encroachment (Hulbert, 1986). Beginning in the early 1900's, however, the US Forest Service began an effort to eliminate fire from the forest (Van Lear and Waldrop, 1989), resulting in the loss of millions of hectares of oak savanna.

Early in the last century, the combination of heavy grazing by domestic livestock and removal of the overstory trees began the process of oak (*Quercus*) savanna degradation in eastern North America (Apfelbaum and Haney, 1987; Noss and Peters, 1995). Following these disturbances, land was often cleared for agriculture. Furthermore, in the absence of fire, remaining savannas that had not been cleared developed into forested systems (Apfelbaum and Haney, 1987). Today, most savannas have been cleared for cropland, converted to pasture or allowed to succeed into closed-canopy forest through fire suppression (Curtis, 1959; Noss and Peters, 1995; Bowles and McBride, 1998). Nuzzo (1985) described a savanna in Wisconsin that covered 74% of a two-county study area in 1833, but by 1934 it had all but disappeared. Forty-two percent of this site was converted to row crops, 36% was converted to pasture, and the remaining 23%, which was white oak (*Q. alba*) savanna, was left idle and developed into closed-canopy oak-hickory (*Quercus-Carya*) forest. Nuzzo (1985) points out that the heavy grazing, plowing, and construction of roads produced functional firebreaks that continue to exclude fire from these fire-dependent ecosystems.

Today, less than one percent of oak savanna habitat remains in central North America and only about 2,600 ha of that is of high quality (Nuzzo 1985). As a result of succession and conversion of savannas, high quality sites are now rare and those that remain are restricted to sites with poor soil fertility that limits succession following fire suppression (Peterson and Reich, 2001). Noss and Peters (1995) concluded that the grassland-savanna-barrens ecosystem is one of the 21 most imperiled ecosystems in North America. This drastic reduction of savanna highlights the need to protect and restore what is left (Curtis, 1959; Noss and Peters, 1995; Leach and Givnish, 1999; Davis et al., 2000; Grundel and Pavlovic, 2007).

Many disturbance-dependent grassland bird species have experienced population declines due to loss of suitable habitat in recent years (Askins, 1993; Herkert, 1995; Brennan and Kuvlesky, 2005). Askins (1993) reported that populations of grassland, savanna, and successional/scrub bird species have declined over the last 35 years largely due to habitat destruction and changes in vegetation structure resulting from succession into forest. Most of these declining species including Henslow's sparrow (*Ammodramus henslowii*), field sparrow (*Spizella pusilla*), dickcissel (*Spiza americana*), grasshopper sparrow (*Ammodramus savannarum*) and northern bobwhite (*Colinus virginianus*), inhabit oak savannas (Askins, 1993; Robinson, 1994; Ford et al., 2000). Brawn et al. (2001) found that 68 of 169 disturbance-dependent grassland, shrub/scrub, and open woodland species across North America have had a significant population decline between 1966 and 1998, while only 29 of those species have increased significantly. Conversely, 58 forest species in their sample increased in population (Brawn et al., 2001). Likewise, Hunter et al. (2001) reported 70% of 37 grassland bird species in eastern North America experienced population declines over the last 50 years.

Restoration of oak savannas is critical; however, such efforts require a better understanding of how fire regulates the vegetation structure and composition in savannas (Leach and Ross, 1995; Peterson et al., 2007). Prescribed fire will gradually alter the composition of understory vegetation by suppressing shrubs and trees (Van Lear and Waldrop, 1989; Elliott et al., 1999; Hutchinson, 2006) but, is slow to alter the overstory (Peterson and Reich, 2001; Nielson et al., 2003). Mechanical thinning of the overstory may rapidly accelerate this process and should be considered as a potential tool for oak savanna restoration (Peterson and Reich, 2001; Nielson et al., 2003). However, few studies have evaluated the combined effects of fire and overstory thinning of mature forest to restore oak savannas (Peterson et al., 2007)

To date, most oak savanna research has been concentrated in states on the western edge of the historic range, such as Arkansas (Milks, 2005), Missouri (Rebertus and Burns, 1997, McCarty, 2002), Iowa (Brudvig and Asbjornsen, 2005), Minnesota (Davis et al., 2000; Peterson and Reich, 2001; Peterson et al., 2007), Wisconsin (Leach and Givnish, 1999; Nielson et al., 2003) and Illinois (Brawn, 2006). In addition, some studies have been conducted in Indiana (Grundel and Pavlovic, 2007) and Ohio (Abella et al., 2001), near the northern periphery of historic oak savanna range. Apfelbaum and Haney (1990) attempted to characterize savannas covering multiple states, such as Indiana, Illinois, and Wisconsin.

These studies have typically addressed changes in vegetative characteristics after the introduction of fire; avian research in savanna ecosystems has only addressed avian response to the reintroduction of fire into the degraded savannas (Davis et al., 2000; Brawn, 2006; Grundel and Pavlovic, 2007a; Grundel and Pavlovic, 2007b; Au et al., 2008). Also, no research has been conducted to evaluate the influence of fire and mechanical overstory thinning on avian species. Information on this subject have been formed from speculated responses of avian species based on species-habitat relationships and how they might respond to shelterwood – burn treatments (Lanham et al., 2002) or have researched the subject but has been unpublished (Dennis, 2002). However, I am aware of no studies involving oak savanna, or its restoration, in the mid-South, nor any studies addressing restoration of this rare ecosystem from a mature hardwood forest that had once been an oak savanna, back to a savanna. Hutchinson (2006) also discussed the lack of studies documenting the effects of fire and mechanical thinning on herbaceous vegetation.

Restoring oak savanna ecosystems will also restore habitats with a unique vegetative structure. The transitional nature of savannas provides a mosaic of vegetative structures that many species of wildlife exploit (Askins, 1993; Davis et al., 2000; Thompson and DeGraaf, 2001). Several herptile species, such as the eastern tiger salamander (*Ambystoma trigrinum tigrinum*), six-lined racerunner (*Cnemidophorus sexlineatus sexlineatus*), prairie racerunner (*Cnomidophorus sexlineatus viridis*), and bullsnake (*Pituophis catenifer sayi*), are known to be strongly associated with savanna habitats (Nelson, 2005). Several birds and mammals are also associated with savannas, such as northern bobwhite (*Colinus virginianus*), Bachman's sparrow (*Aimophila aestivalis*), red-headed woodpecker (*Melanerpes erythrocephalus*), and the Indiana bat (*Myotis sodalis*) (Nelson, 2005).

Savannas also support important flora. At least 20 tallgrass prairie species have been state listed as threatened or endangered (Anderson and Bowles, 1998). Apfelbaum and Haney (1990) found that the herbaceous layer increased in cover after burning and included many species that are known to exist in savanna ecosystems that were not apparent before the fire. Oak savannas have also been shown to be more diverse in herbaceous species than prairie or forest, which is likely a response to micro-site heterogeneity found within light patches (Leach and Givnish, 1999). In a Wisconsin study, forbs were dominant in remnant savannas accounting for up to 64% of the herbaceous species encountered (Leach and Givnish, 1999). Along with the micro-site heterogeneity of herbaceous species, topography can play a crucial role in determining overstory tree, shrub, and herbaceous vegetation diversity by influencing their locations on the landscape, such as more xeric upland ridges or more mesic swales between ridges (Anderson and Anderson, 1975).

LITERATURE REVIEW

The oak savanna ecosystem is often considered to be a transitional state between the tallgrass prairie and the eastern deciduous forest (Nuzzo, 1985). Oak savannas have generally been described as having widely spaced, open-grown oaks (Bray, 1960), and between 10-30% canopy cover (Faber-Langendoen, 2001, Nelson, 2002), though other researchers have described canopy cover between 25-50% (Bray, 1960, Taft, 1997). Representative oak species within savannas include bur oak (*Q. macrocarpa*), black oak (*Q. veluntina*), white oak (*Q. alba*), northern pin oak (*Q. ellipsoidalis*), post oak (*Q. stellata*), and blackjack oak (*Q. marilandica*) (Abrams, 1992).

The herbaceous ground layer of savannas is characterized by a robust diversity of grasses and forbs (Apfelbaum and Haney, 1990; Rebertus and Burns, 1997; Leach and Givnish, 1999; Peterson and Reich, 2001; Nelson, 2005; Grundel and Pavlovic, 2007). Nelson (2002) described an oak savanna in the Missouri Ozarks with 24 tree, 243 forb, 41 grass, and 20 sedge (*Carex spp*.) species. Savannas may be forb- rather than grass-dominated ecosystems (Bray, 1960; Leach and Givnish, 1999). Typical plants of savannas include little bluestem (*Schizachyrium scoparium*) and sideoats grama (*Bouteloua curtipendula*) on xeric sites and big bluestem

(*Andropogon gerardii*) and indiangrass (*Sorghastrum nutans*) on more mesic sites (DeSelm, 1994).

Plant diversity within some remnant savannas has been shown to be greater than that of prairies. This increased diversity may be due in part to the occurrence of savannas on sites with greater topographical relief, which in turn influences slope, aspect, soils, and moisture availability (Muller, 1982; Leach and Givnish, 1999; Abella et al., 2001; Peterson and Reich, 2001; Packard and Mutel, 2007). Plant adaptations within savannas include the ability to coexist with fire and grazing regimes (Rebertus and Burns, 1997; Anderson and Bowles, 1998). Some clear divisions in vegetation types can be based on their position with respect to the canopies of the overstory trees: from the bole to the tree's drip-line, cool-season grasses dominate and in more open areas past the drip-line, warm-season grasses dominate (Scholes and Archer, 1997; Leach and Givnish, 1999). Some prairie species, such as bluestems (*Andropogon spp*.), are able to survive under moderate light conditions associated with canopy gaps (Blewett, 1976).

Savannas are fire-dependent with regard to maintaining the open overstory and rich herbaceous ground layer (Abrams, 1992). Fire return intervals for this vegetative type would have ranged between 1-12 years, based on dendrochronology evidence (Frost, 1998). Van Lear (2004) noted the various burn intervals and fire intensities allowed for the regeneration of oaks, thus resulting in the replacement of canopy trees in oak woodlands and savannas and allowing for the perpetuation of the community. The peak of anthropogenic fires in the South typically occurred during April, whereas the peak of the lightning-set fires would have occurred during May (Barden and Woods, 1973; Huffman, 2006). Fire intensities would have varied greatly across the region as a function of fuels, season, and topography (Frost, 1998; McCarty, 2002).

As long hunters traveled across Tennessee and Kentucky, they described seeing bison (*Bison bison*) and elk (*Cervus canadensis*), both grazers, (DeSelm, 1994) bearing witness to the fact that open grasslands existed in these states during pre-settlement. Greater prairie chickens (*Tympanuchus cupido*) were also common within open grassland areas (Nelson, 2005). Noss and Peters (1995) noted many rare and endemic species in eastern savannas and barrens including Karner blue butterfly (*Lycaeides melissa samuelis*) and loggerhead shrike (*Lanius ludovicianus*). Also, fire-induced mortality of overstory trees could provide crucial habitat for bats (Loeb, 1996), that could have included the endangered Indiana bat (*Myotis sodalist*).

Nuzzo (1985) estimated that prior to European settlement there were about 11-13 million ha of oak savanna in what are now Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, and Ohio. Although Noss and Peters (1995) noted the severe decline of eastern grasslands, savannas, and barrens in areas of the mid-South, such as Tennessee, Kentucky, North Carolina and Arkansas, though there are no estimates of the extent of this vegetative type within this region. Indeed, even areas of the southern Appalachians were described in early accounts as open timber with shoulder-high broomsedge (*Andropogon spp.*) with abundant legumes in the understory (Van Lear and Waldrop, 1989).

Vegetation response to fire and thinning

Fire has a profound impact on the vegetation community. In studies by both Vogl (1964) and Apfelbaum and Haney (1990), frequent fires minimized or eliminated the shrub layer and encouraged the increase of grasses and forbs, many of which were not apparent before fire was introduced. Indeed, many native savanna specialists (e.g., blazing star [*Liatris scariosa*]) have become locally extirpated as a result of fire suppression (Vogl, 1964; Nielsen et al., 2003;

Packard, 1993). Infrequent fires lead to the encroachment of more shade-tolerant and less fire-tolerant species and allow transition to later successional stages (Spurr and Barnes, 1980; Brose et al., 1999). Such fire lapses allow oak grubs (multi-stemmed sprouts), whose roots are well established, to grow vigorously (Abrams, 1992), thus potentially outcompeting fire-stunted oak trees of the savanna, whose growth rates have been reduced by repeated fires (Aubrey, 2004). Leach and Givnish (1999) found that trees in smaller size classes were typically fire intolerant species (e.g., red maple [*Acer rubrum*]) and concluded that they had invaded the site between fires. Wendel and Smith (1986) determined that repeated fires should be implemented based on their results that fire influences on fire-intolerant species would diminish three years post-burning, thus allowing them to begin to re-establish themselves.

Seasonality of fire has a strong influence on plant species composition (Towne and Owensby, 1984). Spring burning eliminates groundcover leaving behind blackened sites that allow the ground to warm earlier and thus, promote warm-season grass germination with less competition from cool-season species (Blewett, 1976; Howe, 1995). Collins' (1992) study in a Kansas prairie reported that frequent burns encouraged fire-adapted C4 species such as bluestems (*Andropogon spp*.). Howe (1995), also working in Kansas, found that cool-season species benefited more from summer burns. Studies have also shown that summer burns are better at controlling undesirable woody species than dormant-season burns in grassland systems (Blewett, 1976; Gruchy et al., 2006). In fact, one South Carolina study showed that not only was dormant-season burning not effective at eliminating hardwood rootstocks, but that it actually increased their abundance (Waldrop et al., 1987). Thor and Nichols (1974) study in the Highland Rim of Tennessee also concluded that dormant-season burns provide poor control of woody vegetation. Repeated dormant-season burning in the Cumberland Plateau has been shown to reduce regeneration of red maple and other non-oak species (Arthur et al., 1998). Similarly, Brose et al. (1999) found that intense dormant-season burning reduced fire-intolerant hardwoods and to a lesser extent, oaks as well.

Fire intensity also plays a critical role in the development of vegetation. The use of low-intensity fires to control woody understory vegetation has not been effective and does not change overall species composition (Wendel and Smith, 1986; Van Lear and Waldrop, 1989). Brose et al. (1999) documented increased competitive position of oak regeneration with increasing fire intensity due to higher rates of mortality among competitor seedlings versus oak seedlings. Intense fires promote a more robust herbaceous layer (Van Lear and Waldrop, 1989; Elliot et al., 1999). Intense burning has been shown to influence both overstory and understory woody vegetation (Elliot et al., 1999). After a single intense (>800 C) dormant-season fire on an upper slope and ridge-top site on the Nantahala National Forest in North Carolina, species richness and basal area of overstory trees decreased significantly and, in turn, deciduous shrubs (*Vaccinium spp. and Gaylussacia spp.*) and non-woody species increased (Elliot et al., 1999). McMurray et al. (2007) found similar results with fire intensity and topography closely influencing herbaceous vegetation diversity and richness in the Missouri Ozarks.

Gaps, created by fire, influence the understory vegetation composition and structure by allowing light to reach the ground (Scholes and Archer, 1997). Studies have shown that for many years post-burn, total basal area will continue to decrease indicating some fire effects continue to be exhibited years after a prescribed burn (Wendel and Smith, 1986; Peterson and Reich, 2001). However, as fire-intolerant overstory species decrease due to mortality, the more fire-adapted species will begin to show dominance (Aubrey, 2004).

Canopy reductions resulting from mechanical overstory removal often lead to an increase in shade-intolerant hardwood species that out-compete oaks (Aubrey, 2004; Van Lear, 2004). However, shelterwood harvest retain enough canopy cover to maintain fine fuel loads (i.e., leaf litter), allow enough light for oak regeneration, and minimize growth of shade-intolerant competitors such as yellow poplar (*Lireodendron tulipifera*) (Van Lear, 2004). Timber stands that have been mechanically manipulated have shown the best results for the restoration of savannas with respect to structure and diversity (Nielsen et al., 2003). Stump sprouts that develop after thinning are easily top-killed by fire (Apfelbaum and Haney, 1990) forcing subsequent sprouts to originate from underground to produce more fire-tolerant sprouts (Van Lear and Waldrop, 1989).

Fire in the southern Appalachians has been used to promote diversity and production of open field plant species (Swift et al., 1993), but more data is still needed to determine effectiveness of prescribed fires in restoring degraded oak savannas (McPherson, 1997). The shelterwood-burn technique (Brose et al., 1999), which involves treating shelterwood harvested stands with ample advanced oak regeneration with spring or summer burns to decrease competitor abundance, could help improve oak regeneration. Although not specifically evaluated as a tool for creation of oak savannas, the shelterwood-burn technique may have the capability to restore rare fire-maintained ecosystems (Brose et al., 1999). Albrecht and McCarthy (2006) found that the length of time between overstory thinning and the initial prescribed fire is important in promoting oak recruitment by allowing development of root systems able to withstand subsequent fires. The initiation of prescribed fires several years post-harvest reduces fire-intolerant species such as red maple and tulip poplar, and promotes regeneration of oaks (Brose et al., 1999).

Through the use of burning and thinning to restore degraded savannas, Abella et al. (2001) found that richness of native vegetation in the ground layer increased within three years. McMurry et al. (2007) observed that when thinning to 10 m^2/ha residual BA and burning were used together, some woody species decreased in cover and frequency, and herbaceous diversity were greater than burned, control, and thinned plots. Similarly, Clinton and Vose (2000) reported that following a very heavy thinning and burning in a southern Appalachian forest, herbaceous-layer species such as low-bush blueberry (*Vaccinium vaccilans*), greenbrier (*Smilax glauca*), and *Lespedeza spp.* responded with higher densities and canopy coverage. Following a wildlife stand improvement cut (thinning of the midstory and some overstory) and subsequent fires, the herbaceous layer was significantly increased in an oak-pine forest in the Ouachita Mountains (Masters et al., 1996). However, few studies provide information on the combination of fire and overstory thinning on the herbaceous vegetation in oak forest (Hutchinson, 2005). Jackson et al. (2006) suggested that in the short-term, herbaceous species that are fire intolerant may be set back by prescribed fires following harvest of the overstory, while fire tolerant species are stimulated.

Avian Response to fire and thinning

Avian species associated with oak savannas reflect their transitional state between a prairie and forest, and as such it supports both grassland and forest birds (Brawn et al., 2001; Hunter et al., 2001; Lanham et al., 2002). However, Temple (1998) argued that there are no true savanna obligates, but rather only prairie or forest species that exploit different niches of the transitional vegetative type. Grundel and Pavlovic (2007) found that total species richness was greatest in savannas and woodlands when compared to grasslands and forest. Hunter et al.

(2001) and Brawn et al. (2001) identified 128 and 169 bird species, respectively, in eastern North America associated with grassy, shrub-scrub, savannas, open woodlands, and forest gaps, indicating the value of these vegetation types to the avian community. From 1966 – 1991, 16 open grassland or savanna species showed declining population trends (Askins, 1993).

Previous research has examined avian response to oak savanna restoration from degraded savannas (Davis et al., 2000; Brawn, 2006; Grundel and Pavlovic, 2007a; Grundel and Pavlovic, 2007b; Au et al., 2008), however, no research has been identified to have examined avian response to oak savanna from a closed-canopy starting point. Although the use of fire to manage oak savannas and woodlands for avian species is poorly understood (Brawn, 1994), it seems apparent that fire, depending on intensity and timing, could have a dramatic impact on composition of avian species utilizing such sites (Lanham et al., 2002). Frequent burning has been shown to shift composition of breeding birds from mature forest to shrub/scrub, woodland and savanna species (Grundel and Pavlovic, 2007a). Lanham et al. (2002) also concluded that similar shifts of breeding birds from mature forest to early successional species would occur with the introduction of annual or biennial fires following a shelterwood harvest.

