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I am submitting herewith a thesis written by John P. Gruchy entitled “An Evaluation of Field Management Practices to Improve Bobwhite Habitat.” I have examined the 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.

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An Evaluation of Field Management Practices to Improve Bobwhite Habitat

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

John P. Gruchy
August 2007

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DEDICATION

This work is dedicated to the memory of Roy Arnold Brown. In life, Uncle Bubba was a model of kindness and integrity. While his passing was hard to bear, his memory provides daily inspiration.

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I have been fortunate to have worked with some truly excellent individuals throughout the course of this project. I will attempt to acknowledge many of them, though oversight is inevitable.

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INTRODUCTION

Data presented here were collected as part of a project investigating various field management practices on tall fescue (*Festuca arundinacea*) fields, a planted native warm-season grass (nwsg) field, and a CRP field originally planted in tall fescue with nearly complete coverage of tree saplings during 2004 – 2005. The objectives of this research were to evaluate the effects of early succession habitat management practices on improving habitat quality for northern bobwhites (*Colinus virginianus*). Although some study areas were enrolled in conservation programs at the time of this research, treatments were not conducted according to program restrictions.

This thesis is organized into parts, rather than chapters. Each part represents a different dilemma for bobwhite management. Parts are formatted for individual submission to peer-refereed journals.

PART I

EFFECTS OF HERBICIDES AND DISKING ON TALL FESCUE ERADICATION AND RESULTING HABITAT FOR BOBWHITES

ABSTRACT

Conversion of tall fescue (*Festuca arundinacea*) to managed native warm-season grasses (nwsg) and associated forbs benefits many wildlife species that depend on early successional habitat. Planting nwsg, however, may not be necessary depending on the composition of the seedbank. Treatments were implemented in a randomized complete block design with replication during 2003 and 2004 at three study sites across Tennessee to determine the effects of seasonal herbicide applications and disking on tall fescue eradication and resulting vegetation composition and structure. Treatments included: fall glyphosate (2.2 kg ai/ha; Gly-4 2qt/ac); fall glyphosate followed by winter disking; fall imazapic (0.2 kg ai/ha; Plateau 12 oz/ac); fall imazapic followed by winter disking; spring glyphosate; spring glyphosate followed by fall disking; spring imazapic; and spring imazapic followed by fall disking. Vegetation composition and structure were measured June – September, and November 2004 and February, April, and June – September 2005. All treatments reduced tall fescue cover compared to control one growing season after treatment. Fall herbicide applications with and without disking decreased tall fescue cover more than spring treatments when measured two growing seasons after treatment. Reduction in tall fescue improved openness at ground level during the brooding season and angle of obstruction during the wintering period for bobwhites. Disking following herbicide application increased cover of bobwhite food plants, including common ragweed (*Ambrosia artemisifolia*), beggar's-lice (*Desmodium* spp.), and beggar-ticks (*Bidens* spp.). Imazapic increased cover of desirable nwsg, such as broomsedge bluestem (*Andropogon virginicus*); however on 2 sites, imazapic

applications resulted in increased cover of orchardgrass (*Dactylis glomerata*), which was structurally identical to tall fescue. Fall glyphosate applications are recommended to eradicate tall fescue. If certain undesirable plants are suspected to germinate from the seedbank after tall fescue is removed, an imazapic application may be necessary in April or May to control species such as johnsongrass (*Sorghum halapense*), crabgrass (*Digitaria sanguinalis*), and yellow nutsedge (*Cyperus esculentus*).

INTRODUCTION

Landscape level changes in land use and the subsequent reduction in quality early successional habitat has been identified as a contributing factor in the decline of several wildlife populations (Brennan 1991, Hunter et al. 2001, Heard 2000). Northern bobwhite (*Colinus virginianus*, hereafter bobwhite) populations have declined approximately 70 percent since 1980 (Sauer et al. 2006, Dimmick et al. 2002). Grassland songbirds, such as Henslow's sparrow (*Ammodramus henslowii*), grasshopper sparrow (*Ammodramus savannarum*), savannah sparrow (*Passerculus sandwichensis*), and field sparrow (*Spizella pusilla*), have experienced similar declines during the same period (Sauer et al. 2006, Hunter 2001).

The small, "patch-farms" of yesteryear no longer occur across the landscape and efficient clean-farming techniques have resulted in magnificently large, uniform crop fields that are mostly barren in winter (Brennan 1991). Fire regimes have been altered because of increased liability and unfavorable public perceptions of burning, resulting in degradation of habitats traditionally maintained by fire (Brennan 1991, Waldrop et al. 1992, Lorimer 2001). Thousands of acres of agricultural lands and forested areas have been converted to high basal area silvicultural systems with limited wildlife habitat value (Brennan 1991, Burger 2000). The introduction of non-native grasses, such as tall fescue, has displaced native vegetation and reduced vegetative structure and diversity across the landscape (Brennan 1991, Barnes et al. 1995, Washburn et al. 2000).

