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Effects of Different Silvicultural Practices on Wild Turkey Brood Habitat and Regeneration in Upland Hardwoods

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To the Graduate Council:

I am submitting herewith a thesis written by John Michael McCord entitled "Effects of Different Silvicultural Practices on Wild Turkey Brood Habitat and Regeneration in Upland Hardwoods." 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.

Craig A. Harper, Major Professor

We have read this thesis and recommend its acceptance:

David S. Buckley, Cathryn H. Greenberg

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

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

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Carolyn R. Hodges
Vice Provost and Dean of the Graduate School

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Effects of different silvicultural practices on wild turkey brood habitat and regeneration in upland hardwoods

A Thesis
Presented for the
Master of Science
Degree
University of Tennessee

John Michael McCord
May 2011

Dedication

I dedicate this to my parents, Greg and Karen, and my wife, Kayla. You have all supported and encouraged me throughout this process.

Acknowledgements

Many people assisted me on this project, and without them, it would not have been possible. I would like to thank the National Wild Turkey Federation for providing funding for this project, as well as the University of Tennessee Department of Forestry, Wildlife, and Fisheries for providing my stipend. I would like to thank the Tennessee Department of Agriculture Division of Forestry and Ted Dailey for allowing us to establish study sites on Chuck Swan State Forest and for assisting with implementing treatments. I want to especially thank Darren Bailey, David Hall, Danny Osborne, Steve Roarke, and Neal White for assisting with prescribed fires.

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Abstract

Optimum brood cover for wild turkeys is composed of herbaceous cover <0.5 m tall that conceals poults from predators and allows travel underneath. On tracts of hardwoods where early succession stages and young forest cover are scarce, a lack of understory development can limit turkey populations. Additionally, retaining oak on these sites after logging or habitat enhancement is important to provide future timber value and hard mast. I compared the effects of silvicultural practices (multiple fires [F], shelterwood cutting [S], shelterwood cutting with one fire [SF], retention cutting [R], retention cutting with multiple fires [RF], retention cutting with herbicide application [RH], and retention cutting with herbicide application and multiple fires [RHF]) with controls (C) on wild turkey brood habitat and oak regeneration in upland central hardwood stands. I measured structure and food resources to quantify the quality of wild turkey brood cover. Shelterwood and retention cuts increased photosynthetically active radiation. However, herbaceous, vine, and bramble groundcover did not increase. Woody regeneration was greater following canopy reduction and understory disturbance compared to C. Disturbance (fire or herbicide) was required to maintain vegetation at the ideal height for wild turkey broods. Soft mast production increased after canopy reduction with and without fire. Invertebrate biomass did not increase following any treatment, but availability exceeded the dietary requirements of a wild turkey brood. I also counted stem density of oak and competitor regeneration in response to these treatments. Seedlings <12.7 cm were ephemeral. S and SF had a greater density of oak stems >1.4 m than C and F. However, S and SF also had the greatest density of oak >1.4 m prior to treatment. Canopy reduction increased oak competitors, but prescribed fire reduced competitors.

I recommend canopy reduction, followed by repeated low-intensity prescribed fire to maintain low groundcover to enhance brood habitat for wild turkeys in mature closed-canopy upland hardwood stands.

Preface

I evaluated the effects of 7 silvicultural practices on food and cover resources for brooding wild turkeys, and the composition of woody regeneration. Chapter I of this thesis provides the background of this project and a brief synopsis of previous findings. Chapter II, "Brood cover and food resources for wild turkeys following silvicultural treatments in mature upland hardwoods," has been formatted for submission to the Wildlife Society Bulletin, and Chapter III, "Response of oak and competitors to eight years of cutting and prescribed fire in upland Central Hardwoods" will be submitted to Northern Journal of Applied Forestry, but has been formatted according to Wildlife Society Bulletin conventions for consistency within this thesis.

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I. INTRODUCTION: MANAGING HARDWOODS FOR WILD TURKEYS AND OAK REGENERATION

Background

The eastern wild turkey (*Meleagris gallapavo silvestris*) is a popular game animal throughout the southeastern United States. Many private landowners, as well as state and federal agencies, actively manage property to improve wild turkey habitat. Historically, management activities for wild turkeys have focused on improving openings and old-fields (Buckner and Landers 1979, Healy and Nenno 1983), and forested acreage has been largely ignored or mismanaged. While mature, unmanaged forests, especially oak (*Quercus* spp.)-dominated stands, can be an important component of home ranges year round (Barwick and Speake 1973, Speake et al. 1975, Everett et al. 1979), early successional cover types and young forest are especially important during the nesting and brooding periods. Ideal brood cover for wild turkeys is composed of vegetation up to 50 cm tall consisting of grasses, forbs, and brambles (Hayden 1979, McCabe and Flake 1985, Metzler and Speake 1985, Campo et al. 1989, Peoples et al. 1996). Mature, closed-canopy stands often lack these understory conditions (Pack et al. 1988, Metzler and Speake 1985, Jackson et al. 2007). Because most wild turkey mortality occurs within two weeks of hatching while poults are flightless (Vander Haegen et al. 1988, Peoples et al. 1995, Miller et al. 1998, Paisley et al. 1998), turkey populations may be limited on large, unbroken tracts of mature timber with few openings. Old-fields and young forest provide the necessary structure and cover at ground level to conceal poults while allowing hens to watch for predators.

Many small, non-industrial forests have been subjected to diameter-limit cuts or “high-grading” that removed only the most valuable species with the best form, reducing the quality of stems left to reproduce in many small woodlots (Trimble 1971, Smith et al. 1997). Additionally, these partial cuttings further degrade future stand value by injuring the residual stems during repeated entries (Fajvan et al. 2002). Species such as red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), eastern redcedar (*Juniperus virginiana*), sweetgum (*Liquidambar styraciflua*), and sassafras (*Sassafras albidum*) are commonly left after more valuable species, such as oaks, black cherry (*Prunus serotina*), and black walnut (*Juglans nigra*), are harvested. Clearcutting is usually the most economical and biologically sound method to renovate these degraded stands. However, because most of the merchantable timber has already been cut, there is no motivation for loggers to cut the stand. Consequently, methods are needed that would allow landowners to enhance these stands on their own without commercial timber harvest.

Wildlife habitat management does not operate within a vacuum, and competing land uses often take higher priority. Timber production is one such use on forested tracts. Wildlife management objectives must be balanced with forest management priorities. In upland hardwood stands, this often means regenerating oak stands following timber harvest. Oaks are a valuable timber resource, representing 45% of the timber volume in Tennessee (Schweitzer 2000), and 48.5% of the sawtimber output (Stratton and Wright 1999). Additionally, oaks are a food resource for 186 birds and mammals (Van Dersal 1940), and their acorns represent a major component in the fall and winter diet of game species, such as white-tailed deer (*Odocoileus virginianus*; Johnson et al. 1995), wild turkey (Dalke et al. 1942), and black bear (*Ursus americanus*; Eagle and Pelton 1983).

Oak regeneration has proven difficult on high-quality (oak SI_{50} >22 m) sites (Loftis and McGee 1993). Many of these stands are dominated by various oak species in the overstory, but have relatively few oak seedlings and saplings (Loftis 1983, Crow 1988). Oak seedlings cannot compete with the more shade-tolerant maples (*Acer* spp.) and American beech (*Fagus grandifolia*) under closed canopy conditions, where available light may be less than 5% of full sunlight (Jackson 2002, this paper). The more shade-tolerant species overtop the oak seedlings and often form a subcanopy, further limiting light infiltration to the smaller oak seedlings.

Oak seedlings are adapted to frequent disturbance. Oaks have numerous dormant buds beneath the soil surface near the root collar (Burns and Honkala 1990). The location of these buds allows oaks to be top-killed by prescribed fire without damaging the remaining dormant buds (Larsen and Johnson 1998). Oak sprouts often dominate the understory of drier sites when drought conditions kill the aboveground portions. Many competitors are not as adapted to these xeric conditions and die. Oak regeneration may accumulate in the understory for decades until light availability increases.

Oaks are under intense competition in the open conditions following timber harvest as well. Faster-growing shade-intolerant species, such as yellow-poplar (*Liriodendron tulipifera*) and sweetgum (*Liquidambar styraciflua*), can quickly dominate a site. Additionally, more shade-tolerant species, such as maples, ashes (*Fraxinus* spp.), and American beech, present prior to harvest can take full advantage of their established crowns and root systems and capture any newly-formed gaps.

The shelterwood method of regeneration has been recommended for promoting oak seedlings and saplings over their competitors (Sander et al. 1983, Loftis 1990, Brose and Van Lear 1998). A shelterwood harvest retains partial shade to hinder shade-intolerant species, while allowing some light to reach oak seedlings and sprouts. After a period of time, usually 6 – 8 years, the residual overstory is harvested and the stand regenerates.

Brose et al. (1999) recommended prescribed fire to promote oak regeneration following a shelterwood harvest. They found prescribed fire decreased the density of yellow-poplar relative to oak sprouts. They recommend burning in spring with a medium to medium-high fire intensity with flame heights of ~1 m. They suggested burning 3 – 5 years after the initial cut to allow oak regeneration to develop the root system characteristics required to promote vigorous sprouting following the fire.

In 2000, a study was initiated to document the effects of silvicultural treatments (multiple prescribed fires, shelterwood harvest, shelterwood harvest with 1 prescribed fire, retention cut, retention cut with multiple prescribed fires, and control) on vegetation structure and composition in mixed upland hardwoods.

Jackson (2002) observed the initial vegetation response in 2000-2001. He found that while overstory removal initially increased light availability, the herbaceous plant community was relatively unchanged, with the exception of disturbance-mediated species, such as fireweed (*Erechtites hieracifolia*) and American pokeweed (*Phytolacca americana*). He also documented an increase in small oak seedlings following prescribed fire. Red maple regeneration was reduced in all size classes by prescribed fire. However, sassafras (*Sassafras albidum*) and yellow-poplar, the two other primary competitors of oak on the study sites, increased in all size classes following prescribed fire.

Basinger (2003) reported on the initial effects of these practices on food and cover for wild turkey broods. He found little soft mast was produced in the first season after treatment, but that soft mast production increased by the second year. Invertebrate biomass did not differ among treatments. Herbaceous groundcover did not increase from pretreatment levels, and woody vegetation dominated treated areas. While woody regeneration is not ideal brood cover, Basinger (2003) found retention cuts, with and without fire, and shelterwood cuts, with and without fire, provided adequate cover for nesting wild turkeys, and that retention cuts with prescribed fire provided the best brood cover because of the dense cover at ground level and relatively open structure >1m aboveground.

Gordon (2005) examined oak regeneration and vegetation development 3 seasons after initial treatments. His findings reinforced the conclusions of Jackson (2002). Sassafras and yellow-poplar (among others) were outcompeting oaks in treated areas, and no treatment differences were found for red (subgenus *Erythtobalanus*) or white oak (subgenus *Leucobalanus*) groups. Treatments did not alter composition or coverage by herbaceous plants. Understory structure <1m tall increased in shelterwood cuts and retention cuts with and without prescribed fire. Groundcover was dominated by woody species, as in previous years. He also reported the greatest white oak acorn production and crown size in retention cuts.

Lashley (2009) compared forage production following these practices to that produced in various warm-season food plot plantings for white-tailed deer. He found that while warm-season food plots resulted in greater production of higher quality forage, partial overstory removal with and without prescribed fire produced adequate tonnage and quality to meet the nutritional requirements of white-tailed deer. Additionally, shelterwood harvests with and without prescribed fire increased forage availability and provided an economic incentive in contrast to the annual expense of establishing warm-season food plots.

From 2006 – 2009, I followed the work of Jackson (2002), Basinger (2003), and Gordon (2005), documenting brooding and nesting conditions for wild turkeys, as well as recording the vegetation response and composition of tree regeneration following these forest management practices. Additionally, understory herbicide treatments with and without prescribed fire were implemented in the previously unburned retention cuts to determine what effect this would have on wild turkey brooding cover.

I evaluated the effects of forest regeneration methods (shelterwood and shelterwood with one prescribed fire) and timber stand improvement practices (retention cut, retention cut with multiple prescribed fires, retention cut with herbicide, retention cut with herbicide and prescribed fire, and multiple prescribed fires) on the composition and structure of the treated stands 6 – 8 years post treatment. Additionally, I quantified summer food resources for wild turkeys in the understory by measuring soft mast production and invertebrate availability in response to these silvicultural practices. My hypotheses were as follows for wild turkey brood cover:

1. Herbaceous groundcover will increase following canopy reduction with and without continued prescribed fire and/or herbicide.

2. Woody groundcover will increase following canopy reduction, and decease after herbicide and prescribed fire.

3. Visual obstruction will increase following canopy reduction, and decrease after herbicide and prescribed fire.

4. Soft mast production will increase following canopy reduction with and without understory disturbance (prescribed fire and herbicide). Prescribed fire without canopy reduction will not increase soft mast production.

5. Invertebrate availability will increase because of increased herbaceous vegetation following canopy reduction and understory disturbance.