Davis et al. (2000) concluded that the shifts in avian species composition due to repeated burning was likely driven by changes in vegetative substrate and the dominant food sources that were available. Changes in food sources shift foraging guilds from bark gleaners and air salliers in mature forest to more omnivorous lower canopy and ground foragers and insectivorous ground gleaners in early successional vegetative type (Davis et al., 2000; Au et al., 2008). These changes have also been proposed as a model for the general response of birds to introduced fires and disturbance (Davis et al., 2000, Hunter et al., 2001). Relying on a regression model, Grundel and Pavlovic (2007a) estimated that if fire frequency increased by 1 fire per 15 years, density of vermivores and ground-granivores would increase by 22.7% and 11.2%, respectively, while density of ground-insectivore species would decrease by 15.7%. The most common guild of avian species present on open woodland and savanna sites in Indiana were omnivorous species that feed primarily in the understory (Grundel and Pavlovic, 2007a).

Other studies have demonstrated the importance of structure to breeding bird use of woodlands and savannas. Brawn (2006) reported indigo buntings (*Passerina cyanea*) and eastern towhees (*Pipilo erythrophthalmus*) were strong indicators of savannas on his Illinois study area. With a decrease in shrub cover these two species decreased in abundance indicating the importance of this type of structure to species diversity. Similarly, Artman et al. (2001) documented declines in abundance of ground and shrub nesting and foraging guilds in response to a reduction in the shrub component as a result of fire. In an Ohio study, repeated late dormant-season burning of a mature forest had the greatest effects on four bird species that did not recover to pre-burn abundance one year post-burn because of a lack of leaf litter; they continued to use the site but at reduced densities (Artman et al., 2001). In the same study, Artman et al. (2001) reported that while some species declined, there were no changes in overall bird species composition with the introduction of fire. However, they were using fire to maintain the current vegetative type rather than for community restoration. Tomcho et al. (2007) detected an increase in shrub-associated birds in the fourth year of annual burning with dormant-season fuel reduction burns in a southern Appalachian hardwood forest.

Controlled burns have the ability to reach high enough intensities to kill trees and create snags important for nesting and foraging by cavity nesting species such as woodpeckers (Van Lear, 2000; Davis et al., 2000). Indeed, despite declines in most of its range, there has been an increase in red-headed woodpecker (*Melanerpes erythrocephalus*) abundance associated with oak savanna vegetative types in Illinois (Brawn, 2001). Snags are also used as perches for hawks and singing perches for songbirds such as indigo buntings (Davis et al., 2000; Lanham et al., 2002).

One limitation to the management of avian species is the understanding of how various silvicultural techniques affect bird communities (Dickson et al., 1995, Annand and Thompson, 1997). Dickson et al. (1995), Gram et al. (2003), and Brawn (2006) all noted that the avian community would be affected by the restoration process due to changes in vegetative structures that occur during transition from mature forest to more savanna-like conditions resulting from mechanical thinning. Indeed, bird use has been closely associated with vegetative structures (Engstrom et al., 1984) including vertical structure (MacArthur and MacArthur, 1961) and successional stage (Shugart and James, 1973). Basal area of large woody vegetation, a good determinant of canopy coverage, was shown to be a significant predictor of avian species diversity; however, this diversity varies with season (Grundel and Pavlovic, 2007).

Modern silviculture treatments include shelterwood cuts, group selection, and clear cuts, all of which result in varying responses by birds (Annand and Thompson, 1997, Engstrom et al., 1984). Undisturbed mature forest is another critical habitat type for birds. Mature forests are variable, but generally have high basal areas and closed canopies (Dickson et al., 1995; Annand and Thompson, 1997). Species such as ovenbird (*Seiurus aurocapillus*) and wood thrush (*Hylocichla mustelina*) are associated with mature forests and are influenced by disturbances that create gap openings or remove leaf litter (Annand and Thompson, 1997). A study in the Missouri Ozarks found mature forest species to not only decline after mechanical overstory removal, but also decline in adjacent control sites by 24 - 69%, which prevents a definitive conclusion about how mature forest birds respond to silviculture harvest (Gram et al., 2003).

This demonstrates that silviculture harvest could have indirect consequences on mature forest species that are adjacent to undisturbed areas of mature forest. Conversely, (Gram et al., 2003) found a general increase in early successional species following even- and uneven-aged harvest.

Group selection cuts, which create two to five 0.2-0.4 ha openings per 8 +/- ha of forest, have been documented to attract late successional forest canopy-gap species as well as early successional species (Annand and Thompson, 1997). After initial harvest, early successional species utilizing the shrub layer tend to increase (Barber et al., 2001, Haney et al., 2001). Moorman and Guynn (2001) documented that the number of early successional species, such as indigo bunting and common yellow-throat (*Geothlypis trichas*) increased as group selection area increased. Hooded warblers (*Wilsonia citrina*) prefer group and single tree selection cuts because of the dense understory vegetation resulting from the harvest (Dickson et al., 1995; Annand and Thompson, 1997; Moorman and Guynn, 2001).

Shelterwood cuts and clearcuts result in higher diversities and abundances of avian species than selection cuts, likely due to the structural diversity created by the harvest (Annand and Thompson, 1997). Augenfeld et al. (2008) also concluded that species diversity increased with shelterwood harvest at their Land Between the Lakes National Recreation Area study site within one year of harvest due to an increase in horizontal heterogeneity. In addition, residual live trees and snags allow canopy species associated with mature forest to continue to use the stand (Dickson et al., 1995). However, shelterwood cuts have also been shown to result in higher nest predation due to increased abundances of predators (Barber et al., 2001).

Conclusion

Prescribed fire and mechanical overstory thinning of forested ecosystems have been shown to be more effective in restoring the herbaceous layer than either method alone (McMurry et al., 2007), indicating the importance of both of these as tools for restoring oak savannas. However, as I learn more about this imperiled ecosystem, adjustment of research and management strategies will have to be continued (Packard, 1993; Leach and Ross, 1995).

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II. VEGETATION AND AVIAN RESPONSE TO OAK SAVANNA RESTORATION IN THE MID-SOUTH

ABSTRACT

Oak savannas are among the most imperiled ecosystems in the United States as a result of land-use conversion, incompatible silviculture, and disrupted fire regimes. Consequently, associated vegetation and avian communities are also in decline. Furthermore, restoration of savanna communities may be an important strategy for conserving avian species that require early successional habitat, a type that is underrepresented on regional landscapes. Therefore, I evaluated savanna restoration strategies through a meta-analysis of twelve case studies in Tennessee and Kentucky. Specifically, I looked at factors influencing vegetation and avian response following mechanical overstory thinning and dormant-season fire. I measured grass, forb, legume, and woody understory cover, regeneration and sapling density. I also conducted point counts to assess breeding bird use of the sites. Groundcovers, regeneration density, sapling density and relative abundances of breeding birds were analyzed using hierarchical linear modeling. Total grass cover was negatively related to canopy cover (P <0.01). Total forb cover was negatively related to total basal area ($P = 0.04$). Oak regeneration density was positively related to canopy cover (P <0.01), while oak competitor regeneration density was positively related to percent slope ($P = 0.01$) and sapling density ($P = 0.01$). Grass and forb cover and herbaceous species richness were not related to topographic variables. With respect to breeding birds, I found forest species persisted within case studies despite increased disturbance. Shrub/scrub birds were common within case studies that were two years post-disturbance. Only three obligate grassland bird species, eastern kingbird (*Tyrannus tyrannus*), Bachman's sparrow (*Aimophila aestivalis*) and dickcissel (*Spiza americana*), were observed on my sites. Presence of indigo buntings (*Passerina cyanea*) was positively related to the groundlayer development;

whereas red-headed woodpeckers were positively related to the basal area of dead trees. Based on my results, canopy reduction and growing-season burns may both be critical to restoration of savannas in the region.

INTRODUCTION

Oak savannas once encompassed >11 million ha in the Midwest, but have been reduced to less than 1% of their original extent (Nuzzo, 1986). Savannas stretched into the southern Appalachians (Waldrop and Van Lear, 1989) and the Piedmont where historic documents describe a “grande savanne” that exists now only in isolated remnants (Davis et al., 2002). Most savannas were cleared for cropland, converted to pasture or succeeded into closed-canopy forests as a result of fire suppression (Curtis, 1959; Noss and Peters, 1995; Anderson, 1998; Bowles and McBride, 1998). Noss and Peters (1995) also concluded savannas were one of the most imperiled ecosystems in the United States, further highlighting the need for restoration.

In the mid-South, where early successional forest landscapes are under-represented, the loss of savannas has contributed to the decline of many grassland avian species (Askins, 1993; North American Bird Conservation Initiative, 2009). Two species described as savanna obligates, Bachman’s sparrow (*Aimophila aestivalis*) and red-headed woodpecker (*Melanerpes erythrocephalus*), have declined annually between 1966- 2007 by -0.67% and -1.53%, respectively (Sauer et al., 2008). Grassland species such as Henslow’s sparrow (*Ammodramus henslowii*) have also experienced population declines due to loss of suitable habitat in recent years (Galligan et al., 2006). Brawn et al. (2001) concluded that 40% of disturbance-dependent species associated with grassland, shrub-scrub, and open woodlands were in decline between 1966 and 1998. The restoration of oak savannas can help reverse this trend by providing high quality habitat (Askins, 1993; Packard, 1993).

Despite the critical need to restore these imperiled habitats (Leach and Ross, 1995), research evaluating the effects of mechanical thinning and prescribed fire when restoring oak savannas is limited. Many investigators have concluded that fire alone may not be sufficient to restore oak savanna ecosystems and that mechanical methods may reduce the time required for restoration to years rather than the decades required when using burning alone (Abella et al., 2001; Peterson and Reich, 2001; Nielson et al., 2003). Although there has been some work conducted on the western periphery of the range of savannas (Apfelbaum and Haney, 1990; Rebertus and Burns, 1997; Davis et al., 2000; Peterson and Reich, 2001), studies in the mid-South are entirely lacking. While some research has incorporated both mechanical thinning and prescribed fire, it has been conducted in partially degraded savannas where succession has not advanced to the point of closed canopy forests (Apfelbaum and Haney, 1987; Nielson, 2003; Au et al., 2008). Studies addressing oak savanna restoration starting from mature closed-canopy forests have not been conducted to date.

Furthermore, research focused on savanna restoration has not adequately addressed changes to avian communities when fire and mechanical overstory thinning are used together. Only informed speculation concerning avian response to overstory thinning and prescribed fire are available for the mid-South (Lanham et al., 2002). This presents a crucial need for research on avian communities in the context of oak savanna restoration efforts.

Therefore, I conducted a meta-analysis of 12 case studies from active savanna restoration projects in the mid-South in various stages of development to help improve my understanding of vegetation and avifaunal responses to restoration. My specific objectives were to document changes in herbaceous vegetation, woody vegetation, and avifauna within mature, oak-dominated forests in the mid-South in response to disturbances imposed for the purpose of savanna restoration. In addition, I evaluated the influence of topographic variables on vegetation during the restoration process. Finally, I evaluated the relationship between breeding bird observations and vegetation during the restoration process.

Study Areas

Twelve case studies from five sites in Kentucky and Tennessee were chosen based on current savanna restoration activities. The first site was the 32,374 ha Catoosa Wildlife Management Area (CWMA) located in Cumberland County, Tennessee. The second site, Land Between the Lakes National Recreation Area (LBL), located in Stewart County, Tennessee, encompassed approximately 69,201 ha. The third and fourth sites were located on the Sterns (STERNS) and Cumberland (CUMB) Ranger Districts , respectively, of the 286,113 ha Daniel Boone National Forest in eastern Kentucky. The fifth site was located on Fort Campbell Military Base (FCMB), a 43,180 ha property located in Stewart and Montgomery Counties, Tennessee and Trigg and Christian Counties, Kentucky, and included an established oak savanna. Within these five sites, I selected 12 case studies (Table 2.1) representing a continuum in the savanna restoration process, from mature, closed-canopy forest to, areas that had been disturbed by a different number of burns, overstory mechanical thinning, or both. One case study also was treated with drum-chopping.

These areas were characterized by topography that ranged from moderately rolling hills and broad drainages to those with narrow ridges dissected by steep ravines. Elevations ranged from 150-549 m above sea level with slopes between 6 and 80%. Between 1971- 2000, average annual temperatures ranged from 11.7-14.4 C and average annual rainfall was 117 – 152 cm (NOAA Climate Data Center, 2009). The soils on these areas were mesic Hapladults or typic

Hapladults over weathered sandstone and weathered cherty limestone parent materials. Forest in these areas were a mixture of oak (*Quercus spp*) and shortleaf pine (*Pinus echinata*) dominated by white (*Q. alba*), black (*Q. veluntina*), scarlet (*Q. coccinea*) and southern red oaks (*Q. falcata*). Pine (*Pinus spp*.) became a minimal component of the stands as a result of pine mortality from a southern pine bark beetle (*Dendroctonus frontalis*) outbreak in 1999-2000.

Four undisturbed sites (C-cont, L-cont, S-cont, and CU-cont), characterized by mature closed-canopy hardwood forests with some pine, were included to provide a baseline (Table 2.1). Three case studies (L-burn1, CU-burn4, S-burn5) were located in closed-canopy forest and had been subjected to one, four, and five prescribed fires, respectively. An eighth case study (C-cut) was subjected to a timber harvest only with no prescribed fire. The ninth (C-cut/burn3) and tenth case studies (C-cut/burn5) were harvested and treated with three and five prescribed fires, respectively. The eleventh case study had a timber harvest, five prescribed fires and was drum chopped (C-cut/burn5 and chop). The twelfth case study (FC-savanna) was included because it was representative of an established oak savanna as a result of 60+ years of annual and biennial burning, which has resulted in a strong herbaceous understory with widely spaced overstory trees. Collectively, these sites represented the broadest gradient in disturbance histories available within the properties and the most advanced stages of oak savanna restoration I was aware of in the region.

Methods

Within each case study, I selected a 40-ha unit, the largest common disturbed area available to all 12 case studies, for sampling. If the size of any case study exceeded 40-ha, I limited my sampling to a 40-ha area selected to be representative of the treated area and configured to maximize core area. To reduce bias associated with edge effects, I limited sampling to the inner 20 ha of each area. Sampling was conducted during 2008 for eight case studies and 2009 for four additional case studies. Case studies were sampled two years post-burning in all cases where fire had been used.

To sample vegetation, I established plots beginning at a randomly located point within each 20-ha core area. Subsequent plots were placed on a 70 x 70 m grid, allowing for a total of 30 per case study (Avery and Burkhart, 2002). At each plot, I centered a 50-m transect perpendicular to the slope and identified plants to species at 1-m intervals along its length to characterize understory cover (Owensby, 1973) (Figure A.1). At each interval, I recorded understory cover as grass, forb, legume, or woody plant. I also sampled vegetation in 1-m^2 and 3-m radius sub-plots (28 m^2) placed at plot center and both ends of the transect (0, 25, 50-m marks). On the 3 1-m^2 sub-plots, I counted tree seedling regeneration and vines and shrubs between 30.48 cm – 1.37 m tall. On the 3 3-m radius sub-plots, I sampled woody sapling stems 2.54 -12.7 cm DBH. I sampled the overstory using an 11.3-m radius sub-plot placed at plot center. A 2.5X metric prism was used to measure basal area (m^2/ha) of live and dead trees from plot center.

I also recorded percent slope, azimuth, and slope position (ridge, shoulder, mid-slope, toe-slope, cove, or alluvial) for each plot at plot center. Four spherical densitometer measurements taken at plot center were used to measure the overstory canopy cover.

I sampled the avian community using standard point count protocol (Ralph et al., 1993). Eight points were distributed throughout the 20-ha core area of the sampling unit. Bird points were separated by >200 m (Ralph et al., 1993). At each point the observer recorded all species seen and heard during a 10 min period. Each point was sampled once between 10 May and 15 June, in 2008 or 2009 depending on the case study. No sampling was conducted during rain or when wind was inhibiting avian detection (Ralph et al., 1993).

Analysis

I conducted a meta-analysis (Johnson, 2002) of my vegetation data using hierarchical linear modeling (HLM) in SAS 9.1 using PROC MIXED (SAS Ins., Cary, N.C, USA). Hierarchical linear modeling is a statistical approach that fits a regression model to cross-level data (Wech and Heck, 2004), in this case fitting regression equations for related variables across all plots (n = 360). I calculated percent cover by dividing the intercepts for a given cover class by 50 (total number of potential intercepts). Means stem densities from the 3 1-m^2 and 3-m radius sub-plots were calculated on a per plot basis (n = 3). All oaks were pooled in the regeneration and sapling size classes as a result of low sample sizes for individual species. Also, other hardwood overstory species including maples (*Acer spp*.), tulip poplar (*Liriodendron tulipifera*), and sweetgum (*Liquidambar styraciflua*) were classed together as oak competitors.

The HLM allowed me to test my dependent variables collected at individual plots across all case studies while accounting for variability within and between levels and has been used in other oak savanna research previously (Peterson et al., 2007). Separate models were developed for groundcover, midstory, and avian measures. Interclass correlation (ICC) was calculated in PROC MIXED to determine the amount of variation in the dependent variable that can be explained by the case study (Wech and Heck, 2004). Dependent variables were tested for normality using a Wilk's test (W > 0.90) using PROC Univariate and transformed, if necessary, using square root, log, or natural log transformation. I tested each of the dependent variables against my independent variables to determine if they could be modeled as random slopes in the final model by entering the independent variable in the random statement in my model. If the relationship did not have random slopes, the independent variables were removed from the random statement and not modeled as random. I then ran a regression model with all of the independent variables using backwards variable selection with a selection criteria for inclusion in the final models being ($P < 0.05$). If the removal of a non-significant variable increased the Akaike's Information Criteria (AIC) value produced by that model, the variable was left in the model as the most parsimonious solution.

Dependent variables included mean percent grass, forb, and legume cover, herbaceous species richness (groundcover model), vine and shrub density, oak regeneration, competitor regeneration density, oak sapling, and competitor sapling density (midstory model). My independent variables for both models were percent slope, slope-position, aspect, percent canopy cover, sapling density (except in midstory model), canopy cover, and total basal area (m^2/ha), and were selected *a priori*, based on their expected influence on the vegetation. In both models, aspect was transformed following Beers (1966), where a value of 0.00 represents a southwest aspect and a value of 2.00 represents a northeast aspect. I used this transformation to account for site productivity based on aspect. I assigned the slope positions as numerical categorical variables such that alluvial, cove, toe-slope, mid-slope, shoulder, and ridge were classified 1-6, respectively.

Eight avian species documented on the point counts were also analyzed using the same HLM approach outlined above. Bird species included in my analysis were selected based on their presence on at least half of the case studies (n = 6) and >46 observations, except for the red-headed woodpecker (RHWO), which only was sighted 11 times. The next highest species, eastern towhee (*Pipilo erythrophthalmus*) was only observed 22 times across six sites, thus towhee's and less frequently observed species were not included in the model. Although, the red-headed woodpecker had low detections, I decided to include it due to its strong association with savanna-like conditions (Brawn, 2006). The other seven species were ovenbird (*Seiurus aurocapillus*; OVEN), red-eyed vireo (*Vireo olivaceus*; REVI), hooded warbler (*Wilsonia citrina*; HOWA), blue-gray gnatcatcher (*Polioptila caerulea*; BGGN), tufted titmouse (*Baeolophus bicolor*; TUTI), indigo bunting (*Passerina cyanea*; INBU), and prairie warbler (*Dendroica discolor*; PRAW), and represented a continuum from mature forest species to early successional species. Detections at each point (n = 96) for each of these species was used as my dependent variable in the HLM. Independent variables were percent grass, forb, and woody understory cover, vine and shrub density, seedling density, sapling density, total basal area, and the basal area of dead trees. These variables were chosen based on their characteristic savanna attributes and their influence on avian site selection along a gradient from forest to savanna (Dickson et al., 1995; Davis et al., 2000; Grundel and Pavlovic, 2007).