Federally funded agricultural subsidy programs created under the Farm Bill, such the Conservation Reserve Program (CRP), offered cost-share incentives for landowners who wished to implement management practices benefiting wildlife (Greenfield 1997). Unfortunately, two of the most commonly implemented CRP practices in the mid-South are cool-season grass plantings (CP – 1 and CP – 10; Burger 2000). Fields planted in non-native cool-season grasses such as tall fescue and orchardgrass are especially troubling as they receive federal subsidy, yet they degrade wildlife habitat.

In 1998, the Southeast Association of Fish and Wildlife Agencies commissioned the Southeast Quail Study Group to write a comprehensive management plan, called Northern Bobwhite Conservation Initiative (NBCI), to reverse the bobwhite population decline. One priority of the NBCI is the conversion of non-native perennial cool-season grasses to quality early successional habitat (Dimmick et al. 2002). Previous studies evaluating the effects of mowing, burning, or disking on fields planted in cool-season grasses found negligible or short-lived improvements in resulting vegetation structure and composition for bobwhites (McCoy et al. 2001, Greenfield et al. 2001, Madison et al. 2001, Greenfield et al. 2002, Greenfield et al. 2003). Bobwhite habitat was most often improved when tall fescue was reduced or eliminated by herbicide application (Madison et al. 2001, Greenfield et al. 2001).

Another conservation practice endorsed by federal and state agencies is the establishment of native warm-season grasses (nwsg) (Washburn et al. 2000, Dimmick et al. 2002). However, nwsg have commonly been planted prior to effective elimination of non-native grass cover (Dykes 2005), thus reducing the potential benefits of nwsg. Furthermore, nwsg and other desirable plants are often present in the seedbank, precluding the need to plant nwsg and saving tax-generated funds.

OBJECTIVES

The objectives of this study were to determine the most effective methods for eliminating tall fescue and improving bobwhite habitat using applications of two herbicides during different seasons with and without disking. Results were evaluated in terms of tall fescue control and resulting habitat quality for bobwhites based on vegetation composition, structure, and invertebrate availability.

LITERATURE REVIEW

The successful renovation of tall fescue fields for improved early succession wildlife habitat requires the removal of tall fescue and subsequent colonization of suitable native plant communities from the seedbank or from cultural methods. Previous studies found disking and burning tall fescue failed to reduce tall fescue cover and did not improve vegetation structure for bobwhite broods two growing seasons following treatment (Madison et al. 2001, Greenfield 1997). Madison et al. (2001) found a single spring application of glyphosate (2.2 kg ai/ha; kilograms active ingredient per hectare) resulted in improved cover of bobwhite food plants and bare ground two growing seasons following treatment, compared to seasonal disking and burning treatments in established tall fescue fields in Kentucky. Greenfield et al. (2001) found bobwhite brood-rearing habitat was improved in tall fescue fields in Mississippi by dormant-season prescribed fire followed by spring glyphosate application (2.6 kg ai/ha) and spring glyphosate application (2.6 kg ai/ha) alone, while prescribed fire alone failed to improve bobwhite habitat.

Tall fescue may be removed using repeated deep conventional tillage followed by cover crop establishment or through the use of herbicides (Fribourg et al. 1988, Smith 1989, Defelice and Henning 1990, Bates 1995). Tall fescue removal using herbicides is often more cost effective, efficient, and applicable in a variety of situations (Fribourg et al. 1988, Smith 1989, Defelice and Henning 1990). In order to increase efficacy of herbicide applications tall fescue should be prepared for herbicide application by haying, grazing, or burning to remove residual thatch and vegetation, thus exposing tall fescue plants. Herbicides should be applied when tall fescue plants are actively growing at a height of 20 – 31 cm (Fribourg et al. 1988).

Several studies have assessed herbicides and timing of application for eliminating tall fescue. Hoveland et al. (1986) found sequential early fall applications of glyphosate at 1.1 and 2.2 kg ai/ha or paraquat at 1.1 kg ai/ha and a single application of glyphosate at 2.2 kg ai/ha provided excellent tall fescue control over three years in north Georgia. A single application of glyphosate or paraquat in March was generally less effective than spring applications. A sequential application of paraquat at 1.1 kg ai/ha was the only treatment that provided satisfactory tall fescue control during March.

Moyer and Kelly (1986) tested the effectiveness of several herbicides applied at different rates in early and late fall in Kansas. Glyphosate at 1.1 and 2.2 kg ai/ha provided 100% tall fescue control. Glyphosate at 0.6 kg ai/ha provided 98% control. Paraquat was effective at removing more than 95% tall fescue cover at rates of 1.1 kg ai/ha and 2.2 kg ai/ha. Herbicides applied in late fall (November) were generally more effective than early fall (September) applications. Additionally, there was no difference in herbicide effectiveness using a low volume spray (37.9 l/ha; 10 gal/acre) compared to the standard volume (75.7 l/ha; 20 gal/acre).

Fribourg et al. (1988) observed both paraquat and glyphosate were effective in killing tall fescue in Tennessee. Paraquat at 2.2 kg ai/ha or glyphosate at 2.2 kg ai/ha were effective at reducing tall fescue cover to less than 5% 10 MAT (months after treatment). Paraquat was more effective when applied in fall than spring. The authors recommended applying herbicides mid-September to mid-October to achieve the best kills under environmental conditions in Tennessee.