My hypotheses for woody regeneration were:

1. Oaks and competitors will increase following canopy reduction compared to C.

2. Prescribed fire will reduce the density maple and yellow-poplar advance regeneration compared to treatments without fire.

3. Repeated prescribed fire (every 2-4 years) will have fewer oaks and competitors in the advanced regeneration size class (>1.4 m tall) than the same overstory treatment without fire.

I predicted canopy reduction with understory disturbance would enhance the quality of brood cover for wild turkeys by increasing soft mast production, invertebrate availability, and understory development. Additionally, I predicted oak and competitor regeneration would increase following canopy reduction, and oak competitors would be reduced following prescribed fire.

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II. BROOD COVER AND FOOD RESOURCES FOR WILD TURKEYS FOLLOWING SILVICULTURAL TREATMENTS IN MATURE UPLAND HARDWOODS

Brood Cover and Food Resources for Wild Turkeys Following Silvicultural Treatments in Mature Upland Hardwoods

ABSTRACT Although wild turkeys have been restored throughout their native range and beyond, populations have not responded well in all areas. One such area is in portions of the southern Appalachians where massive tracts of unbroken hardwood stands dominate. Brood cover for wild turkeys is often limited in these mature hardwood stands as a result of limited understory development. A lack of vegetation at ground level can lead to increased predation and decreased recruitment. Methods are needed that enhance brood cover in forested areas while leaving the overstory intact. I evaluated the effects of 7 silvicultural treatments (repeated fire, shelterwood cut, shelterwood cut with one fire, retention cut, retention cut with repeated fire, retention cut with herbicide, and retention cut with herbicide and repeated fire) on brood cover and food resources for wild turkeys. Photosynthetically active radiation infiltration at 1.4 m was 5x greater in retention cuts with repeated fire than in shelterwood harvests, 2x greater than that within shelterwood harvests with one prescribed fire, and 6x greater than that within control. Herbaceous groundcover was not affected. Woody groundcover dominated all treatments with canopy reduction. Understory disturbance (prescribed fire and broadcast herbicide treatments) reduced visual obstruction above 1 m and midstory density. However, without repeated prescribed fire, woody vegetation exceeded the ideal height for wild turkey broods within 2 years. Soft mast production was greatest following canopy reduction, but varied by year and site. Invertebrate biomass did not increase following any treatment, but all treatments contained

enough invertebrates to meet the protein requirement for a turkey brood (10.1 poults) for 28 days. Where understory structure is inadequate for wild turkey broods, I recommend reducing canopy coverage in closed-canopy stands by 30 – 40% and using low-intensity fire every 2 – 5 years in upland hardwood systems.

INTRODUCTION

Mature, oak (*Quercus* spp.)-dominated hardwood stands provide roosting cover with potential food resources for wild turkeys (*Meleagris gallapavo*) during the fall and winter (Barwick and Speake 1973, Speake et al. 1975, Everett et al. 1979). However, these stands often lack the understory development that characterizes high-quality nesting and brooding cover (Pack et al. 1988, Metzler and Speake 1985, Jackson et al. 2007). Ideal cover for turkey broods is composed of vegetation up to 50 cm tall consisting of grasses, forbs, and brambles (*Rubus* spp.) (McCabe and Flake 1985, Metzler and Speake 1985, Campo et al. 1989, Peoples et al. 1996). These plants form overhead “umbrella” cover that provides protection for the poults, as well as access to invertebrates, seeds, and soft mast. Most wild turkey mortality occurs during the first two weeks after hatching, while poults are still flightless (Vander Haegen et al. 1988, Peoples et al. 1995, Miller et al. 1998, Paisley et al. 1998). The structure of the understory can influence wild turkey production on large forested tracts by exposing nests and broods to predation (Metzler and Speake 1985 Badyaev 1995). In east Tennessee, less than 0.06% of Cherokee National Forest has been regenerated annually since 2002 and early successional cover (forest openings) represents less than 1% of the area (Speaks 2005, Speaks 2006, Wanda Kelly, USFS, unpublished data). The lack of disturbance under this management scenario can result in a relatively poor brood habitat, and stagnant or reduced wild turkey populations (Hillestad and Speake 1970, Metzler and Speake 1985).

Understory vegetation in hardwood forests can be altered through canopy reduction and understory disturbance. Canopy reduction, either through timber harvest or noncommercial thinnings, provides increased light to the understory and increased growing space for retained trees. Increased light infiltration stimulates understory development and increases soft mast production (Perry et al. 1999, Greenberg et al. 2007), which can improve habitat for wild turkey broods. Timber harvest can improve nesting and brood cover; however, this can come at the expense of hard mast production, and woody vegetation will likely dominate and reduce the quality of brood cover within a few years (Sharp 1963, Crawford 1971, Jackson et al. 2007). Subsequent disturbance, such as prescribed fire, should be considered to stimulate groundcover and control woody vegetation (Pack et al. 1988, Jackson et al. 2007).

Management practices proposed to enhance nesting and brood cover for wild turkeys have been largely limited to old-fields (Hurst and Owen 1980, Healy and Nenno 1983, Lafon et al. 2001, Harper and Gruchy 2009) and pine systems (Hurst 1978, Sisson et al.1990, Jones and Chamberlain 2004). Pine stands are commonly thinned, burned, and treated with one or more herbicides to release crop trees and control woody encroachment. These practices provide lush understory vegetation that wild turkey hens seek for raising broods.

Management practices to improve habitat for wild turkeys in hardwood forest systems need to be evaluated. Many large public landholdings are dominated by expanses of closed-canopy hardwood forests and lack the structural diversity required for high-quality brood cover.

Likewise, management practices are needed for private forestland as well. Many private landowners want to improve the condition of their woods for wild turkeys or other wildlife, but do not want to harvest timber for aesthetic reasons, or to maintain hard mast production.

I conducted a field experiment to evaluate the effects of canopy reduction (shelterwood harvests and retention cuts) alone and in combination with understory disturbance (prescribed fire and herbicide application) on 1) the structure and composition of understory vegetation as related to wild turkey brood cover, and 2) the resulting food resources (invertebrate availability and soft mast production) for turkey poults in the understory. I expected herbaceous groundcover and soft mast production to increase following canopy reduction and prescribed fire treatments, and woody vegetation to decline following prescribed fire and herbicide applications. I also predicted invertebrate availability would increase following understory disturbance as the herbaceous groundcover increased.

STUDY AREA

This study was conducted on Chuck Swan State Forest and Wildlife Management Area (CSF). It is managed by the Tennessee Department of Agriculture Division of Forestry (TDF) and the Tennessee Wildlife Resources Agency (TWRA). CSF encompasses 9825 ha and is in the Southern Appalachian Ridge and Valley physiographic province in east Tennessee. Elevation at CSF ranges from 310 m to 520 m. CSF receives approximately 130 cm of annual rainfall.

Approximately 92% of CSF was forested. The main forest types were mixed hardwoods and oak-hickory with scattered shortleaf pine (*Pinus echinata*). Common overstory species included chestnut oak (*Quercus montana*), white oak (*Quercus alba*), northern red oak (*Quercus* *rubra*), black oak (*Quercus velutina*), mockernut hickory (*Carya tomemtosa*), pignut hickory (*Carya glabra*), yellow-poplar (*Liriodendron tulipifera*), blackgum (*Nyssa sylvatica*), American beech (*Fagus grandifolia*), and red maple (*Acer rubrum*). Sassafras (*Sassafras albidum*), flowering dogwood (*Cornus florida*), and sourwood (*Oxydendron arboreum*) were common in the midstory. Hardwood stands were managed on an 80-year rotation, with clearcutting the most common harvest method. Soils belong to the Clarksville-Fullerton-Claiborne association, and are characterized as well-drained, acidic soils with shallow, rocky, A horizons (NRCS 2009).

METHODS

A randomized complete block design with 4 stands (blocks) was used to compare vegetation structure and food resources in response to 7 silvicultural practices and control. Four stands were selected in separate watersheds, but had similar overstory composition, aspect (N to NW), and slope (24 – 30%). Each 9.6-ha stand was divided into 12, 0.8-ha treatment units (Figure 1). Treatments were randomly assigned to treatment units in each stand. In each stand, 2 treatment units were selected as reference (controls) and received no treatment. Two units were burned at each stand without canopy reduction (F) in 2001, 2005, 2007, and 2009. A shelterwood harvest (S) was implemented on 4 units in each stand. Two shelterwood units in each stand were burned (SF) in 2005. Retention cutting (R) was conducted in the remaining 4 units. Two retention cut units at each stand were burned in 2001, 2005, 2007, and 2009. The 2 unburned retention cut units were treated with a broadcast application of triclopyr (Garlon® 3-A, Dow Agrosciences LLC, Indianapolis, Indiana) to the understory (RH) after sampling in 2006. One RH unit at each stand was burned in 2007 and 2009 (RHF).

Retention cut with prescribed fire	Prescribed fire	Shelterwood harvest	Control	Shelterwood harvest with prescribed fire	Shelterwood harvest
Shelterwood harvest with prescribed fire	Control	Retention cut with herbicide	Retention cut with prescribed fire	Prescribed fire	Retention cut with herbicide and fire

Figure 1. Layout of replicated stand with random assignment of treatments to assess silvicultural practices on brood habitat for wild turkeys, Chuck Swan State Forest, TN, USA.

Shelterwood harvest and retention cutting were used for canopy reduction treatments. Shelterwood harvest is an even-aged regeneration method distinguished by a succession (usually two) of partial commercial harvests. Trees are retained after the initial harvest to shelter the regenerating understory, and the residual timber is harvested after regeneration is established. At CSF, high-quality stems with good form and vigor were retained, and cutting oaks was avoided wherever possible. The target canopy closure was 60% after the initial cut. The shelterwood units were harvested June - July 2001. Retention cutting is a non-commercial timber stand improvement practice where undesirable overstory species are killed and left standing. Stems with relative low value to wild turkeys, such as maples and yellow-poplar, were killed while oaks, blackgum, black cherry (*Prunus serotina*), persimmon (*Diospyros virginiana*), and an occasional American beech—species that provide food resources for turkeys—were retained. Canopy closure in retention cuts was reduced to 60%. Undesirable stems were girdled or hacked, and the wound treated with a 1:1 solution of triclopyr (Garlon® 3-A, Dow Agrosciences LLC, 9330 Zionsville Road, Indianapolis, Indiana) and water. The midstory was also killed, with the exception of a few flowering dogwoods, by felling and treating the stump with the herbicide solution. Retention cuts were completed in February and March 2001.

Understory disturbance included low-intensity prescribed fire and understory herbicide applications. All prescribed fires occurred during the early growing season, April – early May. Burns were initiated with backing fires, and strip-heading fires were used to burn the remainder. A low-intensity fire (flame heights < 1 m) was maintained by appropriately spacing strips. Prescribed fires were conducted under the following conditions: 10 – 21º C, 20 –40% relative humidity, 8 – 16 km/hr wind speed, and a >500-m mixing height for the smoke plume. A right-of-way contract spray crew (Innovative Solutions, Inc.) applied triclopyr (Garlon® 4, Dow Agrosciences LLC, 9330 Zionsville Road, Indianapolis, Indiana) via backpack sprayer at a rate of 11.7 L/ha in the unburned R treatment units after sampling was completed in 2006.

I measured vegetation response in 4 randomly placed plots within each treatment unit in 2006, 2008, and 2009, and 3 plots in 2007. Fewer plots were sampled in 2007 because of limited manpower. However, because I used repeated measures analysis, the discrepancy in sampling effort had little influence on statistical power. I measured overstory (stems >11.4 cm dbh) basal area and stem density within 0.04 ha, fixed-radius circular plots (Figure 2). Species and diameter at breast height (DBH) were recorded for each stem. I used a diameter tape to measure DBH of each stem and DBH was used to calculate basal area. I measured light infiltration on a transect in each treatment unit using 2 AccuPAR® LP-80 PAR/LAI ceptometers (Decagon Devices, Inc., Pullman, Washington, 2008). Each transect was oriented diagonally from one corner of the treatment unit to the opposite corner. Measurements were taken every 1 m for 30 m, beginning 20 m from the end of each transect to minimize edge effect. All measurements were taken 1.4 m above ground. PAR measurements were calculated as a percentage of full sun by taking paired, simultaneous measurements with a ceptometer with in each treatment unit and another ceptometer monitoring full PAR in the closest opening.