For all three final models (groundcover, midstory, avian), I tested for normality of the residuals using Wilke's test (W > 0.90) in PROC Univariate. Intercepts were compared among case studies with a chi-square test. Where intercepts differed (P < 0.05), I compared the means for dependent variables among case studies using a one-way ANOVA in PROC MIXED.

I determined avian species richness and diversity at the case study level (8 point counts per case study) using Shannon-Wiener's Diversity Index (Magurran, 1988). Avian species were also separated into three guilds (grassland, shrub/scrub, and forest) based on breeding habitat groups as defined by the Breeding Bird Survey (Sauer et al., 2008). An "other" guild was given to species not belonging to any of these groups, such as chipping sparrow (*Spizella passerina*).

Results

Grass cover differed among case studies ($P < 0.05$) and ranged from 0.7% under closed-canopy forest to 38.3% in the FC-savanna site (Table 2.2). Across the twelve case studies, needlegrass (*Piptochaetium avenaceum*) was the most abundant species and accounted for 29% of the grass cover in C-burn5. Deertounge (*Dicanthelium spp.*) and sedge (*Carex spp.*) were both common and found in all case studies with cover ranging from 0.1 – 9.2% and 0.3 – 3.3%, respectively. Two common grasses in savannas, big bluestem (*Andropogon gerardii*) and indiangrass (*Sorghastrum nutans*), were absent in most of the case studies and when present had minimal cover. Three non-native grass species were encountered (johnsongrass [*Sorghum halepense*], tall fescue [*Festuca arundinacea*], and cheat [*Bromus tectorum*]), however, these species had low percent cover (< 0.5%) in the 5 case studies where present.

Forb cover differed among case studies ($P < 0.05$) and ranged from 0.6 % under closed-canopy forest to 20.3 % in the FC-savanna site, the highest forb cover of any site (Table 2.2). Goldenrod (*Solidago spp*.) was the most abundant forb across the case studies. Two non-native forb species were identified, ox-eyed daisy (*Leucanthemum vulgare*), only found in the C-cut/burn5 and Chop, and red sorrel (*Rumex acetosella*), only found in C-cut/burn3. These two species only made up 0.1% cover in their respective stands.

Legume cover differed ($P < 0.05$) among case studies, but remained a minimal component of all the case studies with cover ranging from none under closed-canopy forest to

2.6 % in the FC-savanna (Table 2.2), except for the S-cont, where legumes averaged 3.2% cover. Beggarlice (*Desmodium spp*.) and lespedeza (*Lespedeza spp*.) were the most abundant legumes observed across the case studies. Three non-native legumes were identified. Crown vetch was identified only at the CU-burn4 and made up 0.9% cover. Serecia lespedeza (*Lespedeza cuneata*) and sweet clover (*Melilotus spp.*) were identified at the FC-savanna and made up 4.3% and 0.1% cover, respectively. Fern cover was minimal in all case studies and moss cover was almost non-existent. Herbaceous species richness differed among case studies ($P < 0.05$) and ranged from 0.83 under closed-canopy forest to 9.2 in the FC-savanna (Table 2.2). Understory woody vegetation cover differed among case studies ($P < 0.05$) and ranged from 15% under closed canopy to 69% in the S-burn5 but was only 10.7% in the FC-savanna case study (Table 2.2).

Vines and shrub, oak regeneration, competition regeneration, and oak sapling densities did not show any trend with the increase in disturbances (Table 2.3). However, oak competitor sapling densities appeared to decrease as disturbance increased. Blackberry (*Rubus spp*.) and greenbrier (*Smilax spp*.) were the most common species across the twelve case studies, with proportions ranging from 0 - 67% and 0 - 36%. Multiflora rose (*Rosa multiflora*) was the only exotic species identified and was only found in the S-burn5 and comprised less than 1.8% of the total stems. Red maple was the most common species within the regeneration pool and proportions of total stem densities for the 9 case studies where it was present ranged from 0 – 70%. Black oak and white oak were the dominant regenerating oaks, but individually each made up a relatively small (<20.4%) portion of the total regeneration on any case study. Red maple, black gum, and sourwood were the most common sapling species across the twelve case studies, with red maple making up the greatest proportion of saplings in each case study. Black oak and white oak made up the largest proportion of oak saplings in each of the case studies. However, oak sapling proportion remained low across all case studies (<11.6%).

Prairie warbler, red-headed woodpecker and indigo bunting all had greater ($P < 0.05$) detections as disturbance increased (Table 2.4). Prairie warblers were absent on three of the four controls as well as the FC-savanna site (Table 2.4). Similarly, red-headed woodpeckers were absent on all control sites and the FC-savanna. Ovenbirds and hooded warblers had fewer ($P < 0.05$) detections on sites with increased disturbance, whereas tufted titmice and blue-gray gnatcatchers did not show any trends with disturbance. Avian species diversity ranged from 2.5 – 3.2 (Table 2.5). The number of forest guild species ranged from 15 –18 in the controls to 7 in the FC-savanna. Only one shrub/scrub species was encountered in the controls and 11 in the FC-savanna. At only two case studies was a grassland-obligate species encountered (Table 2.5). In the C-cut/burn5 and Chop, I observed four eastern kingbirds (*Tyrannus tyrannus*) and at the FC-savanna I observered one Bachman's sparrow (*Aimophila aestivalis*) and two dickcissel's (*Spiza americana*).

Based on the HLM, herbaceous species richness was negatively related to sapling density only ($P = 0.03$) (Table 2.6) and tended to increase with increasing disturbance (Figure 2.1). Grass cover was negatively related to percent canopy cover ($P < 0.01$) and tended to increase with increasing disturbance (Figure 2.1). Forb cover was negatively related to total basal area ($P = 0.04$) and tended to increase with increasing disturbance (Figure 2.1). Legume cover was positively related to slope ($P = 0.03$). Woody understory plant cover was negatively related to both percent canopy cover ($P = 0.02$) and sapling density ($P < 0.01$). Vine and shrub density was positively related to sapling density ($P = 0.04$) (Table 2.7). Oak regeneration was positively related to canopy cover ($P < 0.01$) (Figure 2.1). Competition regeneration was positively related to percent slope ($P = 0.01$) and sapling density ($P = 0.01$). Oak sapling density was not significantly related to any of the variables tested. Oak competition sapling density was positively related to total basal area ($P = 0.02$). With the exception of legume cover, site factors such as aspect, slope and slope position were not related to any groundcover category and were not significant in any of my models.

Ovenbird detections were related to total basal area ($P = 0.01$), positively, and basal area of dead trees ($P = 0.02$), negatively (Table 2.8). Red-eyed vireo detections were negatively related to grass cover ($P = 0.07$), forb cover ($P = 0.04$), and woody understory cover ($P = 0.03$). Detections for hooded warblers were only related to grass cover ($P < 0.01$). Indigo bunting detections were related to grass ($P < 0.01$), forb ($P = 0.06$), and woody plant cover ($P = 0.12$). Red-headed woodpecker detections were positively related to basal area of dead trees ($P < 0.01$). Blue-gray gnatcatcher, tufted titmouse, and prairie warbler detections were not related to any of the variables tested.

Discussion

Despite increased interest in restoration of oak savannas, our understanding of how this process is best accomplished and how such ecosystems function remains limited (Leach and Ross, 1995). In particular, few investigators have addressed oak savanna restoration beginning from a mature close-canopied forest, or the use of mechanical overstory thinning and prescribed fire in combination.

Based on my results and the work of others (Scholes and Archer, 1997; Leach and Givnish, 1999; Peterson et al., 2007), it appears that overstory reduction is important to the development of the herbaceous layer. Overstory thinning is a critical step in restoring oak savannas because it allows species that require additional light to germinate and grow. Indeed, I often found native warm-season grasses growing in canopy gaps within mature hardwood stands where these species did not otherwise occur. Overstory thinning could accomplish two goals quickly: provide revenue from harvested timber and reduce canopies to acceptable levels. During overstory reduction, species common to savannas should be left, shifting the overstory composition towards conditions similar to those reported in historic accounts (Peterson and Reich, 2001).

Scholes and Archer (1997) discuss in depth the role of overstory trees on grasses and cite many factors that influence the presence of grass, including competition for resources with overstory trees and the shading effect caused by overstory canopies. Similarly, Peterson et al. (2007) found forb cover was negatively related to tree canopy cover. In my study, sapling density also negatively influenced herbaceous species richness. This second canopy could have important consequences for savanna restoration by limiting species richness and, potentially, occurrence of rare species. Some species that have been locally extirpated have been found growing in the some of more advanced stages of savanna restoration in my study, including rattlesnake master (*Eryngium yuccifolium*), yellow indigo (*Baptisia tinctoria*), blazing star (*Liatris spp.*), and five species of bluestem (*Andropogon spp.*). Therefore, it may be inferred that overstory reduction is critical for increasing herbaceous vegetation, and sapling reduction for enhancing herbaceous species richness, both important goals of any restoration effort.

Although savannas are rich in forb diversity (Bray, 1960) and may even be forb- rather than grass-dominated (Leach and Givnish, 1999), I did not see forb cover >20.3% on any case study. This might be a reflection of the current stage of development of the sites in my study and indicate the slow response of fire-adapted forbs to reintroduced fire. Other studies have also found forbs respond positively to fire, but with only small increases in cover after multiple fires (Hartman and Heumann, 2003; Hutchinson et al., 2005). I also found legumes to be a minor component of the herbaceous layer, even in stands that had been cut and received multiple burns. Nielson et al. (2003) also noted legumes failed to respond positively, or were absent, after overstory thinning and prescribed fire, and suggested that the seedbank may have been depleted after canopy closure. This could explain the minimal cover of legumes in my study given that the age of timber on my sites exceeded 60 years. Understory woody plant cover was negatively related to canopy cover and sapling density. This relationship has also been shown in Iowa, where the distance from the boles of trees within the savanna was directly correlated with increasing woody plant cover (Brudvig and Asbjornsen, 2009). The understory woody plant cover in my study was dominated by *Vaccinium spp.* and hardwood stems, most arising from the sprouting of stumps and extant root systems. In early stages of savanna restoration, the presence of woody sprouts arising from cut stumps is common (McCarty, 2002), and is likely caused by the increase in nitrogen availability following overstory thinning (Reich et al., 2001) and increase in light reaching the ground (Larson and Johnson, 1998).

I identified nine non-native species in the grass, forb, legume, and vine and shrub categories, eight of which never exceeded 0.9%, and the ninth, serecia lespedeza at the FC-savanna, made up only 4.3% of the groundcover. Other research has noted the invasion of European buckthorn (*Rhamnus cathartica*) (Apfelbaum and Haney, 1990) and serecia lespedeza into established savannas (Eddy and Moore, 1998). Grace et al. (2001) observed the response of various invasive plants to prescribed fire and concluded that the different species respond differently to fire, requiring other management strategies to achieve control. It is important to note these species were found near the peripheries of the sampling area and were likely encroaching from nearby roads. Though continued monitoring is needed on these sites, the limited abundance of non-native species, despite substantial disturbances associated with mechanical overstory thinning and prescribed fire, suggests that protection of the integrity of this ecosystem during restoration is possible.

Although data on four of my case studies was collect in a second year (2009), I do not believe that year differences are a serious concern. The four where data were collected during 2009 included sites that were spread across the full range of the disturbance gradient that I sampled and, therefore, would not be biased in any particular direction with respect to this important factor. Furthermore, woody vegetation, including canopy cover, would not have changed during a single growing season and virtually all of the herbaceous vegetation was perennial and would have been less likely than annual vegetation to change in an appreciable manner. Indeed, on one case study for which I collected data in both years (C-cut/burn5; unpublished data), I found grass and forb cover did not differ between years. Furthermore, under the model that I used, site-level variation was captured by the ICC and could be accounted for as a component of location effect.

Site factors such as aspect, slope and slope position did not influence groundcover. This has important implications for restoration. Because these factors do not appear to be influencing herbaceous groundcover development, managers may be able to restore savannas on a larger scale and not be constrained by topographic limitations. Elliot et al. (1999) observed similar results in the mountains of North Carolina, reporting that though there were some community differences related to topography (e.g., dry mixed-oak vs. mesic hemlock-poplar [*Tsuga-Populus*] or cove hardwoods), individual species were found over a wide range of topographic positions. In another North Carolina study, Clinton et al. (1994) found, as I did, that seedling density did not differ between ridges, mid-slope, or toe-slopes. However, some studies have concluded there were topographic effects on individual herbaceous species and the diversity of herbaceous species (Anderson and Anderson, 1975; Abrams and Hulbert, 1987; Nielson and Haney, 1998).

Although I was unable to isolate site and fire effects under my meta-analysis approach, the substantial site-level effects demonstrated by the ICC values, differing model intercepts, and consistent patterns in the case study means identified in the ANOVA all suggest that this disturbance was a valuable component of restoration with important effects on herbaceous vegetation (Figure 2.1). A replicated experiment with differing fire and canopy treatments would be required to clarify fire effects; however, I did not have access to such an opportunity in my study. Indeed, such research is lacking in savanna restoration literature.

Seasonality of fire should be an important consideration in managing understory woody vegetation during restoration. There is historical evidence that fires typically occurred during the growing season in both oak-pine forest (Barden and Woods, 1973) and in pine savanna ecosystems Huffman (2006). In my study, understory woody vegetation was not adequately reduced with dormant-season fires. Other workers have concluded that dormant-season fires are not effective at reducing hardwood stems because of prolific resprouting (Thor and Nichols, 1973; Blewett, 1976; Waldrop et al., 1987). Conversely, growing-season fires may reduce woody stem densities, including oak, albeit to a lesser extent (Keyser et al., 1996; Brose and Van Lear, 1998; Waldrop et al., 2002). A change to growing-season fire is likely needed to restore savannas more quickly by reducing density of resprouting woody stems.

I found that regeneration and sapling strata were influenced by sapling density and by overstory metrics, respectively. Hutchinson and Sutherland (2000) concluded some species with greater sprouting abilities (e.g., oaks) would persist longer with repeated fires. I did not detect consistent trends for oak or oak competitor regeneration or oak sapling density with increasing disturbance. The low proportion of oak regeneration may have been a result of herbaceous vegetation competing for limited resources (Scholes and Archer 1997; Davis et al. 1999), or the continued acorn production of retained overstory trees. The black and white oaks that remained dominant within the regeneration and sapling pool could reflect the adaptation of these species to fire. As was the case with the oaks, I did not observe any trends associated with competitor regeneration, a finding that could have been a result of the competitors' (e.g., red maple), ability to continue resprouting prolifically, even after multiple fires (Arthur et al., 1998; Blankenship and Arthur, 2006). However, I did find, in agreement with other workers, that competitor saplings decreased with the increase in disturbance (Wendel and Smith, 1986; Elliot et al., 1999; Blankenship and Arthur, 2006), likely as a result of these species being less fire tolerant and, therefore, being top killed. Such stems may have sprouted back, but would have been accounted for within a smaller vegetation size class.

For several of the avian species I studied, I was able to document relationships between detections and vegetative characteristics. The lack of such relationships for blue-gray gnatcatchers and tufted titmice is likely a result of their presence across a wide gradient of site conditions ranging from mature forest to open savanna. Other workers have shown titmice and blue-gray gnatcatchers persist under a wide range of deciduous overstory and shrub conditions (Ellison, 1992; Grubb and Pravasudov, 1994). Indeed, Grundel and Pavlovic (2007*a*) concluded the variation in multiple vegetation strata from the ground to the canopy was not useful in predicting density for 33% of the avian species they tested. That ovenbirds were positively related to basal area is understandable given they require mature forest stands (Annand and Thompson, 1997). Past research has also demonstrated that ovenbird densities are related to basal area, but the significance of this relationship varied among studies (Van Horn and Donovan, 1994). Red-eyed vireo and hooded warbler presence was related to groundcover metrics that are an artifact of overstory condition. That overstory condition itself did not prove an effective predictor may have been because the structural requirements of these species are more complex than the fairly simple measures that I collected could discriminate. Indeed, understory development may actually be a better index of the complex and somewhat open canopy architecture important to these species (Ogden and Stutchbury, 1994; Cimprich et al., 2000) than any direct measures I had available. In any case, that these relationships were documented across 12 sites representing a wide geographic area with a broad gradient of disturbance suggests that the results may be meaningful.

Grundel and Pavlovic (2007*b*) and Au et al. (2008) both concluded savannas were an ecotone, harboring both generalist prairie and forest species. This contention is supported by my observation that forest species persisted in the more disturbed sites in my study. That a number of forest bird species were included in the model is a function of the sites having been in the process of restoration and, therefore, conditions at the time of my study being more like woodlands than savannas. Thus, because savannas provide some benefit to forest species while fostering habitat useful to early successional species, savanna restoration may represent an optimal approach for the conservation of scrub/shrub or grassland species, and in any case, can enhance avian species diversity (Lanham et al. 2002). Red-headed woodpeckers were related to the basal area of standing dead trees, an intuitively obvious finding, but one dissimilar to

Grundel and Pavlovic (2007*a*), who found their occurrence to be associated with a decrease of the shrub layer. My results indicate that conservation for red-headed woodpeckers, which have experienced regional population declines (Sauer et al., 2008), could benefit from savanna restoration. Prairie warblers were quite abundant, though not related to any of independent variables tested. This may be a result of species selecting other aspects of vegetation structure that I did not measure, such as lateral branching or specific trees, such as elm (*Ulmus spp.*) (Nolan et al., 1999),. The absence of prairie warblers from FC-savanna, where they commonly occur, may have been a result of a recent fire that reduced shrub density. In my study, the lack of grassland obligate species is likely a result of continued presence of a woody rather than grass-dominated understory. The presence of grassland and shrub/scrub species at the FC-savanna site is likely a result of a strong herbaceous layer and the presence of a shrub component. At the Fort Campbell Military Base, I observed similar shrub/scrub species to those on the other disturbed case studies. However, the presence of grassland species at the Fort Campbell Military Base site is likely a result of large open tracts of grasslands, which provide a more favorable landscape context for grassland species such as Henslow's sparrow (Herkert et al., 2002) and grasshopper sparrows (*Ammodramus savannarum*) (Vickery, 1996). With the continued use of prescribed fire and the reduced frequency of woody stems, there will likely be a greater presence of grassland species at these sites as grass-dominated understories develop.

My study provides insight into important factors affecting oak savanna restoration. While, my results are not replicated, they still provide information that is lacking in the literature involving oak savanna restoration from mature hardwood forest and extends our understanding of these processes into the mid-South region. Also, my study has provided additional insight into the combined use of fire and canopy reduction. Further, research that is continuing on these sites is likely to help us gain a better understanding of the responses of herbaceous vegetation and woody stems to overstory thinning and prescribed fire.

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Appendix

Table 2.1 Site descriptions for twelve oak savanna restoration case studies in Tennessee and Kentucky sampled during 2008 and 2009.