Research conducted in Georgia found sequential applications of paraquat at 0.14, 0.28, and 0.56 kg ai /ha in September and October were effective in reducing tall fescue cover (< 10% tall fescue cover 12 MAT). Glyphosate applied at 0.84 and 1.7 kg ai/ha as a single application or as a sequential application at 0.84, 0.17, and 0.25 kg ai/ha in September or October was also effective in controlling tall fescue 12 MAT, though treatment effects were inconsistent across application years. Additionally, dalapon, glufosinate, simazine, fluazifop-p, and sethoxydim, provided poor tall fescue control (> 50% tall fescue cover 12 MAT) regardless of application timing or rate. For all herbicides spring applications were not as effective as fall applications for tall fescue removal (Smith 1989).

Defelice and Henning (1990) compared fall (October), spring (April), and late summer (August) applications of glyphosate and paraquat at different rates in Missouri. The authors recommend spring and late summer applications of glyphosate at 1.68 and 2.52 kg ai/ha because they reduced tall fescue cover to less than 15% 30 – 50 DAT (days after treatment). Fall applications of glyphosate at 0.42 and 0.84 kg ai/ha resulted in 56 and 42% tall fescue cover respectively. April and August were identified as the best times to spray tall fescue. Overall, herbicide applications were not as successful as reported by studies previously mentioned. The authors noted tall fescue grows through fall in the South more so than in the Midwest. The increase in active growth as well as greater rainfall and average daily temperatures may explain the increased effectiveness of fall applied herbicides on tall fescue in the South (Defelice and Henning 1990).

Vogel and Waller (1990) evaluated tall fescue control in Nebraska following seasonal applications of glyphosate and tank mixes of glyphosate and atrazine at different rates. Glyphosate applied at 2.2 kg ai/ha during the first week of November reduced tall fescue cover to less than 10% 7 MAT. Herbicides applied during April or May suppressed tall fescue initially; however, treatments were similar to control within 60 DAT.

Washburn and Barnes (2000) compared fall (September) and spring (May) applications of glyphosate at 2.2 kg ai/ha in Kentucky. Both fall and spring applications reduced tall fescue coverage to less than 12% one growing season post treatment. Glyphosate treated plots had similar or greater plant species diversity when compared to untreated control. They also tested the effectiveness of tall fescue control using applications of imazapic and imazapic tank mixes with glyphosate during the fall vegetative, spring vegetative, boot stage, or summer dormancy growth stage. Imazapic alone at 0.2 kg ai/ha, and tank mixtures of imazapic at 0.2 kg ai/ha and glyphosate at 0.6 kg ai/ha and 1.1 kg ai/ha were effective at reducing tall fescue coverage to less than 3%. The authors concluded that imazapic was effective at removing tall fescue and glyphosate may only be necessary when additional imazapic resistant plants are present. Washburn et al. (2000) compared the efficacy of spring (May) and summer (July) applications of imazapic at 0.2 kg ai/ha, glyphosate 2.2 kg ai/ha, and tank mixes containing both at variable rates with and without burning on tall fescue kill and success of nwsg plantings. The authors found summer herbicide applications were not as effective at reducing tall fescue coverage as spring applications. One growing season following treatment summer applied herbicides resulted in 29 – 45% tall fescue cover, whereas spring applied herbicides resulted in 1 – 17% tall fescue cover. Imazapic and tank mixtures containing both imazapic and glyphosate were effective in eliminating tall fescue and aiding in the establishment of nwsg when measured one growing season following treatment (Washburn et al. 2000).

STUDY AREAS

Three fields were selected for study (Figure 1). Site one was located in Rhea County at the J.M. Huber Corp. mill (JMHC) in the Ridge and Valley physiographic province of Tennessee. Elevation within the 6-ha fields ranged from 235 to 238 m. The dominant soil series was Upshur silt loam (Hasty et al. 1948). These soils are moderately well to well drained with moderately deep topsoil (15 – 20 cm) and exhibit moderate to low fertility (Hasty et al. 1948). The site was sown to tall fescue in the late