I measured visual obstruction to quantify vertical structure using a vegetation profile board (Nudds 1977). The board was divided into four, 50-cm intervals, marked in alternating

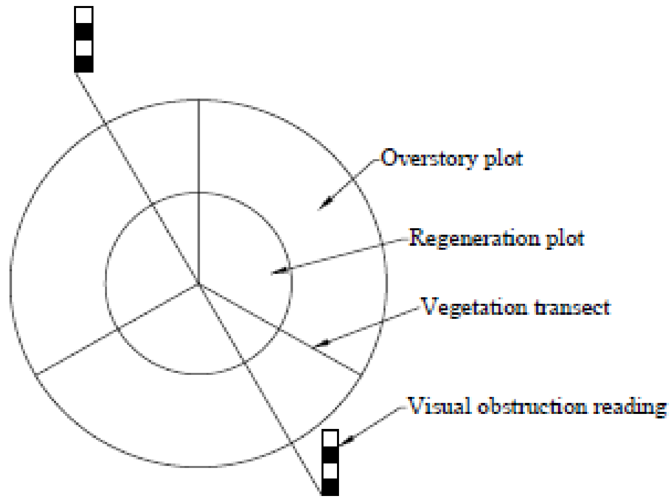

Figure 2. Design of plots used to sample vegetation as related to wild turkey brood habitat following silvicultural treatments at Chuck Swan State Forest, TN, USA, 2006 – 2009.

black and white. Visual obstruction was recorded for each increment on a scale of 1 to 5, where 1 = 0 – 20%, 2 = 20 – 40%, 3 = 40 – 60%, 4 = 60 – 80%, and 5 = 80 – 100% coverage. Visual obstruction was measured 15 m uphill and 15 m downhill from each plot center (Figure 2). I analyzed visual obstruction of the 0 – 0.5 stratum and the sum of the three strata from 0.5 – 2.0 m. I combined these strata because visual obstruction <0.5 m above ground conceals poults, but vegetation above this stratum interferes with a hen’s ability to detect predators.

I measured cover by herbaceous plants, woody vines, and brambles, as well as cover by tree and shrub species, using 3, 11.3-m line-intercept transects radiating from plot center at 0º, 120º, and 240º (Figure 2). Each species and its coverage were recorded to the nearest cm. Percent woody cover <1.4 m high was measured by recording the species present at every 0.5-m increment on 3, 11.3-m point-intercept transects radiating from plot center at 0°, 120°, and 240°.

Density of stems >1.4 m in height and less than 11.4 cm in diameter at breast height was measured within a 5.7-m radius (0.01 ha) circular plot centered on each plot center (Figure 2). Stems were tallied by species into 2.54-cm increment diameter classes: <2.54 cm, 2.54 cm – 5.08 cm, 5.09 cm – 7.62 cm, and 7.63 cm – 11.4 cm. All species and size classes were pooled for this analysis.

I measured soft mast production along 3 50-m transects in each treatment unit in early July, August, and October 2007, and late June, July, August, and September 2008. Transects were systematically placed approximately 25 m apart and at least 5 meters from the edge of the treatment unit. All fruits within 0.61 m of each transect and <2 m above ground were tallied by species or species group. I report soft mast production by species that commonly occur in the diets of wild turkeys, including American pokeweed (*Phytolacca americana*), blackberry (*Rubus* spp.), blueberry (*Vaccinium* spp.), greenbrier (*Smilax* spp.), huckleberry (*Gaylussacia baccata*), sumac (*Rhus* spp.), and viburnum (*Viburnum* spp.) (Dalke et al. 1942, Hamrick and Davis 1971, Hurst and Stringer 1975). Transects were initiated when soft mast first began to ripen. Representative fruit samples were gathered outside of the research stands, dried at 55º C to constant mass, and weighed (whole fruit including seeds) to estimate soft mast biomass. I used the sampling period with peak soft mast biomass (both ripe and unripe) for each treatment cell and species as the total production estimate for each cell (Greenberg et al. 2007).

I measured invertebrate abundance using a modified leaf blower vacuum sampler (Harper and Guynn 1998) and a 0.25 m^2 (0.5 m wide x 0.5 m long x 0.5 m tall) bottomless sampling box with a lid. I sampled during early July 2007 and 2008. In 2007, 4 samples were randomly taken throughout each treatment unit. Sampling sites were at least 30 m apart. With additional assistance in 2008, I vacuumed 9 litter samples from each treatment unit. I systematically located 3 invertebrate sampling plots at least 30.5 m from the edge of the treatment unit and other sampling plots. The bottomless sampling box was placed 15 m from each invertebrate plot center at 0 º, 120º, and 240º. The top layer of litter and all vegetation were vacuumed. I did not sample during windy conditions or rain to avoid biasing results (Hughes 1955). Sample bags were frozen to prevent decomposition until dried to constant mass (usually about 48 hours) at 60º C (Murkin et al. 1994). I sorted all invertebrates to order and weighed them to the nearest 0.0001 g. I report biomass of taxa commonly consumed by wild turkeys: classes Gastropoda and Malacostraca, and orders Arachnida, Coleoptera, Diptera, Hemiptera, Homoptera, Hymenoptera, Lepidoptera, and Orthoptera as reported by Dalke et al. (1942), Hamrick and Davis (1971), Hurst and Stringer (1975), Healy (1985), and Iglay et al. (2005).

I estimated the minimum foraging area (*A*) required for a brood of 10.1 turkey poults (Godfrey and Norman 1999) to meet their dietary invertebrate requirements for the first 28 days after hatching. The mean daily intake of invertebrates by turkey poults has not been reported, so I used weekly body mass (g_w) and mean daily food intake (f_w) by week for blue grouse (*Dendragapus obscurus*) chicks (Stiven 1961), a closely related species with a similar dietary protein requirement (Stiven 1961, Hurst and Stringer 1975, Nenno and Lindzey 1979, Healy 1985), and adjusted daily food requirements to correspond with the weekly mass (p_w) of domestic turkey poults (Knížetová et al. 1995). To calculate *A*, I used the following formula

$$A_t = \frac{\Sigma^{p_w}/_{g_w} * f_w * 0.35 * \mathbf{10.1}}{I_t}$$

where I_t is the mean invertebrate biomass for each treatment*year, p_w is mean poult mass of domestic turkeys for the w^{th} week (Knížetová et al. 1995), g_w is the mean chick mass of blue grouse for the w^{th} week (Stiven 1961), and *f* is the daily invertebrate food requirement for the w^{th} week for blue grouse (Stiven 1961). Stiven's (1961) daily intake values were based on live invertebrate biomass, so I converted the mean daily intake to dry weight assuming dry weight ≈35% of live weight (Carrel 1990, Klein-Rollais and Daguzan 1990, Studier and Sevick 1992).

I used a 2-way, repeated measures ANOVA (PROC MIXED) in SAS 9.1 (SAS Institute, Cary North Carolina) to detect differences in overstory basal area and stem density; vegetation structure; groundcover by herbaceous plants, woody vines, and brambles; groundcover by woody regeneration; midstory stem density; soft mast production; and invertebrate biomass and abundance among treatments and across years. I used a 1-way mixed model ANOVA (PROC MIXED) to determine differences in PAR infiltration among treatments. I used the log transformation to correct for non-normality in soft mast production. Each stand (n=4) was treated as a replication. While treatments were replicated on 2 separate treatment units within each stand, the mean of the 2 units was used as the value for the treatment in each stand. I report nontransformed means. When ANOVAs were significant with α=0.05, I used Tukey's Honestly Significant Differences comparison test to determine differences in treatments and treatment*year.

RESULTS

Basal area was reduced in treatment units that received overstory manipulation (Table 1). Basal area in S harvests and R cuts were about 60% of C. Overstory stem densities in shelterwood harvests (S and SF) were about 60% of C, but were about 30% of C in retention cuts (R, RF, RH, and RHB) (Table 2). When the initial S harvests were conducted, some high-value stems (large diameter oaks) were cut, and some intermediate stems were retained. In R cuts, most of the large diameter oaks were retained and midstory stems removed, so relatively few trees comprised the same basal area found in denser stands. Since the initial shelterwood harvests, regeneration progressed to the extent that PAR levels in S were similar to C (Table 3). Following herbicide application in RH and RHF, light infiltration was greater than S where the midstory was still intact (Table 3). In RF, which was maintained by repeated prescribed fire, PAR levels were 5x

Table 1. Mean basal area (m²/ha) of stems ≥ 11.4 cm DBH following silvicultural treatments to enhance wild turkey brood habitat, Chuck Swan State Forest, TN, USA, 2000 – 2009.

	Year				
Silvicultural treatment [a]	2000 [b]	2006 [c]	2007 [c]	2008 [c]	2009 [c]
C	24 (1)	33 (3) A	29 (3) A	30 (2) A	34 (2) A
F	25 (2)	26 (1) AB	26 (4) AB	26 (3) AB	27 (1) AB
S	24 (1)	20 (2) C	17 (1) C	16 (1) C	-
SF	28 (3)	20 (3) BC	21 (3) BC	24 (3) BC	-
R	23 (3)	16 (4) C	-	-	-
RF	27 (2)	21 (11) BC	21 (2) BC	25 (2) BC	23 (1) BC
RH	-	-	15 (4) C	18 (3) C	22 (1) C
RHF	-	-	21 (3) BC	21 (3) BC	24 (3) BC

Standard errors in parentheses

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, R= retention cut, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fires

[b] Pretreatment data. Treatment units did not differ ($F_{5,15}$ =0.77, p=0.589).

[c] Different letters indicate differences among treatments ($F_{7,20.3}$ =8.58, p<0.001).

Table 2. Mean density (per ha) of stems >11.4 cm DBH following silvicultural treatments to enhance wild turkey brood habitat, Chuck Swan State Forest, TN, USA, 2000 – 2009.

	Years				
Silvicultural treatment [a]	2000 [b]	2006 [c]	2007 [c]	2008 [c]	2009 [c]
C	304 (9)	309 (34) A	325 (25) A	296 (14) A	351 (25) A
F	303 (18)	277 (25) AB	245 (33) AB	213 (31) AB	269 (45) AB
S	329 (33)	217 (30) BC	213 (27) BC	218 (24) BC	-
SF	333 (20)	228 (37) B	222 (18) B	219 (33) B	-
R	336 (27)	124 (36) CD	-	-	-
RF	336 (11)	118 (6) D	92.7 (17) D	105 (5) D	118 (15) D
RH	-	-	119 (17) CD	116 (15) CD	171 (47) CD
RHF	-	-	109 (16) D	104 (10) D	171 (15) D

Standard errors in parentheses

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, R= retention cut, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fires

[b] Pretreatment data. Treatment units did not differ ($F_{5,15}$ =0.87, p=0.523).

[c] Different letters indicate differences among treatments ($F_{7,21}$ =21.42, $p<0.001$).

Table 3. Mean photosynthetically active radiation (PAR) infiltration 1.4 m from the ground following silvicultural treatments to enhance wild turkey brood habitat, Chuck Swan State Forest, TN, USA, 2009.

Silvicultural treatment [a]	% PAR infiltration 2009 [b]
C	4.7 (1.0) D
F	13.3 (3.4) CD
S	5.8 (2.4) D
SF	14.4 (2.4) BCD
RF	29.4 (5.4) A
RH	19.8 (4.6) ABC
RHF	26.6 (7.4) AB

Standard errors in parentheses

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fires

[b] Different letters indicate differences among treatments ($F_{6,18}$=15.18, $p<0.001$).

greater than C and 4x greater than S (Table 3). Groundcover comprised of herbaceous plants, woody vines, and brambles varied among replicate stands as reflected by standard errors (Table 4), but did not differ by treatment or year (treatment). Woody groundcover was more prevalent than herbaceous cover and dominated most sites (Tables 4 and 5). Woody regeneration was dominated by yellow-poplar, red maple, or sassafras in all treatments.

Density of stems >1.4 m tall and <11.4 cm dbh declined over time in S as the regeneration closed the canopy gaps from timber harvest and the entered stem exclusion stage (Table 6). RF showed a steady trend of declining stems >1.4 m tall and <11.4 cm dbh the growing seasons with prescribed fire and a subsequent increase the following season as stems top-killed by prescribed fire repeatedly resprouted. Following the understory herbicide application, density of stems >1.4 m tall and <11.4 cm dbh declined 99% in RHF and 87% in RH in 2007 compared to R in 2006 (Table 6).

Visual obstruction was least in uncut units (C and F) and immediately following herbicide application with fire (Table 7). Increased light resulting from canopy reduction with and without fire (S, SF, and RF) stimulated vegetation at ground level. Prescribed fire in RF top-killed woody vegetation, and visual obstruction 0.5 m – 2 m increased the following growing season. Visual obstruction in the 0.5 m – 2.0 m stratum was greater in S than in C or F. Overstory reduction without subsequent disturbance allowed woody regeneration to reestablish the midstory that failed to develop, or had been shaded out in previously unmanaged stands. Soft mast production varied among sites, which is indicated by the standard errors (Table 8). This variation was apparently a result of differences in the seedbank among stands. Soft mast

Table 4. Mean percent cover by herbaceous plants, woody vines, and brambles <1.4 m tall following silvicultural treatments to enhance wild turkey brood habitat, Chuck Swan State Forest, TN, USA, 2006 – 2009.