Site	Description	Case Study Acronym	Basal Area (m^2/ha)	Soil Description	Latitude/Longitude
CWMA[1]	unburned unthinned	C-cont	22.4	Mesic Typic Hapludults, Mesic Typic Dystrudepts	84° 84' 59.10" 36° 07' 81.70"
CWMA[1]	Thinned only	C-cut	14.4	Mesic Typic Hapludults	84° 87' 06.72" 36° 06' 76.95"
CWMA[1]	thinned and burned three times	C-cut/burn3	10.6	Mesic Typic Hapludults	84° 86' 61.66" 36° 06' 13.12"
CWMA[1]	thinned and burned five times	C-cut/burn5	11.7	Mesic Typic Hapludults, Mesic Typic Dystrudepts	84° 87' 86.54" 36° 05' 63.85"
CWMA[1]	thinned and burned five times and drum chopped	C-cut/burn5 and chop	9.0	Mesic Lithic Dystrudepts, Mesic Typic Hapludults	84° 87' 89.08" 36° 05' 97.16"
DBNF[2]	unburned unthinned	S-cont	25.8	Mesic Typic Hapludults	84° 45' 03.59" 36° 86' 55.45"
DBNF[2]	burned five times	S-burn5	11.5	Mesic Typic Hapludults, Mesic Typic Dystrudepts	84° 23' 01.18" 36° 95' 84.65"
LBL[3]	unburned unthinned	L-cont	19.9	Thermic Typic Hapludluts, Thermic Typic Paleudults	87° 92' 80.47" 36° 64' 23.22"
LBL[3]	burned 1 time	L-burn1	20.3	Thermic Typic Paleudults, Thermic Typic Hapludults	87° 95' 69.72" 36° 64' 05.32"
Cumberland[4]	unburned unthinned	CU-cont	26.3	Mesic Typic Hapludalfs, Mesic Typic Dystrudepts	83° 56' 68.33" 38° 04' 83.14"
Cumberland[4]	burned 4 times	CU-burn4	21.9	Mesic Typic Hapludalfs, Mesic Typic Dystrudepts	83° 55' 82.85" 38° 05' 92.19"
FCMB[5]	current savanna	FC-savanna	1.8	MesicTypic Paleudults, Thermic Glossic Fragiudults	87° 64' 82.53" 36° 63' 35.96"

1. Catoosa Wildlife Management Area

2. Sterns District of the Daniel Boone National Forest

3. Land Between the Lakes National Recreation Area

4. Cumberland District of the Daniel Boone National Forest

5. Fort Campbell Military Base

Table 2.2 Mean (se) percent understory vegetation cover on twelve oak savanna restoration case studies located in Tennessee and Kentucky and sampled during the summers of 2008 and 2009.

Case Study	Grass cover[1,2]		Forb cover[3]		Legume cover[4]		Understory woody cover[5]		Herbaceous species richness[6]	
S-cont	0.7 (0.3)	G	0.9 (0.3)	FG	3.2 (0.8)	A	28.8 (2.0)	CD	1.3 (0.3)	FG
C-cont	1.6 (0.5)	G	1.1 (1.1)	G	0.0 (0.0)	E	22.3 (2.4)	DE	0.8 (0.2)	G
L-cont	5.3 (2.1)	FG	0.6 (0.2)	FG	0.0 (0.0)	E	15.1 (2.2)	EF	0.9 (0.2)	G
CU-cont	2.0 (0.5)	G	2.5 (0.6)	DE	1.0 (0.5)	CD	31.1 (3.3)	C	2.0 (0.0)	EF
C-cut	10.9 (1.8)	DE	1.2 (0.4)	EFG	0.1 (0.1)	E	31.1 (2.6)	C	2.9 (0.3)	DE
L-burn1	7.1 (0.9)	EF	2.1 (0.6)	DEF	1.0 (0.3)	CD	25.3 (3.0)	CD	3.1 (0.4)	DE
CU-burn4	9.0 (1.4)	EF	14.1 (1.9)	B	2.3 (0.6)	AB	42.5 (3.3)	B	6.1 (0.0)	B
S-burn5	14.3 (1.7)	CD	7.3 (1.3)	C	1.1 (0.3)	BC	68.6 (3.8)	A	6.3 (0.6)	B
C-cut/burn3	17.8 (2.3)	C	1.6 (0.6)	EFG	0.1 (0.1)	E	39.4 (2.7)	B	3.8 (0.3)	CD
C-cut/burn5	41.2 (2.9)	A	6.3 (0.9)	C	1.5 (0.4)	BC	44.3 (2.8)	B	5.9 (0.4)	B
C-cut/burn5 and Chop	24.9 (2.6)	B	2.8 (0.5)	D	0.3 (0.2)	DE	42.9 (3.6)	B	4.2 (0.4)	C
FC-savanna	38.3 (2.3)	A	20.3 (2.1)	A	2.6 (0.6)	A	10.7 (1.2)	F	9.2 (0.0)	A

1. Means within columns with the same letters are different (df = 3, 348, $P < 0.05$).
2. ($f = 57.96$) 3. ($f = 39.69$) 4. ($f = 9.31$) 5. ($f = 30.28$) 6. ($f = 46.61$)

Table 2.3 Mean (se) woody vegetation density (stems/ha) for twelve oak savanna restoration case studies located in Tennessee and Kentucky and sampled during the summers of 2008 and 2009.

Case Study	Vines and shrubs[1,2]		Oak Regeneration[3]		Competitor Regeneration[4]		Oak Saplings[5]		Competitor Saplings[6]	
S-cont	14,333.3 (2655.8)	BCD	4666.7 (1495.8)	BCD	4333.3 (1773.6)	BCD	82.5 (32.6)	CD	353.7 (73.9)	B
C-cont	12,000.0 (4583.8)	EF	1333.3 (1043.1)	EF	6333.3 (2170.0)	BC	47.2 (36.9)	E	176.8 (62.9)	C
L-cont	666.7 (463.2)	G	666.7 (463.2)	EF	333.3 (333.3)	DE	70.8 (49.2)	DE	141.5 (55.2)	C
CU-cont	10,222.2 (2113.8)	BC	1777.8 (653.8)	BCD	1555.6 (472.3)	BC	55.0 (16.7)	BC	373.4 (130.7)	B
C-cut	19,000.0 (4632.5)	DE	2000.0 (1005.7)	DEF	2666.7 (1262.5)	BCDE	165.1 (84.4)	DE	70.8 (31.3)	CD
L-burn1	3666.7 (1311.6)	FG	2000.0 (1005.7)	CDEF	0.0 (0.0)	E	212.2 (67.0)	BC	23.6 (16.4)	D
CU-burn4	11,888.9 (2100.2)	AB	1888.9 (591.2)	BC	777.8 (381.0)	CDE	15.7 (7.4)	DE	3.4 (3.9)	D
S-burn5	31,111.1 (3574.9)	A	4777.8 (1092.0)	A	9777.8 (1835.7)	A	345.8 (61.9)	A	562.0 (93.9)	A
C-cut/burn3	13,666.7 (3697.9)	DE	4000.0 (1701.9)	BCDEF	7000.0 (2498.3)	BC	23.6 (16.4)	E	59.0 (48.2)	D
C-cut/burn5	10,000.0 (2626.1)	DEF	6666.7 (2316.0)	B	8333.3 (2448.7)	B	47.2 (28.0)	DE	0.0 (0.0)	D
C-cut/burn5 and Chop	20,000.0 (5274.1)	CDE	4000.0 (1633.0)	BCDE	6000.0 (2067.8)	BC	47.2 (22.3)	DE	0.0 (0.0)	D
FC-savanna	5888.9 (1285.4)	BCD	0.0 (0.0)	F	0.0 (0.0)	E	0.0 (0.0)	E	0.0 (0.0)	D

1. Means within columns with the same letters are different (df = 3, 348, P <0.05).
2. (f = 8.82) 3. (f = 3.75) 4. (f = 6.83) 5. (f = 8.57) 6. (f = 18.37)

Table 2.4 Mean (se) species detections per point count (n = 8) on twelve oak restoration case studies located in Tennessee and Kentucky between May 15 – June 15, 2008 and 2009.

Case Study	PRAW[1,2]		TUTI[3]		RHWO[4]		INBU[5]		OVEN[6]		BGGN[7]		HOWA[8]		REVI[9]	
S-cont	0.0 (0.0)	C	0.4 (0.3)	CD	0.0 (0.0)	C	0.0 (0.0)	D	1.5 (0.3)	AB	0.3 (0.2)	D	1.4 (0.3)	A	1.3 (0.3)	AB
C-cont	1.3 (1.1)	C	0.3 (0.2)	CD	0.0 (0.0)	C	0.0 (0.0)	D	1.6 (0.2)	A	0.0 (0.0)	D	1.0 (0.3)	AB	2.0 (0.4)	AB
L-cont	0.0 (0.0)	C	1.3 (0.3)	A	0.0 (0.0)	C	0.0 (0.0)	D	0.9 (0.3)	C	1.1 (0.4)	AB	0.4 (0.2)	BDE	1.0 (0.3)	AB
CU-cont	0.0 (0.0)	C	1.1 (0.4)	AB	0.0 (0.0)	C	0.1 (0.1)	D	0.9 (0.2)	BC	1.6 (0.3)	AB	0.8 (0.2)	ABC	0.6 (0.3)	BCD
C-cut	1.0 (0.3)	B	0.5 (0.2)	ABC	0.1 (0.1)	BC	0.8 (0.2)	BC	0.8 (0.3)	CD	0.4 (0.2)	BCD	0.6 (0.2)	ABCD	0.9 (0.2)	ABC
L-burn1	0.1 (0.1)	C	0.6 (0.3)	ABC	0.0 (0.0)	C	0.1 (0.1)	D	0.0 (0.0)	E	1.4 (0.3)	AB	0.4 (0.3)	CDE	0.8 (0.3)	BC
CU-burn4	0.1 (0.1)	C	0.5 (0.5)	CD	0.0 (0.0)	C	1.8 (0.4)	A	0.4 (0.3)	DE	0.4 (0.3)	CD	0.3 (0.2)	DE	0.4 (0.3)	CD
S-burn5	0.4 (0.3)	C	0.9 (0.6)	BCD	0.3 (0.3)	BC	1.3 (0.5)	BC	0.0 (0.0)	E	1.3 (0.5)	ABC	0.5 (0.3)	CDE	0.0 (0.0)	D
C-cut/burn3	0.9 (0.2)	AB	0.3 (0.2)	CD	0.8 (0.3)	A	0.9 (0.4)	C	0.0 (0.0)	E	0.4 (0.2)	BCD	0.5 (0.3)	BCDE	0.8 (0.3)	BC
C-cut/burn5	1.1 (0.2)	AB	0.0 (0.0)	D	0.4 (0.2)	B	0.8 (0.3)	BC	0.3 (0.2)	E	0.4 (0.2)	BCD	0.1 (0.1)	E	0.5 (0.2)	BCD
C-cut/burn5 and Chop	1.1 (0.1)	A	0.1 (0.1)	CD	0.1 (0.1)	BC	1.5 (0.3)	AB	0.0 (0.0)	E	0.0 (0.0)	D	0.0 (0.0)	E	1.3 (0.4)	AB
FC-savanna	0.0 (0.0)	C	0.3 (0.2)	CD	0.0 (0.0)	C	1.3 (0.3)	ABC	0.0 (0.0)	E	0.4 (0.2)	BCD	0.0 (0.0)	E	0.0 (0.0)	D

1. Means within columns with the same letters are different (df = 11,84, $P < 0.05$).
2. ($f = 9.00$) 3. ($f = 2.28$) 4. ($f = 6.48$) 5. ($f = 5.73$) 6. ($f = 9.81$) 7. ($f = 4.47$) 8. ($f = 3.80$) 9. ($f = 4.36$)

Table 2.5 Avian species diversity and richness on twelve oak restoration case studies located in Tennessee and Kentucky between May 15 and June 15, 2008 and 2009.

	S-cont	C-cont	L-cont	CU-cont	C-cut	L-burn1	CU-burn4	S-burn5	C-cut/burn3	C-cut/burn5	C-cut/burn5 and chop	FC-savanna
Species diversity	2.63	2.54	2.6	2.63	2.88	2.65	2.95	3.19	2.99	2.99	2.83	2.81
Species richness												
All guilds	20	21	18	21	24	20	26	33	24	26	25	23
Forest guild	18	15	15	18	14	14	15	14	11	10	9	7
Shrub/scrub guild	1	2	1	2	7	3	6	10	8	10	7	11
Grassland guild	-	-	-	-	-	-	-	-	-	-	1	2
Other guild	1	4	2	1	3	3	5	9	5	6	8	3

Table 2.6 Hierarchical linear model results for groundcover variables on twelve oak savanna restoration case studies located in Tennessee and Kentucky and sampled during 2008 and 2009.

Dependent Variables	Independent Variables	ICC	df	f	P	Estimate (se)
Herbaceous Species Richness	Sapling/ha	60.32%	1, 347	4.62	0.03	-0.060 (0.030)
Grass Cover	Canopy Cover (%)	65.50%	1, 347	18.28	< 0.01	-0.001 (0.000)
sqrt(Forb Cover)	Total Basal Area (m^2/ha)	53.69%	1, 347	4.46	0.04	-0.002 (0.001)
sqrt(Legume Cover)	Slope (%)	17.47%	1, 347	5.07	0.03	-0.040 (0.010)
Woody Understory Cover	Canopy Cover (%)	49.39%	1, 346	5.94	0.02	-0.001 (0.000)
	Sapling/ha		1, 346	19.14	< 0.01	-0.009 (0.002)

Table 2.7 Hierarchical linear model results for midstory variables on twelve oak savanna restoration case studies located in Tennessee and Kentucky and sampled during in 2008 and 2009.

Dependent Variable	Independent Variable	ICC	df	f	P	Estimate (se)
sqrt (Vines and Shrubs)	Sapling/ ha	40.53%	1, 347	4.33	0.04	0.12 (0.06)
ln(Oak Regeneration)	Canopy Cover (%)	18.79%	1, 337	0.17	< 0.01	0.03 (0.01)
ln(Competitor Regeneration)	Slope (%)	41.29%	1, 336	6.91	0.01	0.06 (0.02)
	Sapling/ ha		1, 336	7.53	0.01	0.14 (0.05)
ln(Oak Saplings)	No Predictors	44.89%				
ln(Competitor Saplings)	Total Basal Area (m^2/ha)	26.98%	1, 337	5.65	0.02	0.03 (0.01)

Table 2.8 Hierarchical linear model results relating avian species detections to habitat metrics on twelve oak savanna restoration case studies sampled in Tennessee and Kentucky during 2008 and 2009.

Species	Independent Variables	ICC	df	f	P	Estimate (se)
log(ovenbird)	Total Basal Area	52.39%	1, 82	7.92	0.01	-0.02 (0.01)
	Basal Area of Dead Trees		1, 82	5.92	0.02	-0.03 (0.01)
log(red-eyed vireo)	Grass Cover	29.59%	1, 81	3.31	0.07	-0.86 (0.47
	Forb Cover		1, 81	4.42	0.04	-1.69 (0.80)
	Woody Understory Cover		1, 81	5.16	0.03	-0.77 (0.34)
log(hooded warbler)	Grass Cover	25.93%	1, 83	11.15	< 0.01	-1.35 (0.40)
log(blue-gray gnatcatcher)	No Predictors	30.25%				
sqrt(tufted titmouse)	No Predictors	7.69%				
sqrt(indigo bunting)	Woody Understory Cover	37.16%	1, 81	2.46	0.12	0.52 (0.33)
	Forb Cover		1, 81	3.38	0.06	1.43 (0.78)
	Grass Cover		1, 81	8.43	< .01	1.34 (0.46)
log(prairie warbler)	No Predictors	46.66%				
log(red-headed woodpecker)	Basal Area of Dead Trees	22.45%	1, 83	25.21	< 0.01	0.0035 (0.0007)

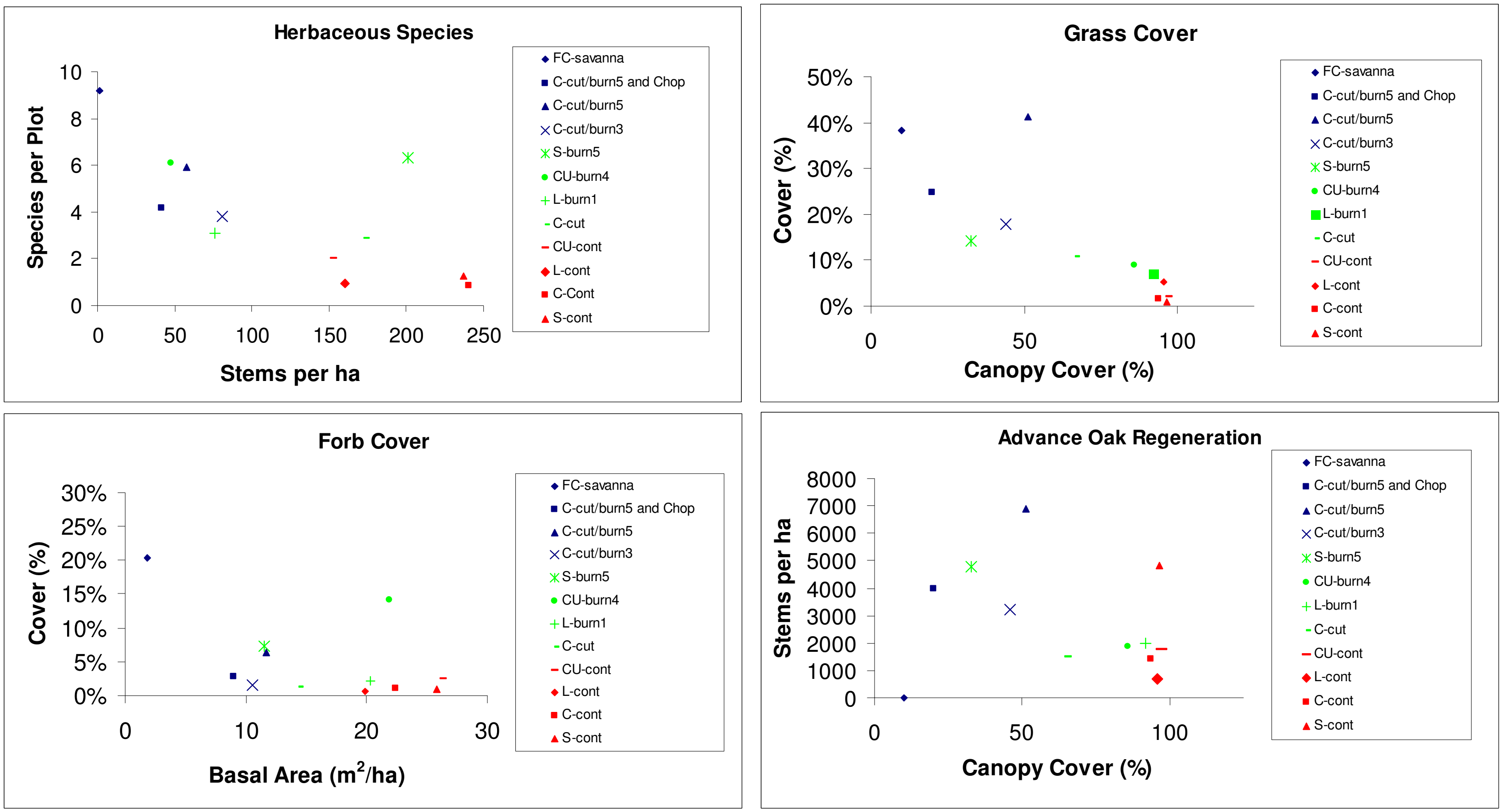

Figure 2.1. Case study means (n = 12) of variables with significant ($P < 0.05$) models developed under HLM for twelve oak savanna case studies in Tennessee and Kentucky during the summers of 2008 and 2009.