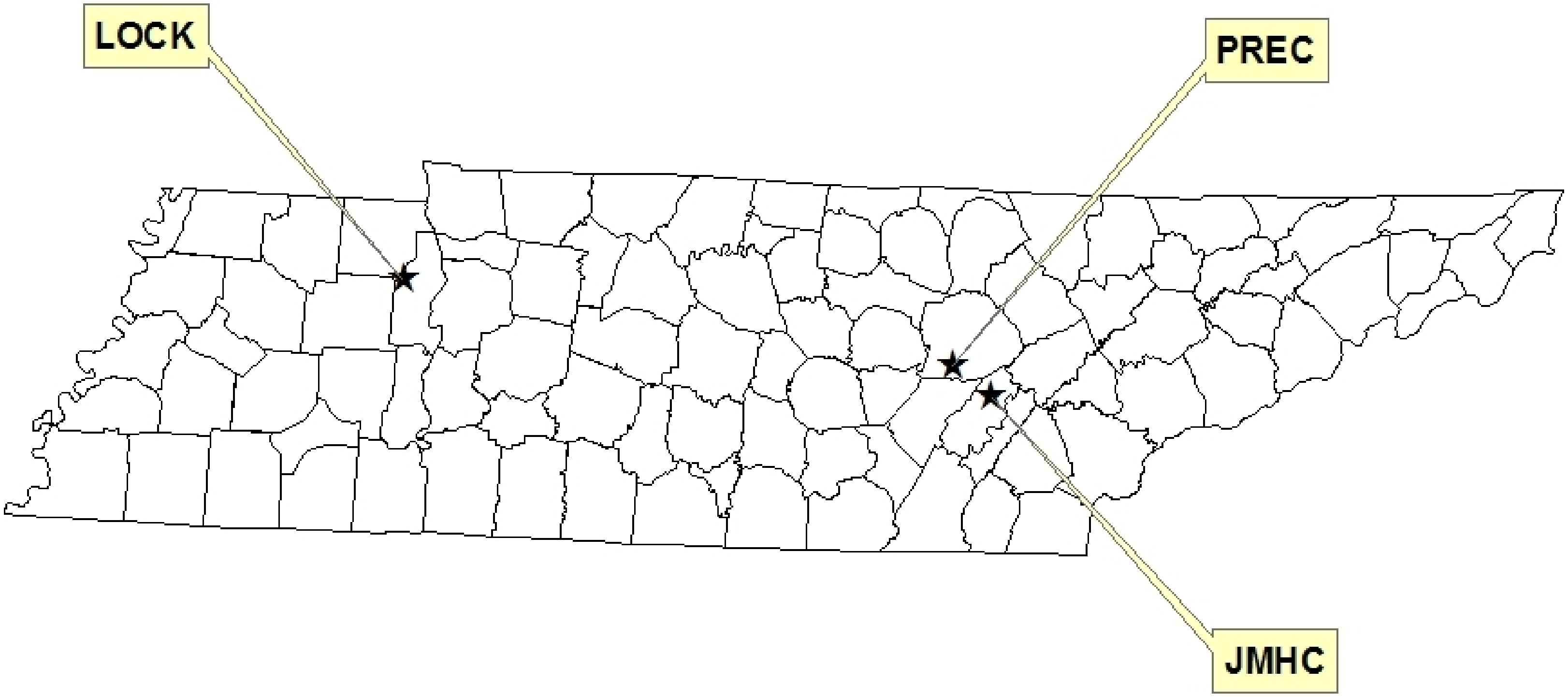

Figure 1.1. Location of J.M. Huber Corp. (JMHC), Plateau Research and Education Center (PREC), and Lockhart Farms (LOCK) study areas.

1980s and hayed annually. Tall fescue was the dominant vegetation at the time of treatment. Other grasses present prior to treatment included orchardgrass, broomsedge bluestem, and johnsongrass.

Site two was located at The University of Tennessee Plateau Research and Education Center (PREC) in Cumberland County in the Cumberland Plateau physiographic province. Elevation within the field ranged from 598 to 605 m. The primary soil series was Hartsells fine sandy loam (Hubbard et al. 1938). These soils are characterized by a thin top layer (0 – 5 cm) and low productivity (Hubbard et al. 1938). Prior to treatment, the field was used as continuously grazed pasture. Tall fescue was the dominant vegetation at the time of treatment. Multiflora rose (*Rosa multiflora*), orchardgrass, timothy (*Phleum pratense*), Kentucky bluegrass (*Poa pratensis*), and velvetgrass (*Holcus lanatus*) were also present.

Site three was located on Lockart Farms (LOCK) in Benton County near the boundary of the Eastern Gulf Coastal Plain and Western Highland Rim physiographic provinces. Elevation within the field ranged from 116 to 122 m. The primary soil series were Engam and Huntington, which are highly productive and may be moderately well drained to poorly drained (Odom et al. 1953). The field was sown to tall fescue in 1985 when it was enrolled in the Conservation Reserve Program. At the time of study, the field was under contract as conservation practice-10 (established grass). Prior to enrollment, the field was used for crop production. Tall fescue was the dominant vegetation at the time of treatment. Broomsedge bluestem and blackberry (*Rubus* spp.) were also present prior to treatments. The field also contained scattered low spots supporting various sedges (*Carex* spp.), rushes (*Juncus* spp.), and cocklebur (*Xanthium* spp.).

METHODS

Treatment application

Eight treatments and a control were implemented at each study site from fall 2003 to fall 2004. Treatments and controls were randomly assigned to 0.2-ha plots with three replicates per treatment and three controls at each study site. Treatments included: fall glyphosate (2.2 kg ai/ha; Gly-4 2qt/ac); fall glyphosate followed by winter disking; fall imazapic (0.2 kg ai/ha; Plateau 12 oz/ac); fall imazapic followed by winter disking; spring glyphosate; spring glyphosate followed by fall disking; spring imazapic; and spring imazapic followed by fall disking. The spring herbicide followed by fall disking treatments were completed in fall 2004. Therefore, no data were collected from those treatments until the 2005 growing season.