	Years			
Silvicultural treatment [a]	2006	2007	2008	2009
C	13.9 (3.1)	15.0 (3.6)	15.8 (5.7)	19.0 (6.1)
F	11.9 (2.4)	8.94 (0.8)	14.9 (0.9)	13.0 (1.2)
S	19.5 (5.0)	15.0 (0.7)	21.8 (2.8)	-
SF	15.8 (1.9)	14.0 (1.8)	25.6 (6.3)	-
R	32.4 (8.6)	-	-	-
RF	24.6 (2.9)	18.0 (4.3)	28.5 (7.5)	20.3 (9.5)
RH	-	9.03 (4.2)	15.9 (6.0)	17.6 (6.8)
RHF	-	15.3 (8.7)	19.9 (4.7)	16.7 (5.6)

Standard errors in parentheses

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, R= retention cut, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fires.

Treatments did not differ ($F_{7, 21.7}$=2.22, p=0.072).

Table 5. Mean percent cover by trees and shrubs <1.4 m tall following silvicultural treatments to enhance wild turkey brood habitat, Chuck Swan State Forest, TN, USA, 2006 – 2009.

	Years			
Silvicultural treatment [a]	2006 [b]	2007 [b]	2008 [b]	2009 [b]
C	11.5 (1.8) E	17.9 (3.7) DE	18.1(2.8) DE	19.2 (3.4) CDE
F	9.6 (3.2) E	17.5 (5.6) DE	27.7 (1.2) BCDE	19.6 (4.0) CDE
S	38.3 (4.6) ABCDE	28.0 (5.2) BCDE	32.4 (9.1) ABCDE	-
SF	17.5 (3.2) DE	35.3 (4.8) ABCDE	47.8 (7.0) ABC	-
R	52.2 (9.0) AB	-	-	-
RF	30.6 (6.9) BCDE	40.7 (5.1) ABCD	57.6 (4.2) A	40.9 (8.9) ABCD
RH	-	8.6 (1.5) E	23.0 (3.6) CDE	25.6 (4.1) BCDE
RHF	-	11.4 (3.3) DE	21.1 (5.5) CDE	20.9 (4.2) CDE

Standard errors in parentheses

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, R= retention cut, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fires

[b] Different letters indicate differences among year (treatment) ($F_{14,45.1}$=2.48, p=0.011).

Table 6. Mean density (per ha) of stems >1.4 m tall and <11.4 cm DBH following silvicultural treatments to enhance wild turkey brood habitat, Chuck Swan State Forest, TN, USA, 2006 – 2009.

	Years			
Silvicultural treatment [a]	2006 [b]	2007 [b]	2008 [b]	2009 [b]
C	1670 (561) CDEFG	1740 (487) CDEFG	106 (281) DEFG	1870 (701) CDEFG
F	716 (311) EFG	240 (184) FG	304 (140) EFG	319 (215) EFG
S	11000 (2790) A	8050 (1680)AB	5500 (1150) ABC	-
SF	2840 (899) BCDE	2430 (380) CDEF	2420 (679) CDEF	-
R	8910 (1570) A	-	-	-
RF	4740 (1750) ABCD	920 (373) EFG	2160 (386) CDEF	297 (172) EFG
RH	-	1120 (250) CDEFG	1140 (286) DEFG	1760 (156) CDEFG
RHF	-	79.2 (35.6) G	444 (192) EFG	235 (131) EFG

Standard errors in parentheses

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, R= retention cut, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fires

[b] Different letters indicate differences among year (treatment) ($F_{14, 45.1}$=2.85, p=0.004).

Table 7. Mean visual obstruction following silvicultural treatments to enhance wild turkey brood habitat, Chuck Swan State Forest, TN, USA, 2007 – 2008.

	0 – 0.5 m [b]		0.5 – 2.0 m [c]	
Silvicultural treatment [a]	2007	2008	2007	2008
C	2.2 (0.4) CD	2.2 (0.2) CD	5.8 (1.2) E	4.9 (0.8) E
F	2.1 (0.4) D	2.9 (0.4) BCD	4.5 (0.6) E	6.2 (0.9) DE
S	4.3 (0.4) AB	5.0 (0.3) A	12.0 (1.1) ABC	12.7 (0.5) AB
SF	4.25 (0.2) AB	4.6 (0.2) AB	10.1 (0.7) ABCD	11.9 (1.2) ABC
RF	4.1 (0.3) ABC	4.7 (0.1) AB	8.4 (1.0) BDE	11.8 (0.2) AC
RH	2.9 (0.7) BCD	3.5 (0.5) ABCD	6.8 (1.3) DE	7.9 (1.2) CDE
RHF	1.7 (0.2) D	2.8 (0.6) BCD	4.5 (0.5) E	6.5 (0.9) DE

Standard errors in parentheses

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fires

[b] Different letters indicate differences among year (treatment) ($F_{7,21}$ =2.80, p=0.032).

[c] Different letters indicate differences among year(treatment) ($F_{7,21}$ =4.65, p=0.003).

Table 8. Mean soft mast production (g/ha) within 2 m of the ground by species commonly consumed by wild turkeys following silvicultural treatments, Chuck Swan State Forest, TN, USA, 2007 – 2008.

	Years	
Silvicultural treatment [a]	2007 [b]	2008 [b]
C	15 (8) ABCD	1261 (1229) ABCD
F	3 (3) CD	821 (337) AB
S	1700 (1030) A	12233 (9301) A
SF	2457 (790) A	8690 (5575) A
RF	25 (25) BCD	22112 (16945) A
RH	0 (0) D	67 (23) ABC
RHF	6216 (4690) ABC	9267 (8008) A

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fires

[b] Different letters indicate differences among year(treatment) ($F_{6, 21}$=4.58, P=0.004).

production was greater in 2008 than 2007 in RF, F, and RH because stands were not disturbed in 2008. Soft mast production in C, F, S, SF, and RF treatments was dominated by *Rubus* spp. *Phytolacca americana* produced most of the soft mast in RHF, and *Vaccinium* spp. in RH.

I collected invertebrates from 10 taxa considered important to wild turkey poults: Gastropoda, Malacostraca, Araneae, Coleoptera, Diptera, Hemiptera, Homoptera, Hymenoptera, Lepidoptera, and Orthoptera. Invertebrate biomass varied greatly by stand (Table 9), and no treatment or year (treatment) differences were detected.

DISCUSSION

Canopy reduction followed by prescribed fire (RF, SF) provided the best structure for wild turkey broods. Moderate levels of canopy reduction (30 – 40%) increased light infiltration to the forest floor to sufficiently stimulate woody regeneration and maintain overhead cover for wild turkey broods. No treatment increased herbaceous groundcover. While canopy reduction alone (R, S) can improve nesting and brooding cover for turkeys in upland hardwoods (Jackson et al. 2007), the effects are short-lived (<5 years) without additional disturbance. Soft mast tended to increase with more intensive management, but invertebrates showed the opposite trend.

Following timber harvest, PAR declined to levels similar to unmanaged mature stands within 8 years. The regenerating understory captured canopy gaps created by timber harvest, and the available light was captured by the new midstory. Repeated prescribed fire in RF prevented woody regeneration from recapturing gaps created by canopy reduction, and herbicide treatments in RH and RHF killed the midstory, allowing PAR to reach the understory. Increased understory

Table 9. Mean biomass (g/ha) of invertebrates commonly consumed by wild turkeys and minimum foraging area (ha) following silvicultural treatments, Chuck Swan State Forest, TN, USA, 2007 – 2008.

	Invertebrate biomass [b]		Minimum foraging area [c]	
Silvicultural treatment [a]	2007	2008	2007	2008
C	1406 (375)	2132 (338)	8	5
F	395 (174)	1465 (331)	29	8
S	1006 (232)	1228 (234)	12	9
SF	886 (204)	1197 (390)	13	10
RF	1188 (662)	606 (99.6)	10	19
RH	755 (199)	791 (108)	15	15
RHF	689 (166)	1069 (373)	17	11

Standard errors in parentheses

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fire

[b] Year(treatment) ($F_{6,21}$=1.72, P=0.165) and treatment ($F_{6, 21}$=1.75, P=0.159) did not differ.

[c] Minimum area in hectares required for a brood of 10.1 poults to meet their dietary invertebrate requirements for the first 28 days after hatching assuming no mortality.

PAR stimulated ground-level vegetation that provided cover, soft mast, and substrate for invertebrates.

Despite differences in PAR infiltration, I found no difference in herbaceous cover among treatments. Low herbaceous cover is important because it provides ideal for wild turkey broods by concealing poults, while allowing the hen to watch for predators. However, competition from woody species and local seedbank differences may have contributed to a lack of herbaceous cover. Additionally, triclopyr, the active ingredient in Garlon ® 4, kills most broadleaf plants (Dow Agrosciences 2008), limiting the herbaceous response in RH and RHF mainly to a few grass species. Pack et al. (1988) found herbaceous cover increased by burning after timber harvest, but not with prescribed fire prior to canopy reduction. Jackson et al. (2007), on the same site as this study, found no difference in herbaceous coverage in response to thinning and canopy reduction. Repeated prescribed fire during the early growing season top-killed established woody vegetation, but also may have set back herbaceous response.

Woody regeneration, however, did respond to increased PAR infiltration. Woody cover tended to increase following canopy reduction compared to unmanaged stands. Similarly, density of stems >1.4 m tall and <11.4 cm dbh increased following canopy reduction. However, without further management, woody regeneration dominated following canopy reduction, and light infiltration was equal to uncut stands within 8 years after the initial cut of the shelterwood cut. Low-intensity prescribed fire after overstory reduction maintained an open midstory and well-developed cover at ground level. Increased woody cover at ground level has been associated with lower poult mortality (Hubbard et al. 2001). Without overstory reduction, prescribed fire was ineffective at improving brood cover in the understory.

Forest management practices altered the structure of the understory as well. Visual obstruction in the 0 – 0.5 m stratum tended to increase following canopy reduction. Low cover is important for concealing poults, and can lead to increased poult survival (Metzler and Speake 1985, Spears et al. 2007). However, visual obstruction 0.5 – 2 m above ground level also tended to increase as established woody vegetation grew into the newly-created canopy gaps. Hens select areas with more open midstories for brood range (Campo et al. 1989, Spears et al. 2007). Prescribed fire after canopy reduction produced the most visual obstruction at ground level while reducing obstruction in the upper strata. However, by the following growing season, visual obstruction returned to pre-burn conditions. Understory disturbance must be repeated at regular intervals to maintain desirable brood cover for wild turkeys. Herbicide application in RH and RHF reduced visual obstruction in all strata, as the triclopyr application killed >87% of the midstory. This reduction will likely be short-lived, similar to prescribed fire, because triclopyr is not soil-active, and woody regeneration had already reestablished in these stands by the summer of 2009.

Soft mast production for wild turkeys was influenced by treatment and weather, and varied from stand to stand. Soft mast production was greater in 2008 than in 2007 in undisturbed treatments (C and S) because of extreme drought conditions in 2007 (NOAA 2008). RH had more soft mast in 2008 than in 2007 because of weather and vegetation recovery a year after herbicide application. Soft mast availability was greatest in RF in the second growing season following fire. Most of the soft mast in S, SF, and RF consisted of blackberries. Blackberries are produced on mature floricanes, so little soft mast was available immediately after prescribed fire in 2007. Soft mast production in RF increased nearly 1000-fold in 2008. Because little soft mast was available immediately following prescribed fire, stands should not be burned annually when managing for wild turkeys. Blackberries are the most commonly consumed soft mast by wild turkeys (Korschgen 1967, Blackburn et al. 1975, Kennamer at al. 1980). Brambles can also provide escape cover and overhead protection from avian predators for older broods. Brambles were present in all retention cut units before herbicide application. Following treatment, coverage was greatly reduced and blackberry was completely absent from some treated units. Jones and Chamberlain (2004) found an increase in blackberry coverage following treatment with imazapyr in managed pine stands. Blackberry is controlled by triclopyr, but responds favorably following imazapyr treatment. American pokeweed was the most prevalent soft mast in RHF. While pokeweed is commonly consumed by wild turkeys, it is relatively unimportant compared to blackberries. Nonetheless, persistent soft mast, such as pokeweed or sumac, can provide buffer food for wild turkeys in years of poor hard mast production and are important for many other wildlife species (McCarty et al. 2002, Greenberg et al. 2007).

While plant material, such as green browse, seeds, soft mast, and hard mast (Dalke et al. 1942, Blackburn et al. 1975, Kennamer et al. 1980), comprises the majority of the diet of juvenile and adult turkeys, vegetation makes up a relatively small portion of a young poult's diet (Blackburn et al. 1975, Healy 1985, Rogers 1985). Poults require a diet of 28% crude protein (Marsden and Martin 1955), and these demands are most easily met by consuming arthropods and other invertebrates. Invertebrates exceed the crude protein requirements of poults (Beck and Beck 1955, Stiven 1961, Despins and Axtell 1994, Zuidhof 2003). Additionally, snails and snail shells are an important source of calcium for hens during laying (Beck and Beck 1955, Pattee and Beasom 1981). All treatments tended to reduce invertebrate availability for turkey poults compared to unmanipulated stands. Most of the invertebrates collected were ground-dwelling. These invertebrates are important because they are within reach of poults. Young poults do not begin scratching in the litter until early fall (Healy et al. 1975); however, litter dwelling invertebrates constitute an important source of protein in forested areas (Harper et al. 2001). While prescribed fire reduced invertebrate availability, this reduction was unlikely detrimental to brood habitat. F provided enough invertebrates in 2007 for a 10.1-poult brood to meet its invertebrate needs the first 28 days post hatching on 29 ha. Godfrey and Norman (1999) found the average home range for wild turkey broods during the first 28 days post hatching was ~200 ha in upland hardwood stands, suggesting understory structure, and not food resources, may limit turkey recruitment in heavily forested areas.