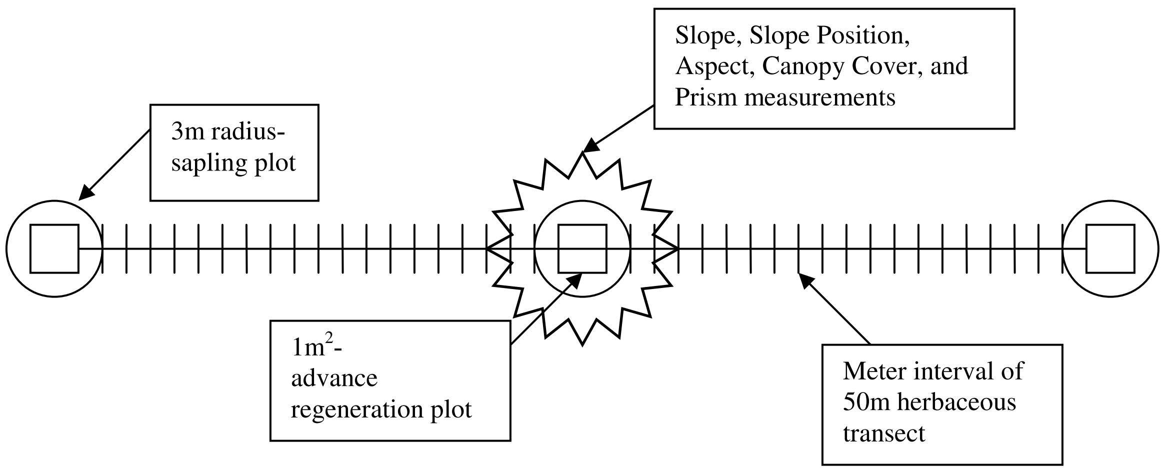

Figure A. 1. Plot layout of both herbaceous transects and woody vegetation plots (1m^2 and 3m radius). Herbaceous transect is 50m in length with woody vegetation plots nested at the 0, 25, and 50m intervals along the herbaceous transect.

Table A.1 Mean (se) percent herbaceous species cover per 50-m transect (n = 30) for twelve oak savanna restoration case studies located in Tennessee and Kentucky and sampled during in 2008 and 2009.

Species	S-cont	C-cont	L-cont	CU-cont	C-cut	L-burn1	CU-burn4	S-burn5	C-cut/burn3	C-cut/burn5	C-cut/burn5 and Chop	FC-savanna
Grass												
Big Bluestem	-	-	-	-	0.7 (0.4)	-	-	-	0.3 (0.1)	0.3 (0.1)	0.7 (0.3)	0.3 (0.2)
Broomsedge Bluestem	-	-	-	-	0.07 (0.07)	-	0.1 (0.1)	-	0.2 (0.2)	-	0.1 (0.1)	1.9 (0.5)
Cheatgrass	-	-	-	-	-	-	-	-	-	-	0.1 (0.1)	0.1 (0.1)
Danthonia	-	-	0.1 (0.1)	0.1 (0.1)	2.3 (0.7)	0.1 (0.1)	0.3 (0.2)	0.7 (0.3)	4.0 (1.2)	0.4 (0.2)	0.9 (0.3)	-
Dicanthelium spp.	0.1 (0.1)	0.6 (0.3)	3.7 (2.1)	1.3 (0.4)	2.4 (0.7)	3.4 (0.6)	6.0 (1.1)	7.3 (1.1)	4.5 (0.9)	9.2 (1.2)	2.9 (0.6)	0.7 (0.3)
Eastern Gama Grass	-	-	-	-	-	-	-	-	-	-	-	0.1 (0.1)
Indiangrass	-	-	-	-	-	-	-	0.1 (0.1)	-	-	-	-
Johnson Grass	-	-	-	-	-	-	0.1 (0.1)	-	-	-	-	0.2 (0.1)
Little Bluestem	-	-	-	-	0.2 (0.1)	-	-	0.3 (0.2)	0.1 (0.1)	0.6 (0.4)	0.5 (0.2)	31.4 (2.6)
Needlegrass	0.1 (0.1)	0.7 (0.3)	-	-	2.3 (0.8)	-	-	4.6 (0.9)	5.9 (1.4)	29.7 (3.2)	17.5 (2.4)	-
Purple Top	-	-	-	-	-	-	-	-	0.1 (0.1)	-	-	-
Rush	-	-	-	-	-	-	0.1 (0.1)	0.2 (0.1)	-	-	-	-
Sedge	0.3 (0.1)	0.3 (0.2)	1.5 (0.4)	0.5 (0.2)	0.3 (0.2)	3.3 (0.6)	1.7 (0.4)	0.7 (0.3)	0.7 (0.3)	1.7 (0.4)	0.7 (0.3)	1.8 (0.4)
Slender Woodoats	-	-	-	-	1.7 (0.7)	-	-	0.1 (0.1)	2.5 (1.0)	1.1 (0.3)	0.7 (0.7)	-
Tall Fescue	-	-	-	-	0.3 (0.3)	-	-	-	0.1 (0.1)	0.3 (0.3)	0.5 (0.3)	0.5 (0.3)
Virginia Wild Rye	0.2 (0.2)	-	-	-	-	0.1 (0.1)	-	-	0.1 (0.1)	-	-	-
Forb												
American Burnweed	-	-	-	-	-	-	0.1 (0.1)	-	-	-	-	-
Agrimonia spp.	-	-	-	0.1 (0.1)	-	-	0.1 (0.1)	-	-	-	-	-
American Ipacec	-	-	-	-	-	0.1 (0.1)	-	-	-	-	-	-
Bastard Toadflax	-	-	-	-	-	-	-	-	-	0.1 (0.1)	-	0.1 (0.1)
Bear's Foot	-	-	-	0.1 (0.1)	-	-	-	-	-	-	-	-
Black Cohosh	-	-	-	0.2 (0.2)	-	0.1 (0.1)	0.3 (0.2)	-	0.1 (0.1)	0.1 (0.1)		-
Butterfly Milkweed	-	-	-	-	-	-	-	-	-	-	-	0.5 (0.3)
Carolina Geranium	-	-	-	0.1 (0.1)	-	-	0.1 (0.1)	0.1 (0.1)	-	-	-	-
Colic Root	-	-	-	-	-	-	-	-	-	-	-	-
Common Blue Violet	0.1 (0.1)	-	-	0.1 (0.1)	-	0.1 (0.1)	0.1 (0.1)	-	-	-	-	-
Common Cinquefoil	-	-	-	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.2 (0.1)	0.1 (0.1)	-	0.3 (0.1)	-	0.4 (0.2)
Common Milkweed	-	-	-	-	-	-	-	-	-	-	-	0.1 (0.1)
Common Ragweed	-	-	-	-	-	-	-	-	-	-	-	1.2 (0.6)

Table A.1 Continued.

Species	S-cont	C-cont	L-cont	CU-cont	C-cut	L-burn1	CU-burn4	S-burn5	C-cut/burn3	C-cut/burn5	C-cut/burn5 and Chop	Fcsavanna
Elephants Foot	-	-	-	-	-	-	-	0.1 (0.1)	-	-	-	-
False Solomons Seal	-	-	-	-	-	-	-	0.2 (0.1)	-	-	-	-
Gallium spp.	-	-	-	-	-	-	0.2 (0.2)	-	-	-	-	0.1 (0.1)
Hairy Skullcap	-	-	-	-	-	0.1 (0.1)	-	-	-	-	-	-
Halberd-leaf Yellow Violet	-	-	-	-	-	-	-	-	0.1 (0.1)	-	-	-
Heath Aster	-	-	-	-	-	0.1 (0.1)	-	-	0.1 (0.1)	0.8 (0.3)	-	-
Helianthus sp.	-	-	-	0.1 (0.1)	0.1 (0.1)	-	3.0 (0.8)	0.3 (0.2)	0.1 (0.1)	-	-	-
Horesweed	-	-	-	-	0.1 (0.1)	-	-	-	0.1 (0.1)	-	-	-
Horse Nettle	-	-	-	-	-	-	0.1 (0.1)	-	-	-	-	-
Little Brown Jug	-	-	-	-	-	-	-	-	-	-	0.1 (0.1)	-
Loomis Mountain Mint	-	-	0.3 (0.2)	-	-	0.8 (0.3)	-	-	-	-	-	-
Lyre Leaf Sage	-	-	-	-	-	-	-	-	-	-	-	-
Mayapple	0.1 (0.1)	-	0.1 (0.1)	-	-	-	0.1 (0.1)	-	-	0.1 (0.1)	0.1 (0.1)	-
Morning Glory	-	-	-	-	-	-	0.1 (0.1)	0.1 (0.1)	-	-	-	0.1 (0.1)
Mullein	-	-	-	-	0.1 (0.1)	-	-	-	-	-	0.1 (0.1)	-
New Jersey Tea	-	-	-	-	-	-	-	0.1 (0.1)	-	-	-	-
Ox-eyed Daisy	-	-	-	-	-	-	-	-	-	-	0.1 (0.1)	-
Pale Blue-eyed Grass	-	-	-	-	0.1 (0.1)	-	-	-	-	-	-	-
Partidgeberry	-	-	-	-	-	-	-	-	0.1 (0.1)	-	-	-
Perfoliate Bellwort	0.3 (0.1)	-	-	-	-	-	-	-	-	-	-	-
Prenanthes sp.	0.1 (0.1)	-	-	0.1 (0.1)	-	-	0.1 (0.1)	0.1 (0.1)	-	0.1 (0.1)	-	-
Pussy Toes	-	-	-	-	-	0.1 (0.1)	-	-	-	-	-	0.3 (0.2)
Rabbit Tobbaco	-	-	-	-	-	-	-	0.1 (0.1)	-	0.1 (0.1)	-	0.2 (0.2)
Rattlesnake Weed	-	-	-	-	-	-	-	0.1 (0.1)	-	-	-	-
Red Sorrel	-	-	-	-	-	-	-	-	0.1 (0.1)	-	-	-
Roundleaf Thoroughwort	-	-	-	-	-	-	-	0.3 (0.3)	-	-	-	-
Rue Anemone	0.1 (0.1)	-	-	-	-	-	-	-	-	-	-	-
Sessile Bellwort	-	-	0.1 (0.1)	-	-	-	0.1 (0.1)	-	-	-	-	-
Silkgrass	-	-	-	-	0.5 (0.4)	-	-	0.1 (0.1)	0.1 (0.1)	0.7 (0.3)	0.6 (0.2)	-
Smooth Solomons Seal	-	-	-	0.1 (0.1)	-	-	0.3 (0.1)	-	-	-	0.1 (0.1)	-
Solidago sp.	-	-	-	-	-	0.1 (0.1)	0.4 (0.2)	2.0 (0.5)	0.3 (0.3)	2.1 (0.4)	1.0 (0.3)	1.7 (0.4)
Slender Mountain mint	-	-	-	-	-	-	-	0.07 (0.07)	-	-	-	1.2 (0.4)
Spotted Ragwort	-	-	-	-	-	-	-	-	0.1 (0.1)	-	-	0.1 (0.1)
Spotted Wintergreen	0.1 (0.1)	-	-	-	-	-	-	0.9 (0.7)	-	-	-	-
St. Andrews Cross	-	-	-	-	-	-	0.1 (0.1)	0.1 (0.1)	-	0.1 (0.1)	-	-
Stiff-haird Sunflower	-	-	-	-	-	-	-	-	-	-	-	-
Thistle	-	-	-	-	-	-	-	-	0.1 (0.1)	-	-	-
White Crownbeard	-	-	-	-	-	-	-	-	-	-	-	0.1 (0.1)
White Milkweed	-	-	-	-	-	0.1 (0.1)	0.1 (0.1)	-	-	-	-	-
Whorled Coreopsis	0.1 (0.1)	0.1 (0.1)	-	-	0.5 (0.2)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.4 (0.2)	1.5 (0.5)	1.1 (0.3)	-
Whorled Loosestrife	-	-	-	-	-	-	-	0.1 (0.1)	0.1 (0.1)	0.2 (0.1)	0.1 (0.1)	-

Table A.1 Continued.

Species	Scont	Ccont	Lcont	Cucont	Ccut	Lburn	Cuburn	Sburn	Ccut/burn3x	Ccut/burn5x	Ccut/burn5x and Chop	Fcsavanna
Wild Burgamont	-	-	-	-	-	-	0.2 (0.1)	-	-	-	-	-
Wild Comfrey	-	-	-	-	-	-	0.1 (0.1)	-	-	-	-	-
Wild Hydrangea	-	-	-	0.1 (0.1)	-	-	-	-	-	-	-	-
Wild Iris	-	-	0.1 (0.1)	-	0.1 (0.1)	-	-	-	-	-	0.1 (0.1)	-
Wild Onion	-	-	-	-	0.1 (0.1)	-	-	-	-	0.1 (0.1)	-	-
Wild Yam	-	-	-	0.20 (0.15)	-	0.1 (0.1)	0.3 (0.3)	-	-	-	-	-
Wingstem	-	-	-	-	-	-	0.1 (0.1)	-	-	-	-	-
Wintergreen	-	-	-	-	0.1 (0.1)	-	-	-	-	-	-	-
Wood Violet	0.1 (0.1)	-	-	-	-	-	0.1 (0.1)	-	-	-	-	-
Yellow Wood Sorrel	-	-	-	-	0.3 (0.2)	0.1 (0.1)	-	-	-	-	0.1 (0.1)	0.1 (0.1)
Yellow Passionflower	-	-	-	-	-	-	0.1 (0.1)	-	-	-	-	-
Legume												
Crown Vetch	-	-	-	-	-	-	0.9 (0.5)	-	-	-	-	-
Desmodium	-	-	-	0.7 (0.5)	-	0.8 (0.3)	0.4 (0.2)	0.2 (0.1)	-	0.3 (0.1)	0.1 (0.1)	1.3 (0.7)
Goats Rue	-	-	-	-	-	-	-	0.1 (0.1)	-	0.1 (0.1)	-	-
Lespedeza sp.	-	-	-	-	-	0.2 (0.1)	0.1 (0.1)	1.1 (0.3)	-	0.7 (0.2)	-	2.4 (0.4)
Hog Peanut	-	-	-	0.6 (0.3)	-	-	-	-	-	-	-	-
Milk Pea	-	-	-	-	-	-	-	-	-	0.2 (0.2)	-	-
Nakedleaf Trefoil	2.7 (0.7)	1.1 (1.1)	-	0.3 (0.1)	-	-	0.9 (0.3)	0.5 (0.2)	-	0.1 (0.1)	-	-
Partidge Pea	-	-	-	-	-	-	-	0.2 (0.2)	-	-	-	0.3 (0.1)
Sensitive Briar	-	-	-	-	-	-	-	-	0.1 (0.1)	-	0.1 (0.1)	-
Serecia Lespedeza	-	-	-	-	-	-	-	-	-	-	-	4.3 (1.2)
Sweet Clover	-	-	-	-	-	-	-	-	-	-	-	0.1 (0.1)
Fern												
Bracken Fern	-	-	0.1 (0.1)	-	1.7 (0.9)	-	-	0.3 (0.2)	0.4 (0.3)	1.3 (1.3)	-	-
Christmas Fern	0.2 (0.2)	2.2 (0.9)	0.1 (0.1)	-	0.5 (0.5).	0.1 (0.1)	-	0.4 (0.3)	0.4 (0.2)	-	-	-
Cinnamon Fern	-	-	-	-	0.4 (0.3)	-	-	0.3 (0.3)	-	-	-	-
Climbing Fern	-	-	-	-	0.1 (0.1)	-	-	0.1 (0.1)	0.7 (0.5)	-	-	-
Maidenhair Fern	0.1 (0.1)	-	-	-	-	-	-	-	-	-	-	-
New York Fern	-	-	-	-	-	-	-	0.1 (0.1)	-	-	-	-
Wood Fern	-	0.2 (0.2)	-	-	0.5 (0.5)	0.1 (0.1)	-	0.7 (0.4)	0.5 (0.3)	0.4 (0.2)	0.4 (0.4)	-
Moss	0.1 (0.1)	-	-	-	-	0.3 (0.1)	-	0.1 (0.1)	-	-	-	-

Table A.2 Proportion of vines and shrubs (30.48 cm – 1.37m tall) measured on three 1m2 subplots per plot (n = 30) on twelve oak savanna restoration case studies in Tennessee and Kentucky and sampled during in 2008 and 2009.

Species	S-cont	C-cont	L-cont	CU-cont	C-cut	L-burn1	CU-burn4	S-burn5	C-cut/burn3	C-cut/burn5	C-cut/burn5 and chop	FC-savanna
Arrowwood	-	-	-	-	-	-	-	-	-	3.57	-	-
Black Raspberry	-	-	-	-	-	-	3.17	0.4	-	-	-	0.79
Blackberry	-	3.03	50	3.03	8.77	36.36	19.84	18.14	67.5	64.29	61.02	21.26
Climbing Fern	-	-	-	-	1.75	-	-	-	-	-	-	-
Coralberry	-	-	-	-	-	9.09	-	-	-	-	-	7.09
Crossvine	-	-	-	-	-	-	-	-	-	-	-	-
Devil's Walking Stick	-	-	-	-	-	-	0.79	1.21	-	-	-	-
Dewberry	-	-	-	1.01	-	-	3.97	4.44	-	-	-	3.15
Flame Azelea	-	-	-	-	-	-	-	0.81	-	-	-	-
Fragrant Sumac	-	-	-	-	-	-	0.79	-	-	-	-	-
Gaylassacia	-	-	-	-	-	-	-	1.21	-	-	-	-
Mapleleaf Viburnum	28.57	-	-	9.09	-	-	0.79	1.21	-	-	-	-
Mountain Laural	9.52	-	-	-	-	-	-	0.4	-	-	-	-
Multiflora Rose	-	-	-	-	-	-	-	0.4	-	-	-	-
Muscadine Vine	2.39	-	-	-	-	-	-	-	-	-	-	-
Poison Ivy	2.39	-	-	1.01	-	9.09	1.59	0.81	-	-	-	0.79
Prairie Wild Rose	-	-	-	1.01	-	-	-	-	-	-	-	0.79
Sassafras	-	-	-	-	-	-	0.79	-	-	-	-	-
Smilax Glauca	-	-	25	12.12	-	-	10.32	11.69	-	-	-	12.6
Smilax Rotundifolium	16.67	12.12	25	36.36	-	-	22.22	14.92	2.5	3.57	10.17	-
Smilax Tamnoides	-	-	-	-	-	-	1.59	-	-	-	1.69	-
Smooth Sumac	-	-	-	-	-	-	0.79	2.82	-	-	-	2.36
Spicebush	-	-	-	-	-	9.09	-	-	-	-	-	-
Strawberry	-	-	-	-	-	-	-	0.4	-	-	-	25.95
Strawberry Bush	-	-	-	5.05	-	-	0.79	1.61	-	-	-	-
Summer Grape	-	-	-	1.01	-	-	7.14	6.85	-	-	-	0.79
Sweet Shrub	-	-	-	-	-	-	-	0.81	-	-	-	-
Vaccinium	40.47	84.85	-	23.23	89.47	36.36	19.05	14.92	27.5	28.57	18.64	2.36
Virginia Creeper	-	-	-	7.07	-	-	0.79	-	-	-	-	-
Whichhazel	-	-	-	-	-	-	-	-	2.5	-	-	-
Winged Sumac	-	-	-	-	-	-	5.56	16.94	-	-	8.47	22.05

Table A.3 Proportion of advanced regeneration (30.48cm – 1.37 m tall) measured on 3 1-m2 per plot (n = 30) from twelve oak restoration case studies in Tennessee and Kentucky and sampled during in 2008 and 2009.