Herbicides were applied using a tractor-operated agricultural boom sprayer with a 6.4-m (21-ft) boom and a total spray volume of 218.5 L/ha (23 gal/ac) (PREC, JMHC) or an agricultural spray coupe with a 15.2-m (50-ft) boom and a total spray volume of 95.1 L/ha (10 gal/ac) (LOCK). Prior to treatment, tall fescue biomass was clipped (LOCK, JMHC) or grazed (PREC) to decrease thatch and increase surface area of tall fescue to facilitate foliar activity. A nonionic surfactant was added to each herbicide (0.025% total solution by volume) as per herbicide label recommendation to increase herbicide uptake. Herbicides were applied 28 October – 30 November 2003 (fall) and 4 April – 25 April (spring) when tall fescue plants were 15 – 30 cm (6 – 12 in) tall and actively growing. Winter disking was conducted 2 March – 12 March 2004. Fall disking was conducted 28 October and 18 December 2004 at the PREC and JMHC sites, respectively. Fall disking was not conducted until 21 March 2005 at the LOCK site because of excessive soil moisture from above average rainfall during fall of 2004. These plots were excluded from analysis. Disking was conducted using a 3-m (10-ft) offset agricultural disk. Plots were disked 3 – 6 passes, or until > 50% of the aboveground residue was incorporated into the soil.

Data collection

Vegetation composition

Vegetation composition, species richness, and average vegetation height were measured along three 10-m line transects within each plot during August 2004 and 2005 (Canfield 1941). Transects were established perpendicular to plot diagonal. Plants intercepting transects were identified to species and the horizontal distance of plant canopy covered by each plant was recorded. Total cover of all plants often exceeded 10 m because of overlapping plant canopy coverage. Portions of the line transect not covered by vegetation were classified as either bare ground or litter. Vegetation height was measured at 0, 5, and 10 m along each transect At one study site (HUBR), orchardgrass was prevalent in treatment plots. Treatment effects on orchardgrass cover were tested within this site using a one-way ANOVA.

Vegetation structure

Total vegetation canopy, bare ground, litter, and cover of vegetation canopy classes, including forbs, warm-season grasses, cool-season grasses, brambles, sedges, and woody species, were estimated to the nearest 5% using a 1-m^2 sampling frame (Bonham 1989). Litter was defined as dead vegetative material on the soil surface undergoing decomposition (McCoy et al. 2001). Litter depth was measured in the center of each sampling frame. Each plot was divided into the four cardinal quadrants: northeast, southeast, southwest, and northwest. A sampling point was located at the center of each quadrant. Sampling frames were placed 4 m from the sampling point in each cardinal direction for a total of 16 subsamples per 0.2-ha plot.

Visual obstruction reading is an index of vertical vegetation structure and was estimated within each plot using a pole 2 m in length and 5 cm in diameter (Robel et al. 1970). Visual obstruction reading (hereafter vertical structure) was measured in the four cardinal directions from a sampling point located systematically at the center of each quadrant providing a total of 16 vertical structure subsamples per 0.2-ha plot. Ground sighting distance, an index of the openness at ground level, was measured from a central sampling point within each quadrant by a stationary observer looking through a PVC tube 3.2 cm in diameter and 15.2 cm in length, mounted horizontally on a metal stake 15.2 cm above ground. The distance at which vegetation obscured the bottom 15 cm of a 5cm diameter pole viewed through the tube was recorded. A prone observer was positioned directly south of the sampling point and ground sighting distance was recorded towards the north, east, and west within each quadrant of each plot for a total of 12 subsamples per 0.2-ha plot.

Angle of obstruction was measured using a 2-m pole and a clinometer (Kopp et al. 1998). The pole was placed at the center of each quadrant and while the bottom of the pole remained at the sampling point, the upper portion of the pole was leaned toward the nearest vegetative obstruction. A clinometer was placed along the pole to measure the angle of obstruction. Measurements were recorded in each of the cardinal directions. Angle of obstruction measurements may be used to determine the *cone of vulnerability* in which an avian predator could readily view a bobwhite (Kopp et al. 1998). Visual obstruction distance was measured using the Robel pole (Kopp et al. 1998). A kneeling stationary observer recorded the closest distance at which the bottom 15 cm of a 5-cm diameter pole disappeared from view. This measurement may be used to determine the *disk of vulnerability* representing the area of a circle in which a mammalian predator may view a bobwhite (Kopp et al. 1998). Angle of obstruction and visual obstruction distance were recorded in each cardinal direction within the four quadrants, providing 16 subsamples per 0.2-ha plot. Angle of obstruction, visual obstruction distance, vertical structure, and ground sighting distance were measured from the same sampling point. Vegetation structural parameters were recorded in the early growing season (June – July), late growing season (August – September), and fall (November – December) 2004 and winter (February – early March), spring (April – May), early growing season (June – July), and late growing season (August – September) 2005.

Invertebrate biomass

Invertebrate samples were collected using a 0.25-m^2 bottomless box and modified hand held blower-vac (Harper and Gyunn 1998). Four subsamples were collected systematically within each 0.2-ha plot by locating the sampling box in the center of each of the 4 cardinal quadrants. The modified blower-vac was used to vacuum the vegetation and substrate within the sampling box into cloth bags. Samples were collected when vegetation was dry and daytime temperature was > 80° F (Palmer 1995). Invertebrate samples were collected 2004 and 2005 during the early (June) and late (August) growing season to coincide with the primary brood-rearing periods for bobwhites in Tennessee (Dimmick 1971). Samples were stored at a constant temperature of -20 C to prevent decomposition (Murkin et al 1996). Invertebrates were separated from vegetation and debris, placed in plastic vials, and dried for 48 hours in a forced-air oven at a constant temperature of 60 C (140 F) (Murkin et al. 1996). Dry weights and abundance for each invertebrate order were recorded.