Broadcast herbicide treatments to the understory appear to have limited application in managing hardwood stands for wild turkeys. Few herbicides are available to kill hardwood shoots without potentially damaging the overstory. Imazapyr is commonly used in pine systems because it provides prolonged suppression of hardwood sprouts without harming pines. However, imazapyr and other forestry herbicides are soil-active, and could potentially harm desirable overstory stems (BASF 2007). Additionally, herbicide treatments were costly (~US $690.00/ ha for RHF, $653.00/ha for RH) compared to prescribed fire (~US $37.00/ha when assisted by Tennessee Division of Forestry), and did little to enhance the quality of brood cover for wild turkeys (McCord and Harper, in press). Because a soil-active herbicide was not used, prescribed fire stimulated the germination of ample seedlings to reestablish the midstory in RHF. Triclopyr also killed most of the desirable forbs, leaving relatively little structure in the understory. In pine stands, herbaceous groundcover recovered and increased by the second growing season after imazapyr treatment (Jones and Chamberlain 2004, Miller and Miller 2004). The residual soil activity of imazapyr may have suppressed woody regeneration for months after treatment, allowing many herbaceous species to establish. Because triclopyr has no soil activity, woody regeneration had reestablished in the understory on my study by the following growing season. Long-term monitoring is needed, however, to determine how the plant community will recover following broadcast herbicide applications in hardwoods.

Dormant-season and early growing-season burning has been promoted as a management tool to improve turkey brood habitat by increasing forb cover and decreasing woody vegetation (Pack et al. 1988). However, other studies have found low-intensity, early growing-season fire alone ineffective at killing woody regeneration and altering composition from woody vegetation to herbaceous plants (Jackson et al. 2007, Harper and Gruchy 2009).

Future research should investigate the effects of the seasonality of prescribed fire on food resources and brood cover for wild turkeys in upland hardwood stands. Low-intensity prescribed fire during the late growing-season (September and October) has not been examined as a tool to enhance brood cover in hardwoods, and may prove more effective at controlling woody regeneration and stimulating herbaceous groundcover. Gruchy et al. (2009) found a single September prescribed fire in old-fields more effective at controlling woody invasion than dormant-season fire, and as effective as applications of triclopyr or imazapyr.

Management Implications

Where cover for wild turkey broods may be limiting in closed canopy upland hardwood stands, I recommend reducing canopy closure to 60 – 70% to increase light and improve understory development and seed and soft mast production. Where appropriate, a shelterwood harvest may be implemented to offset the expense of firebreaks and prescribed fire. If timber value does not warrant commercial harvest, a retention cut may be conducted. Trees should be selected for retention based on their potential to produce both hard and soft mast commonly consumed by wild turkeys. I do not recommend understory applications of triclopyr because this treatment reduced understory structure and invertebrate availability, and herbaceous groundcover did not increase.

I recommend managing thinned stands with low-intensity prescribed fire every 2 – 5 years to stimulate the seedbank, increase soft mast production, and limit the development of the midstory. Because dormant-season and low-intensity early growing-season fire is relatively ineffective at controlling woody regeneration and growth, future research should investigate the efficacy of using prescribed fire during late growing season in upland hardwoods to enhance brood cover for wild turkeys.

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Appendices

Appendix 1. List of plant species encountered along transects and in plots following silvicultural treatments to enhance wild turkey brood habitat, Chuck Swan State Forest, TN, USA 2006 - 2009

Acer rubrum
Acer saccharum
Actaea racemosa
Adiantum pedatum
Ailanthus altissima
Albizia julibrissin
Ambrosia artemisiifolia
Amelanchier arborea
Amianthum muscatoxicum
Amphicarpaea brachteata
Andropogon virginicus
Aralia spinosa
Arisaema quitatum
Aristolochia serpentaria
Asimina triloba
Asplenium platyneuron
Athyrium filix-femina
Aureolaria spp.
Bidens sp.
Boehmeria cylindrica
Campsis radicans
Carex pensylvanica
Carex spp.
Carpinus caroliniana
Carya glabra
Carya ovata
Carya tomentosa
Castanea dentata
Castanea pumila
Cercis canadensis
Chamaecrista nictitans
Chimaphila maculata
Cirsium sp.
Clintonia spp.
Coreopsis major
Cornus florida
Cynoglossum virginianum
Cypripedium sp.
Danthonia spp.
Daucus carota
Desmodium laevigatum
Desmodium nudiflorum
Desmodium rotundifolium
Dichanthelium spp.
Dioscorea villosa
Diospyros virginiana
Elaphantopus carolinianus
Eleagnus umbellata
Elymus canadensis
Erechtites hieraciifolia
Eryngium yuccifolium
Euonymus americanus
Eupatorium spp.
Fagus grandifolia
Fraxinus americana
Galax urceolata
Galium aparine
Galium circaezans
Galium spp.
Gnaphalium obtusifolium
Goodyera pubescens
Helianthus sp.
Hexastylis arifolia
Hypericum spp.
Ilex opaca
Ipomoea spp.
Iris cristata
Juglans nigra
Juniperus virginiana
Lespedeza cuneata
Lespedeza hirta
Lespedeza procumbens
Lespedeza repens
Lespedeza virginicum
Lindera benzoin
Liriodendron tulipifera
Lonicera japonica

Lysimachia quadrifolia
Magnolia acuminata
Magnolia tripetala
Medeola virginiana
Microstegium vimineum
Morus rubra
Ostrya virginiana
Oxalis spp.
Oxydendron arboreum
Nyssa sylvatica
Panax quinqefolius
Parthenocissus quinquefolia
Passiflora lutea
Paulownia tomentosa
Perilla frutescens
Pinus echinata
Pinus virginiana
Pinus strobus
Phytolacca americana
Polygonatum biflorum
Polystichum acrostichoides
Potentilla spp.
Prenanthes sp.
Prunus serotina
Quercus alba
Quercus coccinea
Quercus falcata
Quercus montana
Quercus rubra
Quercus velutina
Rhamnus caroliniana
Rhododendron spp.
Rhus copallina
Rhus glabra
Rosa sp.
Robinia pseudoacacia
Rubus ideaus
Rubus occidentalis
Rubus spp.
Sambucus canadensis
Sanicula spp.
Sassafras albidum
Scutellaria sp.
Smilacina racemosa
Smilax bona-nox
Smilax echirrata
Smilax glauca
Smilax rotundifolia
Solanum carolinense
Solidago spp.
Sonchus sp.
Streptopus roseus
Tilia americana
Thalictrum thalictroides
Toxicodendron radicans
Trillium spp.
Tsuga canadensis
Ulmus americana
Ulmus alata
Uvularia perfoliata
Vaccinium pallidum
Vaccinium spp.
Viburnum acerifolium
Viola spp.
Vitis aestivalis
Vitis rotundifolia

Table 10. Mean soft mast production (g/ha) of all species following silvicultural treatments to enhance wild turkey brood habitat, Chuck Swan State Forest, TN, USA, 2007 – 2008.

	Years	
Silvicultural treatment [a]	2007 [b]	2008 [b]
C	15 (8) ABC	1287 (1222) ABC
F	3 (3) BC	885 (300) A
S	1710 (1037) A	12250 (9295) A
SF	2458 (790) A	8899 (5660) A
RF	25 (25) BC	22127 (16960) A
RH	0.0 (0.0) C	227 (130) AB
RHF	6216 (4690) AB	9374 (7982) A

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, R= retention cut, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fires

[b] Different letters indicate differences among treatment*year ($F_{6, 21}$=9.97, P<0.001).

Table 11. Availability (g/ha) of ripe soft mast commonly consumed by wild turkeys following silvicultural treatments, Chuck Swan State Forest, TN, USA, 2007 – 2008.

	Period						
	2007			2008			
Silvicultural treatment [a]	Late June	Late July	Late Aug	Early July	Early Aug	Early Sept	Early Oct
C	0 (0)	0 (0)	6 (6)	134 (122)	3 (2)	0 (0)	0 (0)
F	0 (0)	0 (0)	0 (0)	66 (40)	33 (23)	0 (0)	0 (0)
S	14 (5)	28 (10)	43 (30)	1906 (1559)	766 (632)	465 (139)	465 (139)
SF	41 (23)	0 (0)	1 (1)	2010 (1618)	110 (42)	94 (42)	94 (42)
RF	0 (0)	0 (0)	0 (0)	176 (97)	259 (211)	751 (544)	280 (171)
RH	0 (0)	0 (0)	0 (0)	12 (4)	14 (10)	0 (0)	37 (37)
RHF	0 (0)	0 (0)	586 (293)	20 (10)	1351 (542)	4981 (4905)	5324 (4321)

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, R= retention cut, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fire

Standard errors in parentheses.

Table 12. Mean abundance (per m²) of invertebrates commonly consumed by wild turkeys following silvicultural treatments, Chuck Swan State Forest, TN, USA, 2007 – 2008.

	Period		
Silvicultural treatment [a]	July 2007 [b]	June 2008 [b]	July 2008 [b]
C	24 (6) A	46 (13) A	28 (5) A
F	7 (3) ABC	20 (5) ABC	23 (7) ABC
S	13 (3) AB	24 (5) AB	36 (12) AB
SF	17 (5) AB	24 (6) AB	47 (21) AB
RF	11 (3) BC	14 (2) BC	18 (4) BC
RH	14 (3) ABC	28 (9) ABC	22 (6) ABC
RHF	8 (3) C	10 (1) C	12 (2) C

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, R= retention cut, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fire

Standard errors in parentheses.

[b] Different letter groupings indicate differences among treatments ($F_{6, 31.3}$=6.32, P<0.001). Year*treatment did not differ ($F_{12, 41.6}$=0.39, P<0.960).

Table 13. Mean biomass (g/ha) of all invertebrates following silvicultural treatments to enhance wild turkey brood habitat, Chuck Swan State Forest, TN, USA, 2007 – 2008.

	Period		
Silvicultural treatment [a]	July 2007 [b]	June 2008 [b]	July 2008 [b]
C	1406 (375) A	2836 (859) A	2132 (338) A
F	395 (174) B	2028 (587) B	1465 (334) B
S	1007 (232) AB	1959 (995) AB	1229 (235) AB
SF	886 (204) AB	1223 (421) AB	1197 (390) AB
RF	1188 (662) B	1372 (461)	609 (101) B
RH	755 (199) B	1105 (103)	791 (108) B
RHF	689 (166) B	924 (276) B	1069 (373) B

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, R= retention cut, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fire

[b] Different letters indicate differences among treatments ($F_{6, 29.7}$=3.33, p=0.012). Treatment*period did not differ ($F_{12, 41.8}$=0.91, p=0.544).

Table 14. Mean abundance (per m²) of all invertebrates following silvicultural treatments to enhance wild turkey brood habitat, Chuck Swan State Forest, TN, USA, 2007 – 2008.

	Period		
Silvicultural treatment [a]	July 2007 [b]	June 2008 [b]	July 2008 [b]
C	27 (6) A	46 (13) A	28 (5) A
F	9 (4) BC	20 (5) BC	23 (7) BC
S	15 (2) AB	24 (5) AB	36 (12) AB
SF	19 (6) AB	24 (6) AB	47 (21) AB
RF	12 (3) BC	15 (2) BC	19 (4) BC
RH	14 (3) ABC	28 (9) ABC	22 (6) ABC
RHF	8 (3) C	10 (1) C	12 (2) C

[a] Silvicultural treatments: C= control, F=multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, R= retention cut, RF= retention cut with multiple prescribed fires, RH= retention cut with understory herbicide application, RHF= retention cut with understory herbicide application and multiple prescribed fire

[b] Different letters indicate differences among treatments ($F_{6, 29.2}$=5.39, p=0.001). Treatment*period did not differ ($F_{12, 40.8}$=0.55, p=0.871).

III. RESPONSE OF OAK AND COMPETITORS EIGHT YEARS AFTER CUTTING AND REPEATED PRESCRIBED FIRE IN UPLAND CENTRAL HARDWOODS

Response of oak and competitors eight years after cutting and repeated prescribed fire in upland central hardwoods

ABSTRACT Regenerating oak stands on productive and some intermediate sites is a challenge for forest managers. Competition from red maple and yellow-poplar is often intense after timber harvest, resulting in a future stand composition with reduced value for timber and wildlife. A field experiment was conducted in 4 upland hardwood stands on good (oak SI_{50}>21 m) sites to compare four silvicultural treatments (multiple prescribed fires, shelterwood cut, shelterwood cut with one fire, and retention cut with multiple fires) with controls to determine their effects on oak and other hardwood species that compete with oak. All species groups <12.7 cm tall were highly variable and fluctuated in density as a result of mast years and prescribed fire. Sassafras >1.4 m tall increased following canopy reduction compared to control stands. Yellow-poplar >1.4 m tall increased in shelterwood cuts compared to control stands. Oak density >1.4 m tall was not meaningfully altered. These results suggest that when regenerating oak stands, disturbance should be delayed until adequate oak stems are present. Other techniques, such as late growing-season prescribed fire, should be evaluated to increase oak seedling establishment.