Species	S-cont	C-cont	L-cont	CU-cont	C-cut	L-burn1	CU-burn4	S-burn5	C-cut/burn3	C-cut/burn5	C-cut/burn5 and chop	FC-savanna
American Beech	-	3.7	-	-	-	-	-	-	-	-	-	-
American Hazel	-	-	-	-	-	-	1.05	-	-	-	-	-
American Holly	-	-	-	-	-	-	-	-	2.04	-	-	-
Black Cherry	-	-	-	-	-	-	-	2.03	-	1.01	-	-
Black Gum	-	-	4.17	2.06	11.11	-	3.16	18.24	20.41	5.05	-	44.44
Black Locust	-	-	-	-	-	-	1.05	-	-	-	-	-
Black Walnut	-	-	-	-	-	-	1.05	-	-	-	-	-
Eastern Redbud	-	-	-	15.46	-	-	30.53	-	-	1.01	-	-
Elm, American	-	-	4.17	-	-	-	-	-	-	-	-	-
Elm, Slippery	-	-	-	-	-	-	2.11	-	-	-	-	-
Elm, Winged	-	-	4.17	-	-	-	-	-	-	-	-	-
Flowering Dogwood	-	-	-	1.03	-	-	-	1.35	-	-	-	-
Hickory	9.38	-	-	10.31	7.41	16.67	7.37	11.49	2.04	2.02	4.55	11.11
Hophornbeam	-	-	12.5	16.49	-	-	1.05	-	-	-	-	-
Maple, Red	40.63	70.37	-	8.25	22.22	-	4.21	26.35	42.86	25.25	27.27	-
Maple, Sugar	-	-	4.17	4.12	-	-	-	-	-	-	-	-
Oak, Black	18.75	-	-	6.19	11.11	16.67	5.26	6.08	-	1.01	7.58	-
Oak, Chestnut	-	-	-	3.09	-	8.33	4.21	0.68	-	1.01	-	-
Oak, Northern Red	-	-	4.17	1.03	-	-	2.11	-	-	-	-	-
Oak, Post	-	-	-	-	-	-	-	0.68	-	-	3.03	-
Oak, Scarlet	6.25	3.7	-	2.06	11.11	-	-	5.41	2.04	5.05	1.52	-
Oak, Southern Red	-	-	-	-	-	-	-	2.70	2.04	-	-	-
Oak, White	18.75	11.11	4.17	-	-	25	2.11	6.76	20.41	13.13	6.06	-
Pawpaw	-	-	20.83	-	-	-	2.11	-	-	-	-	-
Persimmon	-	-	-	-	-	8.33	-	-	-	-	-	-
Pine, Shortleaf	-	-	-	-	-	-	-	0.68	-	-	-	-
Pine, Virginia	-	-	-	-	3.7	-	-	-	2.04	-	-	-
Pine, White	-	7.41	-	-	-	-	-	-	2.04	-	-	-
Sassafras	6.25	3.7	-	11.34	22.22	25	21.05	16.22	4.08	44.44	31.82	44.44
Serviceberry	-	-	-	-	-	-	3.16	0.68	-	-	-	-
Sourwood	-	-	-	-	3.7	-	2.11	0.68	-	1.01	18.18	-
Sweetgum	-	-	-	-	7.41	-	-	-	-	-	-	-
White Ash	-	-	41.67	18.56	-	-	6.32	-	-	-	-	-

Table A.4 Proportion of saplings (<12.7 cm DBH) measured on 3 3-m radius subplots per plot (n = 30) from twelve oak restoration case studies across Tennessee and Kentucky and sampled during in 2008 and 2009.

Species	S-cont	C-cont	L-cont	CU-cont	C-cut	L-burn1	CU-burn4	S-burn5	C-cut/burn3	C-cut/burn5	C-cut/burn5 and chop	FC-savanna
Allegheny Chinkapin	-	-	-	-	-	-	-	-	1.52	-	8.82	-
Amercian Hazel	6.40	0.51	-	1.29	0.74	-	-	0.48	-	-	-	-
American Beech	4.07	-	3.08	0.56	-	7.71	-	-	-	-	-	-
American Chestnut	-	-	-	-	-	-	-	0.48	-	-	-	-
Ash, Blue	-	-	-	0.65	-	-	-	-	-	-	-	-
Ash, White	0.58	-	12.31	7.75	-	-	6.25	-	-	-	-	-
Bigleaf Magnolia	-	-	-	-	-	-	-	2.39	-	-	-	-
Bigtooth Aspen	-	-	-	-	-	-	-	-	-	-	-	-
Black Cherry	0.58	-	0.77	-	-	1.93	-	-	-	-	-	-
Black Gum	9.88	3.06	0.77	6.46	5.15	5.78	6.25	10.52	3.03	2.13	-	33.25
Black Locust	-	-	-	-	-	-	28.83	-	-	-	-	-
Black Walnut	-	-	-	-	-	-	-	-	-	-	-	-
Cucumber Tree	0.58	-	-	-	-	-	-	-	-	-	-	-
Devil's Walking Stick	-	-	0.77	-	-	-	-	-	-	-	-	-
Downy Serviceberry	-	-	-	3.88	-	-	4.17	1.43	-	-	-	-
Eastern Hemlock	2.33	-	-	-	-	-	-	-	-	-	-	-
Eastern Red Cedar	-	-	-	-	-	3.85	-	-	-	-	-	-
Eastern Redbud	2.33	-	-	12.92	-	-	25.00	-	-	2.13	-	-
Elm, American	-	-	3.85	-	-	17.34	-	-	-	-	-	-
Elm, Slippery	-	-	-	,65	-	-	-	-	-	-	-	-
Elm, Winged	-	-	20.77	-	-	3.85	-	-	-	-	-	-
Flowering Dogwood	2.33	1.02	3.85	5.17	15.44	1.93	4.17	0.96	1.52	-	-	-
Hickory	1.74	0.51	0.77	8.39	10.29	1.73	4.17	7.56	-	17.02	8.82	33.50
Hophornbeam	-	-	17.69	13.56	-	-	2.08	-	-	-	-	-
Maple, Red	52.91	46.94	0.77	9.04	22.79	-	-	18.18	68.18	21.28	29.41	-
Maple, Sugar	-	-	9.23	14.85	-	3.85	2.08	10.05	-	-	-	-

Table A.4 Continued.

Species	S-cont	C-cont	L-cont	CU-cont	C-cut	L-burn1	CU-burn4	S-burn5	C-cut/burn3	C-cut/burn5	C-cut/burn5 and chop	FC-savanna
Oak, Black	2.91	0.51	3.08	-	8.09	3.85	2.08	9.60	-	4.26	5.88	-
Oak, Chestnut	0.58	-	-	4.52	-	15.41	6.25	5.26	-	-	-	-
Oak, Northern Red	-	-	-	0.65	-	-	-	-	-	-	-	-
Oak, Post	-	-	-	-	0.74	-	-	0.48	-	-	-	-
Oak, Scarlet	-	-	0.77	-	0.74	1.93	-	6.70	1.51	-	2.94	-
Oak, Southern Red	-	-	-	-	-	1.93	-	-	-	-	2.94	-
Oak, White	0.58	1.53	0.77	-	0.74	11.56	-	-	1.52	4.26	-	-
Pawpaw	-	-	11.54	-	-	-	-	-	-	-	-	-
Persimmon	-	-	-	-	-	-	-	0.48	-	-	-	-
Pine, Shortleaf	-	-	-	-	1.47	-	-	0.96	-	-	-	-
Pine, Virginia	-	-	-	-	-	-	-	-	-	-	-	-
Pine, White	-	38.78	-	-	-	-	-	-	1.52	-	-	-
Red Mulberry	-	-	0.77	-	-	-	-	-	-	-	-	-
Rusty Blackhaw	-	-	-	0.65	-	-	-	-	-	-	-	-
Sassafras	0.58	-	-	8.39	1.47	1.93	14.58	17.70	1.51	27.66	20.59	33.25
Sourwood	6.40	7.14	0.77	0.65	13.24	13.49	2.08	10.05	19.70	21.28	20.58	-
Sweetgum	-	-	3.85	-	19.12	-	-	-	-	-	-	-
Tulip Poplar	1.16	-	3.85	-	-	1.93	-	6.22	-	-	-	-
Umbrella Magnolia	4.07	-	-	-	-	-	-	-	-	-	-	-

Table A.5 Common and scientific names of herbaceous species encountered on twelve oak restoration case studies in Tennessee and Kentucky and sampled during in 2008 and 2009.

Common Name	Scientific Name
Agrimonia spp.	*Agrimonia spp.*
American Burnweed	*Erechtites hieracifolia*
American Ipacec	*Porteranthus stipulatus*
Bastard Toadflax	*Comandra umbellata*
Bear's Foot	*Smallanthus uvedalius*
Big Bluestem	*Andropogon gerardii*
Black Cohosh	*Cimicifuga racemosa*
Bracken Fern	*Pteridium aquilinum*
Broomsedge Bluestem	*Andropogon virginicus*
Butterfly Milkweed	*Asclepias tuberosa*
Carolina Geranium	*Geranium carolinianum*
Cheat	*Bromus tectorum*
Christmas Fern	*Polystichum acrostichoides*
Cinnamon Fern	*Osmunda cinnamomea*
Climbing Fern	*Lygodium palmatum*
Colic Root	*Aletris farinosa*
Common Blue Violet	*Viola sororia*
Common Cinquefoil	*Potentilla simplex var. simplex*
Common Milkweed	*Asclepias syriaca*
Common Ragweed	*Ambrosia artemisifolia*
Crown Vetch	*Coronilla varia*
Deertounge	*Dicanthelium spp.*
Desmodium	*Desmodium spp.*
Dwarf Crested Iris	*Iris cristata*
Eastern Gama Grass	*Tripsacum dactyloides*
Elephants Foot	*Elephantopus carolinanus*
False Solomons Seal	*Smilacina racemosa*
Galium spp.	*Galium spp.*
Goats Rue	*Tephrosia virginiana*
Hairy Skullcap	*Scutellaria elliptica var. hirsuta*
Halberd-leaf Yellow Violet	*Viola hastata*
Heath Aster	*Aster pilosus*
Hog Peanut	*Amphicarpaea bracteata*
Horesweed	*Conyza canadensis*
Horse Nettle	*Solanum carolinense*
Indiangrass	*Sorghastrum nutans*
Johnson Grass	*Sorghum halepense*
Lespedeza sp.	*Lespedeza spp.*
Little Bluestem	*Schizachyrium scoparium*
Little Brown Jug	*Hexastylis arifolia var. arifolia*
Loomis Mountain Mint	*Pycnanthemum loomisii*
Lyreleaf Sage	*Salvia lyrata*
Maidenhair Fern	*Adiantum pedatum*
Mayapple	*Podophyllum peltatum*
Milk Pea	*Galactia volubilis*
Mullein	*Verbascum thapsus*
Nakedleaf Trefoil	*Desmodium nudiflorum*
Needlegrass	*Piptochaetium avenaceum*

Table A.5 Continued.

Common Name	Scientific Name
New Jersey Tea	*Ceanothus americanus*
New York Fern	*Thelypteris noveboracensis*
Ox-eye Daisy	*Leucanthemum vulgare*
Pale Blue-eyed Grass	*Sisyrinchium albidum*
Povertygrass	*Danthonia spp*
Partidge Berry	*Mitchella repens*
Partidge Pea	*Chamaecrista fasciculata*
Perfoliate Bellwort	*Uvularia perfoliata*
Prenanthes spp.	*Prenanthes spp.*
Purple Top	*Tridens flavus var. flavus*
Pussy Toes	*Antennaria plantaginifolia*
Rabbit Tobbaco	*Gnaphalium obtusifolium*
Rattlesnake Weed	*Hieracium venosum*
Red Sorrel	*Rumex acetosella*
Roundleaf Thoroughwort	*Eupatorium rotundifoium spp. rotundifolium*
Rue Anemone	*Thalictrum thalictroides*
Rush	*Juncus spp.*
Sedge	*Carex spp.*
Sensitive Brier	*Mimosa microphylla*
Serecia Lespedeza	*Lespedeza cuneata*
Sessile Bellwort	*Uvularia sessilifolia*
Silkgrass	*Pityopsis graminifolia*
Slender Mountain mint	*Pycnanthemum tenuifolium*
Slender Woodoats	*Chasmanthium laxum*
Smooth Solomons Seal	*Polygonatum biflorum*
Solidago spp.	*Solidago spp.*
Southern Ragwort	*Senecio anonymus*
Spotted Wintergreen	*Chimaphila maculata*
St. Andrews Cross	*Hypericum stragulum*
Stiff-haird Sunflower	*Helianthus hirsutus*
Sunflower	*Helianthus spp.*
Sweet Clover	*Melitotus sp.*
Tall Fescue	*Festuca arundinacea*
Thistle	*Cirsium spp.*
Virginia Wild Rye	*Elymus virginicus*
White Crownbeard	*Verbesina virginica*
White Milkweed	*Asclepias variegata*
Whorled Coreopsis	*Coreopsis major*
Whorled Loosestrife	*Lysimachia quadrifolia*
Wild Burgamont	*Monarda fistulosa*
Wild Comfrey	*Cynoglossum virginianum*
Wild Hydrangea	*Hydrangea arborescens*
Wild Onion	*Allium cernuum*
Wild Potato Vine	*Ipomoea pandurata*
Wild Yam	*Dioscorea villosa*
Wingstem	*Verbesina alternifolia*
Wood Fern	*Dryopteris intermedia*
Wood Violet	*Viola palmata*
Yellow Wood Sorrel	*Oxalis stricta*

Table A.6 Common and scientific names of woody species encountered on twelve case studies in Tennessee and Kentucky and sampled during in 2008 and 2009

Common Name	Scientific Name
American Beech	*Fagus grandiflolia*
American Chestnut	*Castanea dentata*
American Hazelnut	*Corylus americana*
American Holly	*Ilex opaca*
American Hophornbeam	*Carpinus caroliniana*
Arrowwood	*Viburnum dentatum*
Ash, Blue	*Fraxinus quadrangulata*
Ash, White	*Fraxinus americana*
Bigleaf Magnolia	*Magnolia macrophylla*
Black Cherry	*Prunus serotina*
Black Gum	*Nyssa sylvatica*
Black Locust	*Robinia pseudoacacia*
Black Raspberry	*Rubus occidentalis*
Black Walnut	*Juglans nigra*
Blackberry	*Rubus allegheniensis*
Bristly Greenbrier	*Smilax tamnoides*
Cat Greenbrier	*Smilax glauca*
Coralberry	*Symphoriocarpos orbiculatus*
Crossvine	*Bignonia capreolata*
Devil's Walking Stick	*Aralia spinosa*
Eastern Redbud	*Cercis canadensis*
Elm, Slippery	*Ulmus rubra*
Flame Azelea	*Rhododendron spp.*
Flowering Dogwood	*Cornus florida*
Fragrant Sumac	*Rhus aromatica*
Hickory	*Carya spp.*
Huckleberry	*Gaylussacia spp.*
Maple, Red	*Acer rubrum*
Maple, Sugar	*Acer saccharum*
Mapleleaf Viburnum	*Viburnum acerifolium*

Table A.6 Continued.

Common Name	Scientific Name
Mountain Laurel	*Kalmia latifolia*
Multiflora Rose	*Rosa multiflora*
Muscadine Vine	*Vitis rotundifolia*
Northern Dewberry	*Rubus flagellaris*
Oak, Black	*Quercus velutina*
Oak, Chestnut	*Quercus montana*
Oak, Chinkapin	*Quercus muehlenbergii*
Oak, Northern Red	*Quercus rubra*
Oak, Post	*Quercus stellata*
Oak, Scarlet	*Quercus coccinea*
Oak, Southern Red	*Quercus falcata*
Oak, White	*Quercus alba*
Pawpaw	*Asimina triloba*
Persimmon	*Diospyros viginiana*
Pine, Shortleaf	*Pinus echinata*
Pine, White	*Pinus strobus*
Poison Ivy	*Toxicodendron radicans*
Prairie Rose	*Rosa setigera*
Roundleaf Greenbrier	*Silax rotundifolia*
Rusty Blackhaw	*Viburnum rufidulum*
Sassafras	*Sassafras albidum*
Serviceberry	*Amelanchier arborea*
Smooth Sumac	*Rhus glabra*
Sourwood	*Oxydendrum arboreum*
Strawberry	*Fragaria virginiana*
Strawberry Bush	*Euonymus americanus*
Summer Grape	*Vitis aestivalis*
Sweetshrub	*Calycanthus floridus*
Tulip Poplar	*Liriodendron tulipifera*
Vaccinium	*Vaccinium spp.*
Virginia Creeper	*Parthenocissus quinquefolia*
Winged Sumac	*Rhus copallinum*
Wintergreen	*Gaultheria procumbens*

Table A.7 Common and scientific names of avian species observed on twelve oak restoration case studies in Tennessee and Kentucky and sampled during in 2008 and 2009.

Alpha Code	Common Name	Scientific Name
ACFL	Acadian Flycatcher	Empidonax virescens
AMCR	American Crow	Corvus brachyrhynchos
AMGO	American Goldfinch	Spinus tristis
BAWW	Black-and -white Warbler	Mniotilta varia
BBCU	Black-billed Cuckoo	Coccyzus erythropthalmus
BGGN	Blue-gray Gnatcatcher	Polioptila caerulea
BHCO	Brown-headed Cowbird	Molothrus ater
BHVI	Blue-headed Vireo	Vireo solitarius
BLJA	Blue Jay	Cyanocitta cristata
BACS	Bachman's Sparrow	Aimophila aestivalis
BTNW	Black-throated Green Warbler	Dendroica virens
BWWA	Blue-winged Warbler	Vermivora pinus
CACH	Carolina Chickadee	Poecile carolinensis
CANG	Canada Goose	Branta canadensis
CARW	Carolina Wren	Thryothorus ludovicianus
CERW	Cerulean Warbler	Dendroica cerulea
CHSP	Chipping Sparrow	Spizella passerina
CHSW	Chimney Swift	chaetura pelagica
COYE	Common Yellowthroat	Geothlypis trichas
DICK	Dickcissel	Spiza americana
DOWO	Downy Woodpecker	Picoides pubescens
EABL	Eastern Bluebird	Sialia sialis
EAKI	Eastern Kingbird	Tyrannus tyrannus
EATO	Eastern Towhee	Pipilo erythrophthalmus
EAWP	Eastern Wood Pewee	Contopus virens
FISP	Field Sparrow	Spizella pusilla
GCFL	Great Creasted Flycatcher	Myiarchus crinitus
GRCA	Gray Catbird	Dumetella carolinensis
HAWO	Hairy Woodpecker	Picoides villosus
HETH	Hermit Thrush	Catharus guttatus
HOWA	Hooded Warbler	Wilsonia citrina

Table A.7 Continued.