Data analysis

Vegetation composition and invertebrate abundance were analyzed by grouping plant species and invertebrate orders into biologically meaningful associations in order to avoid increased Type I error rates that may result from running multiple ANOVAs on the same data set (Neter et al. 1996). Statistical tests were preformed on cover of tall fescue, desirable native warm-season grasses, desirable bobwhite food plants, undesirable grasses, and undesirable forbs within each plot.

Desirable bobwhite food plants included plants producing seed readily consumed by bobwhites (Rosene and Freeman 1988, Eubanks and Dimmick 1974, Landers and Johnson 1976, Buckner and Landers 1979, Brennan and Hurst 1995; Appendix A.1). Desirable native warm-season grasses included those that provide adequate structure for bobwhite nesting (Appendix A.2). Undesirable forbs included aggressively growing broadleaf plants, such as thistles (*Cirsium* spp.), Canadian horseweed (*Conyza canadensis*), pigweeds (*Amaranthus* spp.), and sericea lespedeza (*Lespedeza cuneata*; Appendix A.3). Undesirable grasses included aggressively growing grasses (other than tall fescue and orchardgrass), such as johnsongrass, broadleaf signalgrass (*Brachiaria platyphylla*), goosegrass (*Eleusine indica*), and crabgrass; (Appendix A.4). Seed from johnsongrass and crabgrass have been reported in the crops of bobwhites (Eubanks and Dimmick 1974, Brazil 1993, Brennan and Hurst 1995); however, no study makes inference about the use of these grasses in proportion to their availability. For the purposes of this analysis, these plants were classified undesirable because they are non-native and tend to dominate sites, reducing diversity and creating a problem when managing for more desirable plants for bobwhites. Several plants did not fit into any category and were accounted for in plant species richness, but were not included in plant species composition analysis to ensure conservative estimates. All plants recorded along transects are listed in Appendix A.5.

Variables used to quantify invertebrates included total density, total biomass, density of orders preferred by bobwhite broods and biomass of orders preferred by bobwhite broods. In foraging trials using pen-reared bobwhite chicks in different habitat types, several invertebrate orders, including Aranea (spiders), Coleoptera (beetles), Diptera (flies), Hemiptera (true bugs), Homoptera (leafhoppers), Hymenoptera (ants and wasp), Lepedoptera larva (butterfly and moth larva), and Orthoptera (grasshoppers), have been reported preferred (Hurst 1972, Jackson et al. 1987, Palmer 1995, Smith 2004, Doxon 2006). For this analysis, invertebrates considered preferred by bobwhite chicks included Coleoptera, Hemiptera, Homoptera, and Orthoptera because these orders are consistently cited as preferred (Burger et al. 1993, Devos and Muller 1993). Limiting analysis to these orders ensured conservative estimates.

Data were averaged across subsamples to obtain a mean for each treatment and control plot (experimental unit; $n = 9$) within each sampling period. One-way analysis-of-variance (ANOVA) with a blocking variable was used to test for differences in vegetation composition and structure, and invertebrate density and biomass among treatments (Montgomery 1997). The null hypothesis that no difference existed among treatments was tested for each variable. Variance among sites was partitioned by blocking on study site. In as much as no unbiased test for block interactions exists, block by treatment interactions were not tested. Additionally, the block by treatment interaction was irrelevant in this study because blocks were used to reduce experimental error and were not of intrinsic interest themselves (Neter et al. 1996:1105).

The assumptions of ANOVA, normality of residuals and equality of variances, were tested using by the Shapiro-Wilk test ($W \geq 0.90$) and Levene's test ($P \geq 0.05$) respectively (PROC UNIVARIATE SAS Institute 2003). Variables failing to meet the assumptions of ANOVA were transformed using the arcsine square root (percent cover variables), $\log_{10}$ plus 1 (structure and composition variables), or square root transformation (invertebrate variables). All variables met the assumptions of ANOVA following transformation. Statistical tests were preformed on 9 variables for vegetation composition (Appendix A.6), 14 variables for vegetation structure (Appendix A.7), and 5 variables for invertebrate abundance (Appendix A.8). When *F*-tests were significant, Tukey's Honest Significant Difference test was used to determine if pair-wise differences existed between treatments. All tests were performed using PROC GLM in the SAS$^{®}$ system (Littell et al. 2002).

RESULTS

Tall fescue eradication

Treatment differences were detected for tall fescue cover across all sampling periods (Table 1.1). All treatments reduced tall fescue cover one and two growing seasons after treatment. One growing season following treatment, tall fescue coverage was lower following fall glyphosate winter disk than fall imazapic, spring herbicide treatments, and control. By the second growing season following treatment, fall herbicide applications with and without disking provided greater reduction in tall fescue than spring herbicide applications with and without disking and control.