INTRODUCTION

Oaks (*Quercus* spp.) represent one of the most important forest resources in the eastern US. Oak systems cover 114 million acres nationwide and account for 23% of the volume of eastern forests

(McWilliams et al. 2002). Oaks are among the most valuable hardwood species and represent an important food resource for 186 species of mammals and birds (Van Dersal 1940).

Although oaks are a common overstory species in many upland hardwood stands, they are often underrepresented or completely absent from the midstory and understory (Crow 1988, Loftis 1983) and are often replaced by later successional species (Lorimer 1989, Abrams 2000). This is especially true on high-quality (oak SI_{50}>18 m) sites, where harvest often results in a stand of less desirable, shade-tolerant species (Loftis 1983, Loftis and McGee 1993). Upland oak species are favored by frequent disturbance, and many of the current oak-dominated stands originated from logging, burning, and clearing land for agriculture (Clark 1993, Crow 1988).

Natural regeneration of oak-dominated stands depends on the establishment of advance regeneration before timber harvest, resprouting of cut trees after harvest, and favorable conditions for oak seedlings and sprouts after harvest. Oak sprouts are intermediate in shade tolerance, but cannot persist indefinitely in the understory under a closed canopy unless light availability increases in the understory. Under a closed canopy, oak seedlings are unable to meet their energy requirements through photosynthesis and grow little in the limited light (Johnson 1941, Phares 1971, Farmer 1975, Hanson et al. 1987). Less desirable, shade-tolerant species, such as maples (*Acer* spp.), survive and grow under low-light conditions that stress oak sprouts. Oaks are under intense competition from shade-intolerant species after canopy reduction as well. Yellow-poplar (*Liriodendron tulipifera*) can quickly overtop oak seedlings after canopy reduction. Oak sprouts are adapted to repeated dieback and resprouting, and these adaptations allow oaks to persist after disturbance. Silviculturists can use regeneration methods and understory disturbances to mimic natural scenarios that favor oaks.

Because oak seedlings are slow to produce shoot growth and are intermediate in shade tolerance, competing regeneration must be managed to successfully regenerate oak. Under closed-canopy conditions, shade-tolerant species, such as sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), and American beech (*Fagus grandifolia*), often thrive and dominate the understory and midstory (Gammon et al. 1960, Christensen 1977). Following canopy reduction, these stems expand their crowns into the newly-created gaps and continue to overtop oak seedlings, creating a stand dominated by species of reduced economic and wildlife value (Hix and Lorimer 1991). Shade-intolerant species are also problematic, as they often outgrow oak stems immediately following timber harvest and monopolize newly created canopy gaps (Gammon et al. 1960, Beck and Hooper 1986). If advance oak regeneration is not established prior to stand regeneration, fast-growing, shade-intolerant competitors, especially yellow-poplar (*Liriodendron tulipifera*), will dominate the site after harvest. Managing for oak regeneration is as much about managing competitors as about providing ideal conditions for advance oak regeneration to flourish.

Clearcutting effectively regenerates oaks on low-quality sites, but generally results in stands dominated by faster growing, shade-intolerant species, such as yellow-poplar, on more productive sites (Ward and Heiligmann 1990). Shelterwood cuts have been recommended to regenerate oaks in the southern Appalachians (Sander et al. 1983, Loftis 1990), and shelterwood cuts with prescribed fire have been recommended for regenerating oaks in the Piedmont (Brose and Van Lear 1998). Shelterwood cuts increase light availability in the understory (Sander et al. 1983, Hannah 1987, Jackson et al. 2006), allowing advance oak regeneration to develop. After advance oak regeneration has become established, the stand is harvested. Loftis (1990) recommended returning to harvest the stand within 6 – 8 years after the initial cut to allow oaks to establish in the understory.

Prescribed fire has been used in combination with shelterwood cuts to give oaks a competitive advantage (Brose et al. 1999). Oaks readily sprout from the root collar after top-kill (Liming and Johnson 1944). Many oak competitors are more susceptible to root-kill from fire than oak (Niering et al. 1970, Swan 1970). When competitors that are not fire-adapted, such as red maple, sugar maple, American beech, or yellow-poplar, are present, it has been hypothesized that subsequent prescribed fire may give oaks an advantage by killing competing vegetation and allowing oak regeneration to resprout from rootstock. Oak seedlings are well-adapted to frequent, low-intensity fire because of their heavy allocation of resources to root growth. Oaks resprout readily after the above-ground portion is top-killed because of these adaptations.

Regeneration methods are also needed for degraded stands with limited timber value. Many small woodlots were historically high-graded, a practice in which the most valuable logs are removed, resulting in a stand of poorly-formed trees and undesirable species composition with limited timber value (Smith et al. 1997). Clearcutting may be the best method for rehabilitating these small stands. Without altering understory composition, however, a stand with degraded species composition will develop. Methods that landowners and foresters can implement to alter understory composition without commercial timber harvest are needed as well. Retention cutting is a non-commercial timber stand improvement practice where undesirable stems are removed by felling and treating the stump with herbicide or treating them while standing with herbicide through girdling or hack and squirt methods. This technique could be applied by landowners to improve the structure and species composition of a stand before regenerating the stand. Retention cutting could potentially aid oak regeneration by selectively removing oak competitors in the overstory and improving light conditions for established seedlings in the understory.

Silvicultural methods exist for enhancing the dominance of existing oak regeneration. However, these methods are contingent on oak regeneration present at the time of harvest. When few oak stems are present or a minor component of the regeneration pool, regeneration methods do not result in oak-dominated stands.

A field experiment was conducted to evaluate the effects of cutting (shelterwood harvests and retention cutting) and prescribed fire with control on the densities of oak and oak competitors of 3 size classes (<12.7 cm tall, 12.7 – 140 cm tall, and >1.4m tall and <11.4 cm diameter at breast height) in the Ridge and Valley physiographic province in east Tennessee. I expected oak and oak competitors in all size classes to increase following canopy reduction, and red maple and yellow-poplar >1.4 m tall and <11.4 cm dbh to decrease after a single prescribed fire. I also predicted that all species groups >1.4 m tall and <11.4 cm would decrease with repeated prescribed fire.

STUDY AREA

My study was conducted on Chuck Swan State Forest and Wildlife Management Area (CSF). It is managed by the Tennessee Department of Agriculture Division of Forestry and the Tennessee Wildlife Resources Agency. CSF encompasses 9825 ha and is in the Southern Appalachian Ridge and Valley physiographic province in east Tennessee. Elevation at CSF ranges from 310 m to 520 m. CSF receives approximately 130 cm of annual rainfall.

Approximately 92% of CSF is forested. The main forest type is oak-hickory with scattered pines (*Pinus* spp.). Common overstory trees include chestnut oak (*Quercus montana*), white oak (*Quercus alba*), northern red oak (*Quercus rubra*), black oak (*Quercus velutina*), mockernut hickory (*Carya tomemtosa*), pignut hickory (*Carya glabra*), yellow-poplar, blackgum (*Nyssa sylvatica*), American beech, and red maple, with scattered shortleaf pine (*Pinus echinata*). Sassafras (*Sassafras albidum*), flowering dogwood (*Cornus florida*), and sourwood (*Oxydendron arboreum*) are common in the midstory. Hardwood stands are managed on an 80-year rotation at CSF, with clearcutting being the most common harvest method. Soils belong to the Clarksville-Fullerton-Claiborne association and are characterized as well drained, acidic soils with shallow, rocky, A horizons (NRCS 2009). Site index for these stands ranged from 22 – 27 m for oak at age 50, and as such are considered high-quality sites for oak (Neal White, Tennessee Division of Forestry, unpublished data).

METHODS

A randomized complete block design with four stands (blocks) was used to compare oak and oak competitor (maples, sassafras, yellow-poplar, and others) density in response to four silvicultural practices, and in controls. Stands were selected in separate watersheds, but had similar overstory composition, aspect (N to NW), and slope (24 – 30%). Each 8.1 ha stand was divided into ten, 0.81 ha treatment units. Treatments were randomly assigned to treatment units in each stand. Two treatment units were selected as reference units (controls) within each stand, and received no treatment (Figure 3). Two units within each stand that did not receive canopy reduction treatments were burned (F) in 2001, 2005, and 2007. A shelterwood harvest (S) was conducted on four units within each stand. Two shelterwood units within each stand were burned four years

Retention cut with fire	Shelterwood with fire	Shelterwood with fire	Shelterwood	Fire only
Shelterwood	Control	Fire only	Retention cut with fire	Control

Figure 3. Example layout of replicated stand with random assignment of silvicultural treatments to assess effects on understory composition and structure, Chuck Swan State Forest, TN, USA.

after harvest (SF) in 2005. Retention cutting (R) was implemented in the two remaining units. They were burned in 2001, 2005, and 2007.

Two methods of canopy reduction were used in this study: shelterwood harvest and retention cutting. The shelterwood units were harvested June - July 2001. High-quality stems with good form and vigor were retained with a target canopy closure of 60% after the initial cut. Retention cutting is a non-commercial timber stand improvement practice where undesirable overstory species are killed and left standing. Stems with relative low value to wild turkeys were killed as part of a related study of silvicultural effects on wild turkey habitat. Species such as maples and yellow-poplar were killed, whereas oaks, blackgum, black cherry (*Prunus serotina*), persimmon (*Diospyros virginiana*), and an occasional American beech—species that provide food resources for turkeys—were retained. Canopy closure was reduced to 60% by killing overstory stems. Undesirable stems were girdled or hacked and the wound treated with a 1:1 solution of triclopyr (Garlon® 3-A, Dow Agrosciences LLC, 9330 Zionsville Road, Indianapolis, Indiana) and water. Most of the midstory was felled or killed, with the exception of a few flowering dogwoods.

Fire was prescribed during April-early May. Burns were initiated with backing fires, and a strip-heading fire was used to burn the remainder. Low-intensity fire (flame heights<0.5 m) was maintained by appropriately spacing strips. Prescribed fires were conducted under the following conditions: temperature of 10 – 21º C, 20 – 40% relative humidity, wind speed of 8 – 16 km/h, and a mixing height of >500 m.

Three randomly-placed plots were sampled in each treatment unit in 2000, 2001, 2003, and 2007, and four in 2006 and 2008. Additional plots were sampled in 2006 and 2008 because additional manpower was available. Plot centers were located at least 30 m from each other and the edge of the treatment area to prevent plot overlap and edge effect.

Overstory composition and basal area was measured in 0.04-ha circular plots (Figure 4). Diameter at breast height was measured for all trees to the nearest 0.25 cm and species was recorded. Diameters were subsequently used to calculate basal area within each plot.

Photosynthetically active radiation (PAR) infiltration was measured in the understory in July 2009 along a transect in each treatment unit. Two AccuPAR® LP-80 PAR/LAI ceptometers (Decagon Devices, Inc., Pullman, Washington, 2008) were used. Transects were oriented to run from one corner to the opposite corner diagonally. Measurements were taken every 1 m for 30 m, beginning 20 m from the end of each transect to minimize edge effects. All measurements were taken 1.4 m (breast height) aboveground. PAR measurements were calculated as a percentage of full sun by taking paired, simultaneous measurements with one ceptometer in the treatment units and the other monitoring full sun in the closest opening. When cloud cover passed over, measurements were halted until both devices were under clear skies. PAR data collected immediately after cutting were included as well (Jackson and Buckley 2004).

Woody regeneration <1.4 m tall was measured in 0.004-ha circular plots. All stems were tallied according to species into one of two size classes: <12.7 cm tall and ≥12.7 cm tall. Composition of stems ≥1.4 m tall and <11.4 cm dbh was measured within a 0.01-ha circular plot. All stems were tallied by 2.54 cm dbh diameter class (<2.54 cm dbh, 2.54 – 5.08 cm dbh, 5.09-7.62 cm dbh, and >7.62 cm dbh), but all diameter classes were combined for this analysis.