Alpha Code	Common Name	Scientific Name
INBU	Indigo Bunting	Passerina cyanea
KEWA	Kentucky Warbler	Oporornis formosus
MODO	Morning Dove	Zenaida macroura
NOBO	Northern Bobwhite	Colinus Virginianus
NOCA	Northern Cardinal	Cardinalis cardinalis
NOFL	Northern Flicker	Colaptes auratus
NOMO	Northern Mocking bird	Mimus polyglottos
NOPA	Northern Parula	Parula americana
OVEN	Ovenbird	Seiurus aurocapilla
PHVI	Philadelphia Vireo	Vireo philadelphicus
PIWA	Pine Warbler	Dendroica pinus
PIWO	Piliated Woodpecker	Dryocopus pileatus
PRAW	Prairie Warbler	Dendroica discolor
PROW	Prothonotary Warbler	Protonotaria citrea
RBWO	Red-bellied Woodpecker	Melanerpes carolinus
REVI	Red-eyed Vireo	Vireo olivaceus
RHWO	Red-headed Woodpecker	Melanerpes erythrocephalus
RWBL	Red-winged Bluebird	Agelaius phoeniceus
SCTA	Scarlet Tanager	Piranga olivacea
SUTA	Summer Tanager	Piranga rubra
TUTI	Tufted Titmouse	Baeolophus bicolor
TUVU	Turkey Vulture	Cathartes aura
WBNU	White-breasted Nuthatch	Sitta carolinensis
WEVI	White-eyed Vireo	Vireo griseus
WEWA	Worm-eating Warbler	Helmitheros vermivorum
WITU	Wild Turkey	Meleagris gallopavo
WODU	Wood Duck	Aix sponsa
WOTH	Wood Thrush	Hylocichla mustelina
YBCH	Yellow Breated Chat	Icteria virens
YEWA	Yellow Warbler	Dendroica petechia
YTVI	Yellow-throated Vireo	Vireo flavifrons
YTWA	Yellow-throated Warber	Dendroica dominica
YWAR	Yellow Warbler	Dendroica petechia

III. DRUM-CHOPPING AS A SAVANNA RESTORATION TOOL: PRELIMINARY OBSERVATIONS

ABSTRACT

Oak savannas are critically imperiled throughout the eastern United States. Managers seeking to restore this ecosystem have used prescribed fire and mechanical overstory canopy reduction. Woody vegetation within the midstory and ground strata, however, can be difficult to control. One tool that could prove useful in this regard, a drum-chopper, has not been evaluated in the context of oak savanna restoration. Therefore, I evaluated drum-chopping effects on herbaceous vegetation and woody plants in a savanna restoration project located at Catoosa Wildlife Management Area on the Cumberland Plateau in Tennessee. Two adjacent sites with similar fire and overstory removal histories were selected for this study. One of these sites was subjected to drum-chopping in September of 2007, the adjacent site was not chopped. I evaluated the response of groundcover and woody regeneration and sapling densities. Grass cover in the NOCHOP was greater than the CHOP treatment ($P < 0.01$) and year*treatment ($P = 0.03$). Forb cover in the NOCHOP was greater than the CHOP treatment ($P < 0.01$) and legume cover differed by year ($P < 0.01$), treatment ($P < 0.01$), and year*treatment ($P = 0.01$). Exposed bare ground was greater in 2008 than 2009 ($P < 0.01$) and less in the CHOP than the NOCHOP treatment ($P < 0.01$). Exposed leaf litter was less in 2008 than 2009 ($P < 0.01$). Vines and shrubs (<1.37m) was greater in the CHOP than the NOCHOP by treatment ($P < 0.01$). Oak seedling (0-30.48 cm) densities was greater in the NOCHOP than CHOP treatment ($P = 0.05$). Based on my results, drum-chopping may be a valuable tool where woody encroachment has become too thick for fire to be effective or herbicides are not a viable option, but has limited utility otherwise.

INTRODUCTION

Oak savannas are critically imperiled due to the degradation of the ecosystem throughout the mid-South (Noss and Peters, 1995). Nuzzo (1986) estimated that less than one percent of the historic 11 million ha of this ecosystem remains today. This decline in area has been attributed to fire suppression (Curtis, 1959; Wendel and Smith, 1986; Noss and Peters, 1995; Bowles and McBride, 1998; Yahner et al., 2005; Nowacki and Abrams, 2008) and agriculture (Nuzzo, 1986; Noss and Peters, 1995). Perhaps because of their historic formation by and associated dependence on fire, it has been the most common tool used to restore savannas (Anderson et al., 1999). Additionally, thinning has been advocated as a tool for reducing the overstory to levels consistent with historic conditions (Leach and Ross, 1995; Peterson and Reich, 2001; Nielson et al., 2002). However, many managers seek to restore savannas within a shorter time period than possible through use of fire and mechanical overstory thinning alone (i.e., years vs. decades). One tool that could be used to expedite restoration, but has not been evaluated, is the drum-chopper, which could control woody encroachment and, therefore, result in more rapid development of herbaceous understories.

Drum-chopping has not been evaluated for its effects on vegetation in the mid-South or as a tool to restore oak savannas. Welch et al. (2004) investigated the influence of drum-chopping on vegetation in a Florida pine savanna. In the southeastern United States, drum-chopping typically has been used in pine plantation establishment as a site preparation tool to control hardwood sprouts (Miller, 1980; Fredrickson et al., 1991; Welch et al., 2004). However, drum-chopping has also been used to control saw palmetto (*Serenoa repens*) in the Florida flatwoods (Lewis, 1970; Moore, 1974; Tanner et al., 1988; Fitzgerald and Tanner, 1992) and brush and shrub encroachment in south Texas rangeland (Bozzo et al., 1992; Schindler and Fulbright, 2003).

Past research on drum-chopping has produced varying results with respect to vegetation response. Fitzgerald and Tanner (1992) found that herbaceous species richness was not significantly different between chopping and burning in their south Florida study. In a South Carolina study, wiregrass (*Aristida stricta*) decreased in cover as a result of drum-chopping (Walker et al., 2004). However, another study conducted in western South Carolina and Georgia found that grass cover increased, but forb cover decreased after drum-chopping and burning, something the investigators attributed to die-back of annual composites (Lantagne and Burger, 1987). In a study in the North Carolina Piedmont, chopping, measured six years post-treatment, was less effective at controlling hardwood root sprouts than windrowing slash and disking for loblolly pine (*Pinus taeda*) establishment (Fredrickson et al., 1991). Similarly, Welch et al. (2004) concluded that chopping increased hardwood stem density compared to herbicide treatment on their Florida site. On the other hand, Moore (1973), working in south Florida, found that densities of shrub species such as dwarf liveoak (*Quercus minima*) and saw-palmetto were greatly reduced.

Due to the lack of information on the effects of drum-chopping in the context of oak savanna restoration and conflicting results of existing studies, I examined drum-chopping on a site that had already been treated with fire and mechanical overstory reduction in the Cumberland Plateau of Tennessee. The first objective was to evaluate the efficiency of drum-chopping for control of woody vegetation including vines, shrubs, and sprouts of overstory species. The second objective was to evaluate the response of herbaceous vegetation to drum-chopping.

STUDY AREA

My study was conducted on the 32,374 ha Catoosa Wildlife Management Area (CWMA) located in Cumberland, Morgan, and Fentress Counties, Tennessee. The site consisted of oak-dominated hardwoods and pine-hardwood stands approximately 74 years old with some small, scattered fields nearby. Pine (*Pinus spp*.) became a minimal component of the stands as a result of pine mortality from a southern pine bark beetle (*Dendroctonus frontalis*) outbreak in 1999-2000. Located within the Cumberland Plateau and Mountains physiographic region (DeSelm et al., 1994), the terrain is gently rolling to moderately rolling and dissected by step ravines. Elevations ranged between 530-701 m and slopes ranged between 5-60%. The loam soils of this area were mesic Hapladults over a weathered sandstone parent material. Average annual precipitation between 1971 and 2000 was 152 cm and mean annual temperature was 12 C (NOAA Climate Data Center, 2009). Dominant overstory species include red maple (*Acer rubrum*), white oak (*Quercus alba*), black oak (*Q. veluntina*), scarlet oak (*Q. coccinea*), and southern red oak (*Q. falcata*), and tulip poplar (*Liriodendron tulipifera*). The midstory was comprised of black gum (*Nyssa sylvatica*), downy serviceberry (*Amelanchier arborea*), red maple, and sassafras (*Sassafras albidum*). The ground layer was comprised of a mixture of native grasses and forbs and a large component of hardwood regeneration.

Two immediately adjacent 40 ha areas were chosen for this study. Both areas were salvage harvested in 2001 to remove standing pine from the site. Prescribed fires started one year prior to harvest and continued on annual or biennial basis thereafter. Both areas were burned five times during the late dormant-season (15 February to 30 March) with the last fire occurring in February 2007. One area was not drum-chopped (NOCHOP) and served as my control. The second area was drum-chopped in September of 2007 using a 1.5 m diameter X 4 m wide single, un-weighted drum-chopper pulled by a tracked bulldozer (CHOP). Average overstory canopy cover for NOCHOP and CHOP was 53% and 42%, respectively. The approximate cost of the drum-chopping was $353 per ha. I sampled both areas during June the first two growing seasons following treatment, 2008 and 2009. During this period the two areas received no other disturbances.

METHODS

The 40-ha sampling units were representative of the treated area and were configured to maximize core area. To reduce bias associated with edge effects, I limited sampling to the inner 20 ha of each sampling unit. To sample vegetation, I established plots beginning at a randomly located point within each 20-ha core area. Subsequent plots were placed on a 70 x 70 m grid (Avery and Burkhart, 2002), allowing for a total of 30 plots within the not drum-chopped and drum-chopped areas. At each plot, I centered a 50-m transect perpendicular to the slope, and identified plants to species at 1-m intervals along its length to characterize understory cover. At each intercept, I recorded understory cover as grass, forb, legume, or woody plant. I also sampled vegetation in 1-m^2 and 3-m radius sub-plots (28 m^2) placed at plot center and both ends of the transect (0, 25, 50 m marks). On the 3 1-m^2 sub-plots I counted advanced regeneration tree seedlings, and woody vines and shrubs by height class (0-30.48 cm and 30.48 cm – 1.37 m). On the 3 3-m radius sub-plots, I sampled sapling vegetation within three diameter (DBH) classes (<2.54 cm, 2.54-7.62 cm, and 7.62-12.7 cm). I sampled the overstory using an 11.3-m radius sub-plot placed at plot center.

ANALYSIS

I calculated percent cover for each plot (n = 30) by dividing the intercepts for a given cover class by 50 (total number of potential intercepts per plot). All oaks were pooled in the regeneration and sapling size classes due to low sample sizes for individual species. Also, other hardwood overstory species including red maple, tulip poplar (*Liriodendron tulipifera*), and sweetgum (*Liquidambar styraciflua*) were classified together as competitors for oaks. Response variables based on the 50-m transect were groundcover values for grass, forb, legume, woody, bare ground, and herbaceous species richness. Based on the 1-m^2 sub-plots I calculated mean densities for stems 0-30.48 cm and 30.48 cm – 1.37 m tall and their combined total for vine and shrub, oak, and oak competitors. I calculated mean stem densities of oak sapling and oak competitor saplings from the 3-m^2 plots. I used a two-way ANOVA (Ott and Longnecker, 2001) to compare treatment means between NOCHOP and CHOP between years, treatments, and year*treatment interaction for all response variables using PROC GLM in SAS© software (SAS Inst. Inc., Cary, NC). I used least significant difference with alpha = 0.05 to declare differences among treatment means.

RESULTS

In 2008, the three herbaceous plants with the greatest cover in NOCHOP were needlegrass (*Piptochaetium avenaceum*), deertongue (*Dicanthelium spp*.), and goldenrod (*Solidago spp.*). The three herbaceous plants with the greatest cover in CHOP were needlegrass, deertounge, and whorled corepsis (*Coreopsis major*). Dominant species in NOCHOP for 2009 were similar to 2008, needlegrass, deertounge, and goldenrod. In 2009 the dominant plants for CHOP were needlegrass, deertongue, and povertygrass (*Danthonia spp*.). Grass cover ranged from 24.9% to 41.2% (Table 3.1). Forb and legume cover were minimal and ranged from 2.8% to 6.3% and 0.1% to 1.5%, respectively. Exposed bare ground ranged from 2.3% to 12.5%, whereas exposed leaf litter ranged from 7.2% and 24.2%. Woody plants ranged from 42.9% to 46.1%.

The dominant vine/shrub species (0- 30.48 cm) within NOCHOP in 2008 were blackberry (*Rubus. spp.*), blueberry (*Vaccinium spp.*), and both greenbriar and dewberry (*Rubus flagellaris*). The dominant plants in CHOP were blackberry, greenbrier, and both dewberry and blueberry. In 2009 the dominant plants in the NOCHOP and CHOP were the same and included blueberry, blackberry, and greenbrier. Vines and shrubs (0- 30.48 cm) density ranged from 61,000 to 111,000 stems/ha (Table 3.2). In 2008, the dominant seedlings (0-30.48 cm) in the NOCHOP were sassafras (*Sassafras albidum*), white oak, and red maple; while in the CHOP, sassafras, red maple, and black oak were dominant. In 2009, the most dominant regeneration species were sassafras, white oak, and red maple, for NOCHOP. Oak seedlings (0- 30.48 cm) densities ranged from 5,000 to 12,000 stems/ha (Table 3.2). In 2008, the dominant advanced regeneration (30.48 cm – 1.37 m) in the NOCHOP was sassafras, red maple, and white oak; while sassafras, red maple, and sourwood (*Oxydendrum arboreum*) were dominant in the CHOP area. In 2009, the dominant advanced regeneration stems in the CHOP were red maple, sassafras, and white oak. Similarly, dominant advanced regeneration stems were sassafras, red maple, and white oak for NOCHOP and CHOP, respectively. In 2008, the dominant saplings (<2.54 – 12.7 cm DBH) in the NOCHOP were sassafras, sourwood, and red maple; while red maple, sassafras, and sourwood were dominant in the CHOP area. In 2009, the dominant species among the sapling size class for the NOCHOP were red maple, sourwood, and hickory (*Carya* *spp*.). However, the saplings dominating the CHOP area were sourwood, black oak, and sassafras.

Grass cover differed between treatments ($P < 0.01$) and year*treatment ($P = 0.03$) (Table 3.3). Forb cover differed between treatments ($P < 0.01$). Legume cover differed among years ($P < 0.01$), treatments ($P = 0.03$), and year*treatment ($P = 0.01$). Exposed bare ground differed among years ($P < 0.01$) and treatments ($P < 0.01$). Exposed leaf litter differed between years ($P < 0.01$).

Total vine and shrub densities differed ($P < 0.01$) between treatments (Table 3.4). Vine and shrub (0 - 30.5 cm) densities also differed ($P < 0.01$) between treatments. Oak seedlings (0 - 30.48 cm) in the NOCHOP and CHOP differed ($P < 0.05$) between treatments. Competitor saplings differed among year ($P < 0.01$), treatments ($P < 0.01$), and year*treatment ($P < 0.01$).

Discussion

I recognize that inferences from my study are limited by a lack of replication and pretreatment data. However, this study still provides some insight into the use of a tool that has not been previously evaluated within this region or for its effectiveness in oak savanna restoration.

Even two years post-chopping, the percent of bare ground exposed by drum-chopping remained elevated. Exposure of bare ground was likely caused by disturbance of soil by the teeth on the drum-chopper and toppling over of larger trees. Miller (1980) reported that the majority of soil exposure in his study was caused by the overthrow of trees where their root systems were pulled from the ground. This difference between the two areas does not represent an undesirable condition for early successional species, such as northern bobwhite (*Colinus virginianus*), which require bare ground for ease of travel (Schroeder, 1985).

Drum-chopping reduced grass and forb cover during the first year post-treatment, which was likely a result of a reduction in perennial vegetation and a lack of a compensatory increase in annual vegetation. By the second growing season, however, these differences were no longer apparent. Welch et al. (2004) observed a decrease in forb cover after drum-chopping and drum-chopping plus burning treatments, similar to my first–year results. The most likely reason for the reduction of herbaceous vegetation in my study was the setting back of succession in a perennial-dominated herbaceous community coupled with a lack of annual species on my sites. The lack of a response by annuals may have been due to a limited seedbank; after >60 years of site dominance by a closed canopy forest, this seedbank may have been depleted. Indeed, I did not observe annual grasses or forbs on this or other nearby sites.

In my study, woody groundcover did not decrease as a result of chopping, which may have been due to the rapid flush of woody sprouts replacing destroyed vegetation. Much of the increase in woody vines and shrubs I observed could be attributed to the large number of small greenbrier (*Smilax spp.*), blackberry, and *Vaccinium* stems. Fredrickson et al. (1991) also found that chopping increased vine densities and resulted in high stem densities of blackberries. That woody groundcover already comprised >40% of both areas the first growing season post-treatment, suggests that there may be increased competition for herbaceous cover in the future without some further disturbance, such as fire.

Other studies have found soil conditions influence the effectiveness of drum-chopping in reducing shrub densities. Moore (1974) found drum-chopping during dry soil conditions was most effective for reducing shrub densities, but in contrast, Tanner et al. (1988)

found drum-chopping during the wet conditions provided better control. These and other studies in Florida, however, were conducted on sandy soils, and in a number of cases, were subjected to grazing by cattle during the study (Lewis, 1970; Moore, 1974; Tanner et al., 1988; Fitzgerald and Tanner, 1992; Watts et al., 2006), both in substantial contrast to the loamy, ungrazed soils at my study site. The variation in results from these studies underscores the need for additional research on drum-chopping and how soil conditions and types contribute to vegetative response (Fitzgerald and Tanner, 1992).

The lack of a chopping effect on seedling density could be a result of top-killed hardwood stems sprouting and increased seedling recruitment following drum-chopping (Walker et al., 2004; Welch et al., 2004). Such an increase in seedlings may result from drum-chopping providing favorable conditions, (e.g., bare mineral soil, and increased light) for establishment and germination of new seedlings (Greenburg et al., 1995). The competitive position of oak seedlings could be enhanced by chopping through the reduction in midstory stems.

Midstory reduction, which in the context of savanna restoration may be the most appropriate role for drum-chopping, was accomplished effectively in my study by the use of this tool. Where restoration efforts have been unsuccessful with fire alone, or where herbicides cannot be used, drum-chopping could be an important tool for restoring savannas with dense midstory vegetation. However, as noted by Miyata et al. (1983), saplings not oriented parallel to the direction of travel of the drum-chopper are typically not crushed, limiting the effectiveness of the technique. Without the use of fire or herbicides following drum-chopping, hardwood stems are likely to persist and increase in density (Welch et al., 2004; Watts et al., 2006). The use of herbicide may be a more effective and inexpensive tool for reducing hardwood stem densities where fire alone has not been successful. Herbicides have also been shown to increase herbaceous groundcover in longleaf pine and wire grass savannas (Brockway and Outcalt, 2000; Welch et al., 2004) and in the cross timbers area of Oklahoma (Stritzke et al., 1991). However, caution should be exercised when treating oak savannas with herbicides to avoid damage to retained overstory stems. Also, timing of application may be a concern with respect to development of oak regeneration that may be needed to replace the overstory cohort.

As a tool for savanna restoration, drum-chopping generally doesn't appear to be effective. However, drum-chopping may be a valuable tool where woody encroachment has become too thick for fire alone to be effective. The application of fire to these areas soon after drum-chopping (e.g., <6 weeks) could utilize slash created by the chopping as fuel to help kill rootstocks and reduce stems not affected by the drum-chopper. Despite the value of chopping in such circumstances, the substantial cost ($353/ha) may make other tools more desirable for savanna restoration.

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Appendix

Table 3.1 Mean percent ground cover (se) within control (NOCHOP) and drum-chopped (CHOP) areas at Catoosa Wildlife Management Area, Cumberland County, Tennessee during June 2008 and 2009.

		Year	
	Treatment	2008	2009
Grass	NOCHOP	41.2 (2.9)	32.1 (3.9)
	CHOP	24.9 (2.6)	29.0 (2.2)
Forb	NOCHOP	6.3 (0.8)	4.6 (0.8)
	CHOP	2.8 (0.5)	3.2 (0.8)
Legume	NOCHOP	1.5 (0.4)	0.1 (0.1)
	CHOP	0.3 (0.2)	0.2 (0.2)
Exposed Bare Ground	NOCHOP	6.1 (1.1)	2.3 (0.6)
	CHOP	12.5 (1.9)	4.2 (0.7)
Woody Plant	NOCHOP	44.3 (2.8)	45.8 (3.7)
	CHOP	42.9 (3.5)	46.1 (2.0)
Exposed Leaf Litter	NOCHOP	7.2 (1.4)	24.2 (3.5)
	CHOP	7.2 (1.3)	17.4 (1.6)

Table 3.2 Woody stem density (stems/ha) within control (NOCHOP) and drum-chop (CHOP) areas at Catoosa Wildlife Management Area, Cumberland County, Tennessee, during June 2008- 2009.