Bobwhite habitat response

First growing season post-treatment (2004)

Vegetation structure

Early growing season

Treatment differences were detected during the early growing season (June – July) for 11 of 14 variables (Table 1.2). Ground sighting distance was greater in the fall glyphosate winter disk treatment than control. Angle of obstruction was similar between spring herbicide applications and control. Greatest increase in angle of obstruction was from fall applications of either herbicide followed by winter disking. Vertical structure was greatest in fall herbicide winter disking treatments. Total vegetation cover and litter depth decreased while bare ground increased in all treatments except spring glyphosate. Forb cover was increased by fall herbicide and fall herbicide winter disk treatments with the greatest forb cover in fall glyphosate and fall herbicide winter disk treatments. Warm-season grass cover increased following spring or fall herbicide applications. Cool-season grass cover was decreased by all treatments.

Late growing season

Treatment differences were detected late in the first growing season (August – September) for 12 of 14 variables (Table 1.2). Ground sighting distance increased following fall herbicide winter disk treatments compared to control. Angle of obstruction increased following fall herbicide, and fall herbicide winter disk treatments.

Table 1.1 Mean tall fescue cover along 10-m line transects following treatments in three tall fescue fields, Tennessee, 2004-2005.

	Summer 2004		Fall 2004		Winter 2005		Spring 2005		Summer 2005	
Treatment	$\bar{x}$[1] (SE)		$\bar{x}$ (SE)		$\bar{x}$ (SE)		$\bar{x}$ (SE)		$\bar{x}$ (SE)	
Control	9.25 (0.36)	a	9.40 (0.25)	a	8.81 (0.53)	a	8.81 (0.60)	a	9.48 (0.24)	a
Fall imazapic	0.88 (0.29)	bc	1.25 (0.47)	c	1.43 (0.44)	c	1.97 (0.94)	c	1.14 (0.58)	de
Fall glyphosate	0.50 (0.34)	cd	0.44 (0.16)	cd	0.38 (0.14)	cd	0.42 (0.13)	cd	0.17 (0.07)	e
Fall imazapic spring disk	0.27 (0.10)	cd	0.86 (0.35)	cd	0.53 (0.16)	cd	1.17 (0.53)	cd	1.00 (0.34)	de
Fall glyphosate spring disk	0.05 (0.04)	d	0.06 (0.02)	d	0.06 (0.04)	d	0.24 (0.08)	d	0.20 (0.10)	e
Spring imazapic	2.03 (0.51)	b	3.68 (0.95)	b	4.28 (1.01)	b	4.42 (1.00)	b	4.02 (1.15)	b
Spring glyphosate	1.99 (0.53)	b	3.80 (0.63)	b	4.76 (0.60)	b	5.37 (0.58)	ab	4.21 (0.69)	b
Spring imazapic fall disk									2.19 (0.84)	cd
Spring glyphosate fall disk									2.43 (0.55)	bc

[1] Means within columns followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

Table 1.2 Mean vegetation structural characteristics following treatments in three tall fescue fields, Tennessee, June – September 2004.