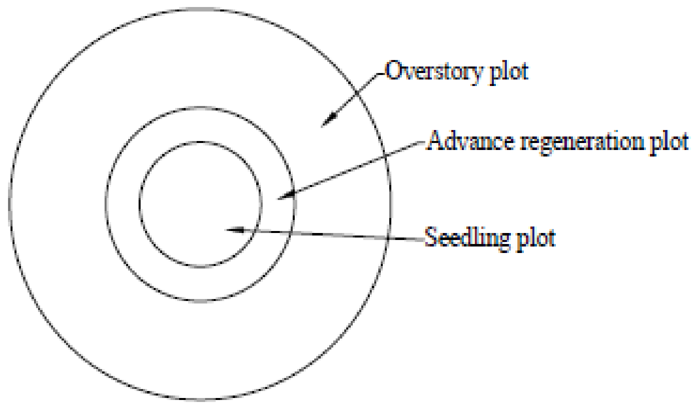

Figure 4. Design of plots used to assess effects on understory composition and structure with nested overstory (>11.4 cm dbh) circular plot, advanced regeneration (≥1.4 m tall and ≤11.4 cm dbh) circular plot, and seedling plot (<1.4 m tall), Chuck Swan State Forest, TN, USA, 2000 – 2008.

A repeated measures analysis of variance (PROC MIXED) in SAS® 9.1 (SAS Institute, Cary, NC) was used to compare overstory basal area before treatment (2000), immediately following treatments (2001), and eight years after overstory manipulations (2008), and to determine how these treatments changed among years (treatment*year). Because repeated measures analysis was used, discrepancies in sampling effort had a minimal effect on statistical power.

A two-way analysis of variance (PROC MIXED) in SAS® 9.1 (SAS Institute, Cary, NC) was used to determine if any differences existed in stem density by species groups by size class before treatments were implemented in 2000, and again in 2008 after canopy reduction in 2001, and prescribed fires in 2001, 2005, and 2007. Species were combined into five groups (Table 15): oaks (all *Quercus* spp.), maples (all *Acer* spp.), sassafras, yellow-poplar, and other species. Stems of each species group were assigned to the following size classes: < 12.7 cm tall, 12.7 cm – 1.4 m tall, and >1.4 m tall.

Each stand (n=4) was treated as a replication. While treatments were replicated on two separate treatment units within each stand, the mean of the two units was used as the value for the treatment in each stand. Square-root, log, and rank transformations were used to correct for non-normality and unequal variance.

RESULTS

Treatment units did not differ in basal area (Table 16) before treatments were implemented. PAR was initially greater in S and SF than in C because trees were removed during shelterwood harvest (Table 17). Some stems treated in the retention cut did not die immediately, and PAR

Table 15. Regenerated species and species groups, Chuck Swan State Forest, TN, USA, 2000 – 2008.

Oaks	Maples	Sassafras	Yellow-poplar	Other	
Quercus alba	*Acer rubrum*	*Sassafras albidum*	*Liriodendron tulipifera*	*Ailanthus altissima*	*Magnolia tripetala*
Quercus coccinea	*Acer saccharum*			*Albizia julibrissen*	*Nyssa sylvatica*
Quercus falcata				*Amelanchier arborea*	*Ostrya virginiana*
Quercus montana				*Aralia spinosa*	*Oxydendron arboreum*
Quercus rubra				*Asimina triloba*	*Paulownia tomentosa*
Quercus velutina				*Carpinus caroliniana*	*Pinus echinata*
				Carya glabra	*Pinus strobus*
				Carya ovata	*Pinus virginiana*
				Carya tomentosa	*Prunus serotina*
				Castanea dentata	*Rhamnus caroliniana*
				Castanea pumila	*Rhododendron spp.*
				Cercis canadensis	*Rhus glabra*
				Diospyros virginianus	*Rhus copallina*
				Eleagnus umbellata	*Robinia psuedoacacia*
				Fagus grandifolia	*Sambucus canadensis*
				Fraxinus americana	*Tilia americana*
				Ilex opaca	*Tsuga canadensis*
				Juniperus virginianus	*Ulmus alata*
				Lindera benzoin	*Ulmus americana*
				Magnolia acuminata	*Viburnum acerifolium*

Table 16. Mean basal area (m²/ha) of stems ≥11.4 cm dbh following silvicultural treatments, Chuck Swan State Forest, 2000, 2001, & 2008.

	Year		
Silvicultural treatment [a]	2000 [b]	2001 [b]	2008 [b]
C	24 (1) ABC	24 (1) ABC	30 (2) A
F	25 (2) ABC	24 (2) ABC	26 (3) ABC
S	24 (1) ABC	19 (2) BC	16 (1) C
SF	28 (3) AB	16 (1) C	25 (2) ABC
RF	27 (2) AB	22 (2) ABC	25 (2) ABC

Standard errors in parentheses. Year 2000 represents pretreatment data.

[a] Silvicultural treatments: C= control, F= multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, RF= retention cut with multiple prescribed fires

[b] Different letters indicate differences among year*treatment ($F_{8,69.7}$=3.14, p=0.004).

Table 17. Photosynthetically active radiation (PAR) infiltration following silvicultural treatments, Chuck Swan State Forest, 2001 & 2008.

Silvicultural treatment [a]	2001 % PAR infiltration [b]	2009 % PAR infiltration [c]
C	3.8 (0.6) B	4.7 (1.1) C
F	9.4 (1.8) AB	13.3 (3.4) B
S	19.7 (3.7) A	5.8 (2.4) C
SF	21.5 (4.5) A	14.4 (2.4) B
RF	15.5 (3.5) AB	29.4 (5.4) A

[a] Silvicultural treatments: C= control, F= multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, RF= retention cut with multiple prescribed fires

[b] From Jackson and Buckley (2004). PAR measurements taken at 1 m height. Different letters indicate differences among treatments.

[c] PAR measurements taken at 1.4 m height. Different letters indicate differences among treatments ($F_{4,12}$=22.7, $p<0.001$).

infiltration was slow to increase. However, repeated prescribed fires after treated stems died increased PAR infiltration compared to all other treatments and C in 2009 (Table 17). By 2008, advance regeneration in S had captured all the light made available in the initial cut, and did not differ from C.

Seedlings <12.7 cm tall were highly variable across sites for all species and treatments. Oak, sassafras, yellow-poplar, and others tended to increase in density in 2001 following the first prescribed fire, but soon decreased to densities comparable to those that existed before the first fire (Table 18). Maples <12.7 cm tall tended to decrease over time (Table 18). Some of these stems were likely recruited into larger size classes, or were killed by subsequent prescribed fire.

Prescribed fire treatments (F, SF, and RF) all contained a greater density of sassafras 12.7 cm – 1.4 m tall than C (Table 19). Sassafras apparently germinated following the first prescribed fire in 2001 in F and RF (Table 19). Yellow-poplar 12.7 cm – 1.4 m tall was greater in treatments with canopy reduction (S, SF, and RF) than in C (Table 19).

Sassafras >1.4 m tall and <11.4 cm dbh was greater in cut stands (S, SF, and RF) than in uncut stands (Table 20). S had a greater density of maple >1.4 m tall than repeatedly burned units (F and RF). Oak >1.4 m tall and <11.4 cm dbh was greater in S than in uncut stands, and greater in SF than in F. However, S and SF had the greatest density of oak >1.4 m tall and <11.4 cm dbh prior to treatment (Table 20).

DISCUSSION

Density of oak >1.4 m tall and <11.4 cm dbh was highly variable, decreasing and increasing over the course of the study. Shelterwood cuts without fire had a greater density of oak

Table 18. Density (stems/ha) of regeneration <12.7 cm tall following silvicultural treatments, Chuck Swan State Forest, TN, USA, 2000 – 2008.

		Year					
Species	Treatment [a]	2000	2001	2003	2006	2007	2008
Oak	C	2448 (1249)	3771 (2793)	1594 (1076)	117 (117)	4731 (4083)	1674 (1034)
	F	2542 (1142)	10979 (6871)	1438 (587)	86 (76)	2032 (936)	1471 (820)
	S	1948 (778)	1177 (987)	927 (748	0 (0)	375 (117)	461 (194)
	SF	1866 (900)	3333 (2516)	834 (352)	16 (16)	771 (439)	2328 (1651)
	RF	2250 (962)	10167 (5035)	959 (601)	23 (15)	1073 (549)	1648 (1166)
Maple	C	19906 (5236)	21958 (2634)	8969 (3137)	12716 (10031)	20833 (11885)	4799 (887)
	F	27510 (6293)	16875 (2208)	9271 (1877)	3609 (1136)	11890 (2485)	4898 (1859)
	S	27427 (14170)	14219 (4773)	10000 (2696)	812 (446)	9010 (4864)	2711 (487)
	SF	28219 (8288)	11469 (1803)	11469 (1803)	2141 (253)	6766 (2341)	3188 (1315)
	RF	30677 (8732)	12708 (4901)	5313 (1577)	1227 (476)	2427 (1057)	2477 (785)
Sassafras	C	438 (292)	729 (471)	386 (296)	86 (59)	1678 (946)	417 (309)
	F	1156 (402)	23490 (5490)	1845 (464)	461 (149)	8655 (3031)	2850 (755)
	S	510 (79)	750 (204)	1157 (426)	55 (45)	516 (142)	758 (293)
	SF	854 (145)	2678 (1569)	2303 (812)	930 (315)	4101 (2738)	4861 (3195)
	RF	1073 (326)	48771 (35586)	2584 (1651)	78 (68)	4012 (1819)	2863 (515)
Yellow-poplar	C	125 (38)	188 (128)	500 (173)	534 (414)	1428 (902)	281 (261)
	F	542 (275)	32219 (21267)	3552 (2280)	773 (309)	1746 (654)	435 (270)
	S	344 (75)	313 (260)	2094 (796)	70 (52)	740 (181)	531 (196)
	SF	459 (211)	229 (124)	2011 (800)	2125 (1029)	2605 (537)	821 (310)
	RF	292 (104)	26313 (15419)	3428 (988)	461 (223)	375 (224)	276 (80)
Other	C	4948 (2796)	3938 (904)	1354 (555)	253 (127)	2365 (587)	1466 (854)
	F	2052 (579)	8917 (3312)	1292 (267)	617 (442)	7292 (1867)	1016 (306)
	S	1917 (394)	2708 (636)	938 (202)	164 (144)	2000 (672)	1266 (353)
	SF	1958 (875)	2385 (506)	813 (202)	211 (142)	1115 (223)	1367 (316)
	RF	2021 (415)	6490 (997)	1000 (283)	78 (30)	1792 (299)	961 (255)

Standard errors in parentheses. Treatments did not differ within species in 2000 or 2008. Only 2000 and 2008 were tested for treatment differences within each species. Statistics available in Table 21. Year 2000 represents pretreatment data.

[a] Silvicultural treatments: C= control, F= multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, RF= retention cut with multiple prescribed fires

Table 19. Density (stems/ha) of regeneration 12.7 cm – 1.4 m tall following silvicultural treatments, Chuck Swan State Forest, TN, USA, 2000 – 2008.

		Year					
Species	Treatment [a]	2000	2001	2003	2006	2007	2008
Oak	C	26906 (21718)	18854 (14248)	9656 (6533)	11672 (8161)	10281 (7476)	5250 (3118)
	F	25927 (17778)	6740 (3366)	7219 (3700)	4891 (1650)	3208 (1572)	4026 (1817)
	S	10406 (7138)	6250 (4528)	6260 (3951)	10453 (7306)	5828 (3664)	4266 (2423)
	SF	16438 (10176)	7552 (3338)	8000 (3398)	8703 (5177)	9323 (5727)	9633 (6388)
	RF	22542 (15338)	7938 (5637)	6385 (4406)	8336 (4482)	6823 (4501)	7422 (4258)
Maple	C	37594 (18758)	34250 (16211)	21291 (10519)	27768 (3917)	46187 (10632)	12036 (2521)
	F	35854 (19528)	18104 (12058)	16427 (11603)	20914 (4372)	21141 (4471)	12464 (4022)
	S	40625 (14258)	25010 (5919)	20541 (5910)	32430 (5932)	23057 (5981)	12695 (3491)
	SF	33417 (5986)	20958 (5835)	20125 (3428)	25063 (8340)	22120 (5679)	13758 (4724)
	RF	36667 (15626)	15844 (7992)	10614 (4153)	14008 (790)	10104 (1193)	9789 (1836)
Sassafras	C	3729 (2792)	2063 (1122)	1854 (1196)	4068 (2895)	5104 (3553)	2219 (1814) C
	F	4510 (1719)	8990 (3413)	13167 (2678)	17671 (7251)	25370 (9263)	13263 (3985) AB
	S	2125 (276)	1938 (735)	7125 (724)	4602 (1180)	3781 (948)	3484 (1370) BC
	SF	2635 (546)	2916 (429)	12135 (4214)	22719 (5459)	18171 (8594)	14460 (6799) AB
	RF	3823 (1641)	21760 (12170)	19167 (11370)	26047 (10400)	29240 (11263)	22992 (9833) A
Yellow-poplar	C	500 (187)	417 (178)	250 (148)	1013 (453)	2427 (895)	633 (561) B
	F	1000 (598)	1917 (922)	9281 (4755)	3594 (1632)	3203 (1059)	2133 (855) AB
	S	1094 (680)	1063 (581)	4781 (1286)	5336 (1443)	3984 (615)	2453 (285) A
	SF	1177 (558)	958 (387)	3895 (820)	5875 (743)	6010 (2056)	3742 (1740) A
	RF	594 (249)	3698 (1285)	8542 (1810)	5000 (2203)	2521 (857)	2445 (194) A
Other	C	35073 (5587)	11281 (3899)	5375 (1683)	10396 (1991)	9813 (1218)	6302 (2268)
	F	30792 (10349)	6948 (559)	5990 (959)	8469 (932)	11817 (2926)	3674 (803)
	S	36792 (6066)	9197 (2397)	7344 (1434)	10836 (1345)	11557 (1807)	8680 (1789)
	SF	32281 (8351)	6313 (687)	6052 (785)	11172 (2393)	8708 (897)	7289 (1921)
	RF	33052 (14991)	12167 (991)	6740 (1856)	12813 (2134)	18323 (6272)	11742 (3657)

Standard errors in parentheses. Different letters indicate differences among treatments within species. Only 2000 and 2008 were tested for treatment differences within each species in each year. Statistics available in Table 21. Year 2000 represents pretreatment data.