		Year	
	Treatment	2008	2009
Vines and Shrubs	NOCHOP	80,000 (11,214)	60,767 (6331)
	CHOP	111,000 (10432)	105,222 (8727)
0-30.5 cm	NOCHOP	70,000 (11,111)	43,553 (4721)
	CHOP	91,000 (9277)	90,555 (8075)
30.5 cm- 1.37 m	NOCHOP	10,000 (2626)	17,220 (3538)
	CHOP	20,000 (5274)	14,222 (3243)
Oak Seedlings	NOCHOP	18,667 (4439)	14,111 (1777)
	CHOP	8667 (2743)	13,889 (1932)
0-30.5 cm	NOCHOP	12,000 (3231)	8444 (1204)
	CHOP	4667 (1417)	7889 (1233)
30.5 cm- 1.37 m	NOCHOP	6667 (2316)	5667 (1240)
	CHOP	4000 (1633)	6000 (1331)
Competitor Seedlings	NOCHOP	17,667 (3856)	13,000 (2599)
	CHOP	13,000 (3856)	15,556 (3068)
0-30.5 cm	NOCHOP	6000 (2068)	6333 (1617)
	CHOP	7000 (2257)	9333 (1880)
30.5 cm- 1.37 m	NOCHOP	8333 (2449)	6667 (1808)
	CHOP	6000 (2068)	6222 (1588)
Oak Saplings	NOCHOP	47 (28)	90 (29)
	CHOP	47 (28)	75 (20)
Competitor Saplings	NOCHOP	0 (0)	303 (65)
	CHOP	0 (0)	31 (15)

Table 3.3 Two-way ANOVA results for ground cover response within control (NOCHOP) and drum-chop (CHOP) areas at Catoosa Wildlife Management Area, Cumberland County, Tennessee, during June 2008- 2009.

	Effect	*f*[1]	*P*
Grass	Year	0.7	0.41
	Treatment	10.54	<0.01
	Y*T	4.93	0.03
Forb	Year	0.73	0.39
	Treatment	9.97	<0.01
	Y*T	1.86	0.18
Legume	Year	9.25	<0.01
	Treatment	4.89	0.03
	Y*T	6.19	0.01
Bare Ground	Year	25.83	<0.01
	Treatment	11.93	<0.01
	Y*T	3.54	0.06
Litter Cover	Year	39.92	<0.01
	Treatment	2.49	0.12
	Y*T	2.49	0.12
Woody Understory Cover	Year	0.59	0.45
	Treatment	0.03	0.87
	Y*T	0.07	0.79

1. df= 3, 116

Table 3.4 Two-way ANOVA results for woody vegetation response within control (NOCHOP) and drum-chop (CHOP) areas at Catoosa Wildlife Management Area, Cumberland County, Tennessee, during June 2008-2009.

	Effect	*f*[1]	*P*
Vines and Shrubs	Year	1.84	0.18
	Treatment	15.96	<0.01
	Y*T	0.48	0.49
0-30.5 cm	Year	2.43	0.12
	Treatment	15.57	<0.01
	Y*T	2.28	0.13
30.5 cm- 1.37 m	Year	0.04	0.85
	Treatment	0.85	0.36
	Y*T	2.93	0.09
Oak Seedlings	Year	0.01	0.91
	Treatment	3.06	0.08
	Y*T	2.8	0.09
0-30.5 cm	Year	0.01	0.93
	Treatment	4.04	0.05
	Y*T	2.98	0.09
30.5 cm- 1.37 m	Year	0.09	0.77
	Treatment	0.48	0.49
	Y*T	0.79	0.38
Competitor Seedlings	Year	0.03	0.86
	Treatment	0.03	0.86
	Y*T	0.34	0.56
0-30.5 cm	Year	0.46	0.5
	Treatment	1.03	0.31
	Y*T	0.26	0.61
30.5 cm- 1.37 m	Year	0.13	0.72
	Treatment	0.48	0.49
	Y*T	0.22	0.64
Oak Saplings	Year	2	0.16
	Treatment	0.1	0.75
	Y*T	0.1	0.75
Competitor Saplings	Year	24.83	<0.01
	Treatment	16.36	<0.01
	Y*T	16.36	<0.01

1. df= 3, 116

Table A.8 Mean (se) of herbaceous species identified along 30 50-m transects within control (NOCHOP) and a drum chopped (CHOP) areas at Catoosa Wildlife Management Area, Cumberland County, Tennessee, during June 2008 and 2009.

	Species	NOCHOP-2008	CHOP- 2008	NOCHOP-2009	CHOP- 2009
Grass	Big Bluestem	0.3 (0.1)	0.7 (0.3)	0.1 (0.1)	0.2 (0.1)
	Broomsedge	-	-	0.1 (0.1)	0.3 (0.2)
	Cheatgrass	-	0.1 (0.1)	-	-
	Danthonia spp.	0.4 (0.2)	0.9 (0.3)	1.3 (0.6)	2.2 (0.5)
	Dicanthelium spp.	9.2 (1.2)	2.9 (0.6)	5.3 (1.0)	3.9 (0.8)
	Little Bluestem	0.1 (0.4)	0.5 (0.2)	-	0.5 (0.3)
	Needlegrass	29.7 (3.2)	17.5 (2.4)	21.5 (2.9)	19.2 (2.3)
	Rush	-	-	0.1 (0.1)	0.1 (0.1)
	Sedge	1.7 (0.4)	0.7 (0.3)	1.5 (0.7)	0.4 (0.2)
	Tall Fescue	0.3 (0.3)	0.5 (0.3)	-	-
Legume	Desmodium spp.	0.3 (0.1)	0.1 (0.1)	-	-
	Goats Rue	0.1 (0.1)	-	-	-
	Lespedeza spp.	0.7 (0.2)	-	0.3 (0.2)	0.1 (0.1)
	Milk pea	0.2 (0.2)	-	-	-
	Nakedleaf Trefoil	0.1 (0.1)	-	-	-
	Sensitive Briar	-	0.1 (0.1)	-	-
	Slender Lespedeza	-	-	-	-
Forb	Bastard Toadflax	0.1 (0.1)	-	-	-
	Black Cohosh	0.1 (0.1)	-	-	-
	Bracken Fern	1.3 (1.3)	-	-	-
	Christmas Fern	-	-	-	0.1 (0.1)
	Cinnamon Fern	-	-	0.1 (0.1)	0.5 (0.5)
	Common Cinquefoil	0.3 (0.1)	-	0.1 (0.1)	-
	Coreopsis Major	1.5 (0.5)	1.1 (0.3)	-	0.6 (0.3)
	False Dandilion	-	-	0.2 (0.1)	-
	Fire Pink	-	-	0.1 (0.1)	-
	Gallium spp.	-	-	0.1 (0.1)	0.1 (0.1)
	Halbard Yellow Violet	-	-	0.2 (0.2)	-
	Heath Aster	0.8 (0.3)	-	0.1 (0.1)	-
	Helianthus sp.	-	-	0.1 (0.1)	-
	Little Brown Jug	-	0.1 (0.1)	-	-
	Mayapple	0.1 (0.1)	0.1 (0.1)	-	-
	Moss	-	-	0.3 (0.2)	0.3 (0.2)
	Mullein	-	0.1 (0.1)	-	-
	Ox-eyed Daisy	-	0.1 (0.1)	-	-
	Perfoliate Bellwort	-	-	-	0.1 (0.1)
	Prenanthes spp.	0.1 (0.1)	-	-	-
	Rabbit Tobacco	0.1 (0.1)	-	0.1 (0.1)	0.1 (0.1)
	Reclining St. Johns Wort	0.1 (0.1)	-	-	0.1 (0.1)
	Silkgrass	-	0.6 (0.2)	0.3 (0.2)	0.8 (0.3)
	Slender Woodoats	1.1 (0.3)	0.7 (0.7)	1.8 (0.6)	1.2 (0.3)
	Smooth Solomons Seal	-	0.1 (0.1)	-	-
	Solidago spp.	2.1 (0.4)	1.0 (0.3)	2.0 (0.6)	1.6 (0.5)
	Whorled Loosestrife	0.1 (0.1)	0.1 (0.1)	-	-
	Wild Comfrey	-	-	-	0.1 (0.1)
	Wild Iris	-	0.1 (0.1)	-	-
	Wild Onion	0.1 (0.1)	-	-	-
	Wood Fern	0.4 (0.2)	0.4 (0.4)	0.1 (0.1)	0.1 (0.1)
	Wood Violet	-	-	0.1 (0.1)	0.1 (0.1)
	Yellow Wood Sorrel	-	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)

Table A.9 Mean number (stems/ha) of vines and shrubs (<30.48 cm tall) within a control (NOCHOP) and a drum-chopped (CHOP) area at Catoosa Wildlife Management , Cumberland County, Tennessee, during June 2008 and 2009.

Height Class	Species	NOCHOP - 2008	CHOP - 2008	NOCHOP - 2009	CHOP - 2009
0- 30.48 cm	Arrowwood	333 (333)	-	222 (222)	-
	Black Raspberry	-	-	-	-
	Blackberry	6,333 (895)	7,667 (1038)	4,222 (658)	5,444 (517)
	Crossvine	-	-	111 (111)	-
	Dewberry	2,667 (821)	1,667 (692)	2,000 (495)	556 (231)
	Greenbrier	2,667 (821)	3,791 (692)	3,667 (626)	4,667 (520)
	Multiflora Rose	-	-	222 (154)	-
	Muscadine Grape	-	-	222 (154)	222 (154)
	Poison Ivy	667 (463)	-	556 (231)	222 (154)
	Smooth Sumac	-	-	111 (111)	-
	Strawberry	-	-	111 (111)	-
	Strawberry Bush	-	-	222 (154)	111 (111)
	Summer Grape	333 (333)	-	111 (111)	-
	Vaccinium	4,667 (926)	1,667 (692)	4,333 (699)	7,444 (471)
	Virginia Creeper	333 (333)	-	-	-
	Winged Sumac	1,000 (557)	-	778 (262)	1,111 (292)
30.48 cm- 1.37 m	Arrowwood	333 (333)	-	-	-
	Black Raspberry	-	-	111 (111)	-
	Blackberry	3,000 (1088)	5,000 (1,150)	3,444 (741)	2,778 (508)
	Crossvine	-	-	-	-
	Dewberry	-	-	111 (111)	-
	Greenbrier	333 (333)	556 (231)	556 (231)	1,000 (326)
	Multiflora Rose	-	-	-	-
	Muscadine Grape	-	-	111 (111)	111 (111)
	Poison Ivy	-	-	-	-
	Smooth Sumac	-	-	111 (111)	-
	Strawberry	-	-	-	-
	Strawberry Bush	-	-	-	-
	Summer Grape	-	-	111 (111)	-
	Vaccinium	2,000 (743)	1,667 (692)	1,333 (441)	889 (355)
	Winged Sumac	-	1,000 (557)	1,000 (363)	667 (295)

Table A.10 Woody seedling (<1.37 m tall) and saplings (<12.7 cm DBH) within control (NOCHOP) and a drum chopped (CHOP) area at Catoosa Wildlife Management Area, Cumberland County, Tennessee, during June 2008 and 2009.

	Species	NO-CHOP- 2008	NOCHOP- 2009	CHOP-2008	CHOP-2009
Seedling Regeneration (0-37.5 cm)	Alleghaney Chinqapin	666 (666)	-	-	-
	American Holly	666 (666)	111 (111)	-	-
	Bigleaf Magnolia	-	111 (111)	-	-
	Black Cherry	333 (333)	-	333 (333)	333 (186
	Black Gum	333 (333)	1222 (298)	333 (333)	1333 (343)
	Black Oak	2333 (1413)	778 (307)	2333 (1038)	1333 (343)
	Chestnut Oak	-	111 (111)	-	111 (111)
	Downy Serviceberry	-	222 (154)	-	-
	Eastern Hophornbeam	-	222 (154)	-	-
	Eastern Redbud	1333 (1333)	111 (111)	-	-
	Flowering Dogwood	-	-	-	111 (111)
	Hawthorn	-	111 (111)	-	111 (111)
	Hickory	2000 (884)	556 (281)	-	1000 (326)
	Post Oak	-	-	666 (666)	333 (186)
	Red Maple	6000 (2068)	3222 (608)	7000 (2257)	4556 (649)
	Sassafras	15,000 (3946)	3667 (514)	9666 (3215)	4333 (622)
	Scarlet Oak	1333 (793)	1000 (284)	-	889 (317)
	Sourwood	-	444 (210)	2000 (1006)	333 (186)
	Southern Red Oak	666 (666)	-	333 (333)	667 (295)
	Tulip Poplar	-	111 (110)	-	111 (111)
	White Oak	7666 (2612)	3222 (465)	1333 (631)	1889 (497)
	Winged Elm	333 (333)	-	-	-
Advanced Seedling Regeneration (37.5 cm- 1.37 m)	Alleghaney Chinqapin	-	111 (111)	-	-
	American Holly	-	333 (245)	-	-
	Black Cherry	333 (333)	-	-	-
	Black Gum	666 (666)	556 (231)	-	667 (248)
	Black Oak	333 (333)	778 (262)	1333 (793)	1222 (338)
	Chestnut Oak	333 (333)	111 (111)	-	-
	Downy Serviceberry	-	222 (154)	-	-
	Eastern Redbud	333 (333)	-	-	-
	Flowering Dogwood	-	-	-	333 (186)
	Hawthorn	-	-	-	-
	Hickory	666 (666)	778 (262)	1000 (557)	1111 (402)
	Hophornbeam	-	111 (111)	-	-
	Pawpaw	-	-	-	111 (111)
	Post Oak	-	111 (111)	666 (463)	444 (210)
	Red Maple	8333 (2449)	2667 (606)	6000 (2068)	2889 (524)
	Sassafras	13,000 (4652)	3778 (692)	7000 (2843)	3778 (524)
	Scarlet Oak	1666 (1183)	778 (262)	333 (333)	778 (307)
	Shortleaf Pine	-	111 (111)	-	-
	Sourwood	333 (333)	778 (307)	4000 (2426)	222 (154)
	Southern Red Oak	-	-	-	333 (186)
	White oak	4333 (333)	1556 (415)	1333 (1043)	1222 (407
	Winged Elm	666 (463)	-	-	-
Saplings (<2.54- 12.7 cm DBH)	Allegheny Chinkapin	-	4 (4)	35 (35)	-
	Bigleaf Magnolia	-	4 (4)	-	-
	Black Gum	12 (12)	20 (10)	-	4 (4)
	Black Oak	24 (16)	16 (9)	24 (17)	35 (13)
	Eastern Hemlock	-	4 (4)	-	-
	Eastern Redbud	12 (12)	-	-	-
	Flowering Dogwood	-	24 (12)	-	4 (4)
	Hickory	94 (63)	39 (14)	35 (35)	24 (9)
	Post Oak	-	8 (5)	-	4 (4)
	Red Maple	118 (78)	114 (21)	118 (46)	28 (12)
	Sassafras	153 (67)	31 (13)	83 (50)	31 (13)
	Scarlet Oak	-	8 (5)	12 (12)	20 (8)
	Sourwood	118 (55)	98 (17)	83 (44)	51 (13)
	Southern Red Oak	-	-	12 (12)	-
	White Oak	24 (16)	43 (12)	-	16 (9)
	White Pine	-	39 (16)	-	-

Table A.11 Common and scientific names of herbaceous species encountered within control (NOCHOP) and drum chopped (CHOP) area at Catoosa Wildlife Management , Cumberland County, Tennessee, during June 2008 and 2009.

Common Name	Scientific Name
Bastard Toadflax	*Comandra umbellata*
Big Bluestem	*Andropogon gerardii*
Black Cohosh	*Cimicifuga racemosa*
Bracken Fern	*Pteridium aquilinum*
Broomsedge	*Andropogon virginicus*
Cheatgrass	*Bromus tectorum*
Christmas Fern	*Polystichum acrostichoides*
Cinnamon Fern	*Osmunda cinnamomea*
Common Cinquefoil	*Potentilla simplex var. simplex*
Danthonia	*Danthonia spp.*
Desmodium	*Desmodium spp.*
Dicanthelium	*Dicanthelium spp.*
Dwarf Crested Iris	*Iris cristata*
False Dandelion	*Pyrrhopappus carolinianus*
Fire pink	*Silene virginica*
Galium spp.	*Galium spp.*
Goats Rue	*Tephrosia virginiana*
Goldenrod	*Solidago spp.*
Halbarld Yellow Violet	*Viola hastata*
Heath Aster	*Aster pilosus*
Lespedeza spp.	*Lespedeza spp.*
Little Bluestem	*Schizachyrium scoparium*
Little Brown Jug	*Hexastylis arifolia var. arifolia*
May Apple	*Podophyllum peltatum*
Milk Pea	*Galactia volubilis*
Mullein	*Verbascum thapsus*
Nakedleaf Trefoil	*Desmodium nudiflorum*
Needlegrass	*Piptochaetium avenaceum*
Ox-eye Daisy	*Leucanthemum vulgare*
Perfoliate Bellwort	*Uvularia perfoliata*
Prenanthes spp.	*Prenanthes spp.*
Rabbit Tobacco	*Gnaphalium obtusifolium*
Reclining St. Johns Wort	*Hypericum stragulum*

Table A.11 Continued.

Common Name	Scientific Name
Rush	*Juncus spp.*
Sedge	*Carex spp.*
Sensitive Brier	*Mimosa microphylla*
Silk Grass	*Pityopsis graminifolia*
Slender Lespedeza	*Lespedeza viginica*
Slender Woodoats	*Chasmanthium laxum*
Smooth Solomons Seal	*Polygonatum biflorum*
Sunflower	*Helianthus spp.*
Tall Fescue	*Festuca arundinacea*
Whorled Coreopsis	*Coreopsis major*
Whorled Loosestrife	*Lysimachia quadrifolia*
Wild Comfrey	*Cynoglossum virginianum*
Wild Onion	*Allium cernuum*
Wood Fern	*Dryopteris intermedia*
Wood Violet	*Viola palmata*
Yellow Wood Sorrel	*Oxalis stricta*

Table A.12 Woody vegetation (common and scientific) encountered within control (NOCHOP) and drum chopped (CHOP) area at Catoosa Wildlife Management Area, Cumberland County, Tennessee, during June 2008 and 2009.

Common Name	Scientific Name
Allegheny Chinkapin	*Castanea pumila*
American Holly	*Ilex opaca*
American Hophornbeam	*Carpinus caroliniana*
Arrowwood	*Viburnum dentatum*
Bigleaf Magnolia	*Magnolia macrophylla*
Black Cherry	*Prunus serotina*
Black Gum	*Nyssa sylvatica*
Black Raspberry	*Rubus occidentalis*
Blackberry	*Rubus allegheniensis*
Crossvine	*Bignonia capreolata*
Downy Serviceberry	*Amelanchier arborea*
Eastern Hemlock	*Tsuga canadensis*
Eastern Redbud	*Cercis canadensis*
Flowering Dogwood	*Cornus florida*
Greenbrier	*Smilax sp.*
Hawthorn	*Crataegus sp.*
Hickory	*Carya sp.*
Maple, Red	*Acer rubrum*
Multiflora Rose	*Rosa multiflora*
Muscadine Grape	*Vitis rotundifolia*
Northern Dewberry	*Rubus flagellaris*
Oak, Black	*Quercus veluntina*
Oak, Chestnut	*Quercus montana*
Oak, Post	*Quercus stellata*
Oak, Scarlet	*Quercus coccinea*
Oak, Southern Red	*Quercus falcata*
Oak, White	*Quercus alba*
Oak, White Pine	*Pinus strobus*
Pawpaw	*Asimina triloba*
Pine, Shortleaf	*Pinus echinata*
Poison Ivy	*Toxicodendron radicans*
Sassafras	*Sassafras albidum*
Sourwood	*Oxydendrum arboreum*
Strawberry	*Fragaria virginiana*
Strawberry Bush	*Euonymus americanus*
Sumac, Smooth	*Rhus glabra*
Sumac, Winged	*Rhus copallinum*
Summer Grape	*Vitis aestivalis*
Tulip Poplar	*Liriodendron tulipifera*
Vaccinium	*Vaccinium spp.*

Vita

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