[a] Silvicultural treatments: C= control, F= multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, RF= retention cut with multiple prescribed fires

Table 20. Density (stems/ha) of regeneration >1.4m tall and <11.4 cm dbh following silvicultural treatments, Chuck Swan State Forest, TN, USA, 2000 – 2008.

		Year					
Species	Treatment	2000	2001	2003	2006	2007	2008
Oak	C	21 (12)	10 (10)	10 (10)	0 (0)	0 (0)	31 (31) BC
	F	185 (171)	82 (82)	113 (77)	39 (39)	41 (41)	23 (23) C
	S	309 (214)	41 (24)	93 (59)	100 (56)	21 (21)	687 (379) A
	SF	329 (302)	144 (144)	144 (144)	69 (60)	185 (185)	378 (327) AB
	RF	10 (10)	0 (0)	31 (31)	8 (8)	0 (0)	46 (30) ABC
Maple	C	1215 (227)	597 (301)	1194 (397)	1712 (819)	762 (255)	741 (287) AB
	F	783 (187)	206 (128)	1477 (654)	726 (331)	10 (10)	114 (39) B
	S	2739 (1296)	762 (408)	2142 (242)	8849 (4148)	5807 (1601)	2988 (1210) A
	SF	1977 (825)	535 (276)	1596 (268)	919 (337)	803 (188)	1737 (602) AB
	RF	1668 (455)	82 (38)	1524 (450)	239 (120)	329 (329)	239 (89) B
Sassafras	C	21 (12)	0 (0)	0 (0)	0 (0)	175 (175)	139 (139) B
	F	62 (62)	134 (134)	571 (412)	234 (121)	72 (42)	100 (69) B
	S	0 (0)	10 (10)	309 (80)	2795 (818)	1678 (162)	1243 (288) A
	SF	41 (29)	0 (0)	700 (420)	3992 (2080)	2162 (788)	1745 (796) A
	RF	412 (358)	227 (132)	1030 (278)	6981 (3354)	793 (352)	1789 (288) A
Yellow-poplar	C	113 (54)	72 (59)	62 (39)	51 (30)	93 (54)	85 (53) C
	F	422 (409)	216 (216)	633 (405)	286 (171)	299 (299)	162 (61) BC
	S	196 (118)	21 (21)	669 (376)	5351 (2117)	5858 (2621)	3946 (1330) A
	SF	422 (345)	31 (20)	669 (409)	834 (142)	1364 (636)	579 (368) BC
	RF	10 (10)	10 (10)	1225 (688)	2216 (601)	721 (349)	1832 (760) AB
Other	C	1555 (836)	1472 (716)	1411 (832)	1833 (606)	1452 (596)	1189 (418) B
	F	999 (689)	494 (440)	613 (254)	116 (69)	0 (0)	85 (48) B
	S	1616 (525)	587 (276)	1225 (325)	7792 (2287)	5941 (2210)	3846 (580) A
	SF	1699 (674)	741 (245)	1792 (282)	1027 (406)	1210 (388)	1390 (595) B
	RF	1019 (380)	288 (197)	2059 (446)	2263 (1015)	422 (220)	1421 (616) B

Standard errors in parentheses. Different letters indicate differences among treatments within species in each year. Only 2000 and 2008 were tested for treatment differences within each species. Statistics available in Table 21. Year 2000 represents pretreatment data.

[a] Silvicultural treatments: C= control, F= multiple prescribed fires, S= shelterwood harvest, SF= shelterwood harvest with one prescribed fire, RF= retention cut with multiple prescribed fires

Table 21. F-statistics and p-values for species by height class analysis of variance following silvicultural treatments, Chuck Swan State Forest, TN, USA, 2000 & 2008.

Species	Height class	2000 F (4,12)	2000 p value	2008 F (4,12)	2008 p value
Oaks	<12.7 cm	0.36	0.830	1.50	0.262
	12.7 cm - 1.4 m	1.53	0.255	1.72	0.211
	<1.4 m	0.63	0.650	**6.46**	**0.005**
Maples	<12.7 cm	0.74	0.585	1.13	0.386
	12.7 cm - 1.4 m	0.15	0.961	0.12	0.972
	<1.4 m	0.76	0.571	**6.40**	**0.005**
Sassafras	<12.7 cm	1.65	0.227	2.27	0.122
	12.7 cm - 1.4 m	0.37	0.829	**9.03**	**0.001**
	<1.4 m	0.97	0.461	**9.49**	**0.001**
Yellow-poplar	<12.7 cm	1.07	0.413	1.15	0.379
	12.7 cm - 1.4 m	0.78	0.562	**4.77**	**0.016**
	<1.4 m	0.76	0.569	**10.10**	**<0.001**
Other	<12.7 cm	0.70	0.607	0.22	0.925
	12.7 cm - 1.4 m	0.10	0.992	2.69	0.823
	<1.4 m	0.99	0.451	**15.76**	**<0.001**

Statistically significant values in bold regeneration >1.4 m tall and <11.4 cm dbh in 2008 than C and F. This is not surprising since treatment units randomly selected for S had 1.5x and 15x as many large oak sprouts as units assigned to F and C, respectively. In spite of this, oak stems represented only 5% of the stems >1.4 m tall and <11.4 cm dbh in S in 2008, and many of these oak sprouts had already been overtopped by yellow-poplar, which represented 31% of stems >1.4 m tall and <11.4 cm dbh. Because treatments were initiated in all stands at the same time, no consideration was given to promoting understory oak stems when treatments were initiated, so it is not surprising oak stems were not more numerous in the regeneration composition of S in 2008 (5%) than before treatments were initiated (6%). Two stands were nearly devoid of oak regeneration, and encouraging the initial establishment of oak seedlings in the presence of their competitors is a real challenge to regenerating oak stands. Many oak sprouts 12.7 cm – 1.4 m tall were available to recruit into the advance regeneration pool in 2000, but failed to do so by 2008.

The majority of the oak stems >1.4 m tall and <11.4 cm dbh encountered in 2000 were found in 2 stands. These 2 stands contained almost all of the oak regeneration in 2008, with six oak stems >1.4 m tall and <11.4 cm dbh tallied in the remaining two stands. The stands with poor oak recruitment contained numerous smaller oak stems, but oak stems not present in the advance regeneration pool when canopy closure is reduced are unlikely to be subsequently recruited. On high-quality sites for oak (oak SI_{50}>21 m), competition with other species is often greater than on poorer sites. When regenerating oak stands on high-quality sites, regeneration composition must be considered before the stand is regenerated if an oak-dominated stand is the objective. Regeneration composition can be influenced by killing the non-oak subcanopy with herbicides prior to disturbing the canopy (Loftis 1990) when oak advance regeneration is inadequate, or by using prescribed fire after the initial cut in a shelterwood harvest (Brose et al. 1999) when advance oak regeneration is present, but outnumbered by fire-susceptible species, such as maples and yellow-poplar.

Results of this study suggest that canopy reduction and early growing-season prescribed fire do not promote oak as much as they alter the competing species composition. Maples tended to be the most prevalent group in all size classes prior to treatments. Because maples are shade-tolerant, they were able to persist beneath a canopy with very little light infiltration. Canopy reduction allowed established regeneration to grow into taller size classes, while prescribed fire treatments top-killed stems, setting them back into shorter size classes. Prescribed fire was effective at killing maples and other thin-barked competitors, such as American beech, but prescribed fire resulted in ideal conditions for yellow-poplar and sassafras to germinate or sprout. Both sassafras and yellow-poplar <12.7 cm were nearly absent prior to the first prescribed fires in 2001. Following the first fires in F and RF, yellow-poplar and sassafras were the two most prevalent species <12.7 cm. Sassafras <12.7 cm increased 19x in F and 44x in RF, and yellow-poplar <12.7 cm increased 58x in F and 89x in RF. These small yellow-poplar and sassafras stems recruited into larger size classes the following years. Subsequent fires killed many of the yellow-poplar seedlings, but sassafras continued to resprout. Early growing-season prescribed fires were ineffective at reducing sassafras density. Van Lear and Brose (2002) suggested multiple fires after partial cutting would result in one of two outcomes: either the regeneration would be dominated by stockpiled oak seedlings, or a herbaceous understory would develop, resulting in an oak savanna. RF resulted in neither of these. Instead, woody groundcover exceeded herbaceous groundcover, and sassafras dominated the regeneration pool on these sites.

While sassafras is rarely an important component of mature stands, it successfully competed with oaks on sites that had been burned repeatedly.

Shelterwood harvest has proven effective as a tool to favor established oak advance regeneration. However, future research should investigate burning in early fall just prior to acorn drop as a technique to encourage oak seedlings. Burning at this time, with a good acorn crop present, would provide good seed-to-soil contact for acorns that will be covered by the subsequent leaf fall, and would top-kill competitors before senescence.

Management Implications

In order to successfully regenerate oaks on good sites, such as those at CSF, timber harvest should be delayed until adequate oak sprouts are established. In my study, cuts were initiated in 2 stands that contained few large oak sprouts, and few additional oak stems >1.4 m tall were recruited after treatments were initiated, regardless of previous oak density. Light availability should be increased only after adequate oak seedlings are established. Otherwise, undesirable species will be favored. Future research should evaluate low-intensity prescribed fire during the late growing season (September) to control undesirable understory species. Dormant-season or early growing-season prescribed fire did not control sassafras. Late growing-season fire may improve oak seedling establishment by killing competitors prior to senescence and removing litter, thereby facilitating better conditions for acorns to germinate.

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IV. CONCLUSION

Conclusion

When managing hardwood stands to enhance cover and food resources for wild turkeys or other wildlife species, timber production and forest regeneration goals must be considered as well. Canopy reduction, whether by timber harvest or timber stand improvement, improved brood conditions for wild turkey broods by increasing visual obstruction and soft mast production, and allowed advance regeneration to grow. However, understory disturbance was required to maintain vegetation at a height that was usable by turkey broods. Early growing-season prescribed fire top-killed the regeneration, preventing the stems from increasing in height. Herbicide application killed almost all of the woody regeneration and soft mast-producing plants in the understory.

Herbaceous groundcover did not increase following any treatment throughout the study. Woody groundcover dominated. However, prescribed fire after canopy reduction maintained the woody regeneration within the range that defines brood cover for wild turkeys. As predicted, soft mast (mainly pokeweed and blackberry) increased after canopy reduction and prescribed fire. Invertebrate abundance and biomass did not increase following disturbances. However, invertebrate biomass on the forest floor was more than adequate in all treatments to support wild turkey broods.

Woody regeneration was also altered by canopy reduction and prescribed fire. Canopy reduction allowed established regeneration to increase in height. However, regeneration was dominated by maples. Prescribed fire with and without canopy reduction effectively reduced maples, but provided ideal conditions for yellow-poplar and sassafras to sprout. Subsequent fire reduced yellow-poplar density, but sassafras was not affected. Oaks were a minor component of the understory before treatments were initiated, and remained so afterwards.

Oak seedlings must be present in order to regenerate an oak-dominated stand. Many productive sites (oak SI_{50}>18 m) have inadequate advance oak regeneration. If oak seedlings are not present, the regenerated stand will not be dominated by oak. Silvicultural techniques are needed to encourage establishment and subsequent growth of oak seedlings on these sites. Once oak seedlings are established, canopy reduction can be implemented to release seedlings. Additionally, prescribed fire can be used as needed to set back fire-intolerant competitors such as maples, yellow-poplar, and American beech. When managing stands for wild turkeys, prescribed fire can be repeated every 3 – 5 years to maintain vegetation at a useful height for wild turkey broods. Burning more often may further limit woody encroachment, but would also limit soft mast production. Where oak regeneration is the objective, stands should be burned less often to allow regeneration to develop.

Future research should investigate the effects of late growing-season (September – early October) prescribed fire on forest regeneration and wildlife habitat. Late growing-season fire is effective at controlling woody invasion in old-fields (Gruchy et al. 2007), and has been shown to increase desirable forb cover in a restored oak woodland (J.M. McCord, unpublished data). Additionally, late growing-season prescribed fire may improve oak seedling establishment by killing competitors prior to acorn drop and removing litter, thereby facilitating better seed to soil contact.

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