	Treatment																				
	Control			Fall imazapic			Fall glyphosate			Fall imazapic winter disk			Fall glyphosate winter disk			Spring imazapic			Spring glyphosate		
Variable[1]	$\bar{x}$ [2]	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)	
Early growing season																					
GSD	0.03	(0.01)	b	0.28	(0.04)	bc	0.27	(0.03)	bc	0.53	(0.04)	ab	0.75	(0.20)	a	0.29	(0.06)	bc	0.30	(0.08)	bc
AO	10.68	(0.95)	c	29.06	(4.29)	b	34.88	(4.03)	b	54.96	(3.00)	a	53.97	(5.16)	a	10.85	(2.10)	c	18.65	(5.80)	bc
VOD	0.25	(0.05)	b	0.34	(0.03)	ab	0.29	(0.05)	ab	0.27	(0.04)	ab	0.80	(0.38)	ab	0.81	(0.16)	a	0.59	(0.17)	ab
VOR	7.17	(0.74)	bc	6.80	(0.56)	bc	8.43	(0.74)	b	13.33	(1.41)	a	14.24	(1.80)	a	3.32	(0.23)	c	6.09	(1.29)	bc
Cover	99.24	(0.24)	a	91.25	(2.35)	bc	92.26	(1.84)	b	87.19	(2.81)	bc	87.71	(2.06)	bc	78.82	(7.91)	c	90.03	(2.66)	bc
Bare	0.52	(0.16)	c	7.81	(2.07)	ab	6.28	(1.21)	ab	12.81	(2.81)	a	11.04	(2.15)	a	5.94	(1.95)	b	3.61	(1.46)	bc
Litter	0.24	(0.14)	bc	1.01	(0.32)	bc	1.46	(0.85)	bc	0.00	(0.00)	c	0.00	(0.00)	c	15.24	(7.65)	a	5.94	(2.49)	ab
Ldepth	2.02	(0.25)	a	0.37	(0.05)	bc	0.25	(0.07)	c	0.00	(0.00)	d	0.00	(0.00)	d	0.83	(0.23)	b	0.78	(0.22)	b
Forbs	30.69	(4.63)	c	61.22	(5.48)	b	87.92	(1.57)	a	89.62	(3.04)	a	94.55	(2.74)	a	45.35	(6.14)	bc	51.74	(6.71)	bc
Brambles	0.07	(0.07)	a	0.35	(0.35)	a	0.83	(0.54)	a	0.00	(0.00)	a	0.00	(0.00)	a	0.17	(0.17)	a	1.39	(1.21)	a
Sedges	1.10	(0.98)	ab	0.09	(0.07)	b	0.10	(0.10)	b	0.30	(0.23)	a	0.15	(0.10)	bc	0.00	(0.00)	b	5.44	(2.22)	a
Woody	2.12	(0.63)	a	3.44	(1.30)	a	2.36	(1.13)	a	0.39	(0.15)	a	0.63	(0.33)	a	2.53	(0.90)	a	1.77	(0.81)	a
CS grass	96.35	(0.60)	a	35.03	(8.36)	b	4.03	(1.68)	d	6.94	(1.57)	cd	1.15	(0.50)	d	47.88	(10.75)	b	29.69	(10.38)	bc
WS grass	5.97	(1.26)	c	33.13	(4.49)	ab	28.65	(3.98)	ab	24.38	(4.23)	abc	19.51	(6.48)	bc	29.55	(6.04)	ab	47.81	(9.18)	a
Late growing season																					
GSD	0.01	(0.00)	c	0.19	(0.03)	bc	0.19	(0.04)	bc	0.49	(0.09)	ab	0.57	(0.16)	a	0.17	(0.04)	bc	0.26	(0.10)	abc
AO	19.85	(3.03)	d	44.10	(5.51)	bc	50.53	(3.18)	b	65.01	(4.60)	a	67.84	(3.01)	a	26.81	(5.78)	d	32.33	(8.27)	cd
VOD	0.09	(0.03)	c	0.24	(0.03)	abc	0.20	(0.04)	bc	0.35	(0.07)	ab	0.42	(0.15)	ab	0.31	(0.05)	abc	0.73	(0.19)	a
VOR	7.32	(0.57)	d	12.40	(1.30)	bc	13.72	(0.74)	b	17.74	(1.32)	a	18.44	(0.46)	a	6.33	(0.92)	d	9.19	(1.40)	cd
Cover	99.10	(0.26)	a	93.82	(1.23)	b	94.76	(1.02)	b	93.65	(1.16)	b	93.22	(1.49)	b	89.72	(3.26)	b	92.33	(1.61)	b
Bare	0.24	(0.13)	c	5.59	(1.16)	ab	4.62	(1.14)	ab	6.35	(1.16)	a	6.18	(1.08)	a	4.03	(1.25)	ab	2.92	(0.98)	b

Table 1.2 (continued).

	Treatment																				
	Control			Fall imazapic			Fall glyphosate			Fall imazapic winter disk			Fall glyphosate winter disk			Spring imazapic			Spring glyphosate		
Variable	$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)	
Litter	0.66	(0.26)	bc	0.59	(0.20)	bc	0.63	(0.25)	bc	0.00	(0.00)	c	0.03	(0.03)	c	6.25	(3.47)	a	4.07	(1.71)	ab
Ldepth	3.74	(0.40)	a	0.51	(0.10)	c	0.40	(0.11)	c	0.00	(0.00)	d	0.00	(0.00)	d	0.90	(0.27)	b	1.76	(0.65)	bc
Forbs	31.28	(4.51)	c	72.01	(3.27)	b	88.92	(2.39)	a	91.08	(2.25)	a	94.51	(2.81)	a	53.99	(6.11)	b	56.04	(4.39)	b
Brambles	0.09	(0.07)	a	0.35	(0.35)	a	0.83	(0.54)	a	0.00	(0.00)	a	0.00	(0.00)	a	0.17	(0.17)	a	1.39	(1.21)	a
Sedges	1.63	(1.00)	ab	0.07	(0.07)	b	0.31	(0.21)	ab	0.42	(0.28)	ab	0.14	(0.14)	b	0.03	(0.03)	b	6.46	(3.81)	a
Woody	3.02	(0.47)	a	1.91	(0.97)	a	1.94	(0.80)	a	1.01	(0.51)	a	0.80	(0.43)	a	1.63	(0.49)	a	2.40	(0.90)	a
CS grass	93.33	(1.58)	a	35.07	(9.18)	b	5.24	(2.35)	c	7.71	(4.33)	b	0.35	(0.25)	c	41.88	(9.06)	b	25.97	(9.33)	b
WS grass	9.24	(2.26)	c	29.24	(3.40)	abc	24.86	(3.15)	abc	27.29	(5.79)	abc	24.10	(7.84)	bc	32.19	(7.55)	ab	48.96	(9.83)	a

[1] GSD = ground sighting distance (m), AO = angle of obstruction (0-90°), VOD = visual obstruction distance, VOR = visual obstruction reading or vertical structure, Cover = total vegetative cover (%), Bare = bareground (%), Litter = litter (%), Ldepth = litter depth (cm), Forbs = forb cover (%), Brambles = *Rubus* spp. Cover (%), Sedges = sedge cover (%), Woody = woody cover (%), CSgrass = cool-season grass cover (%), WSgrass = warm-season grass cover (%).

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

Visual obstruction distance was increased by spring glyphosate and fall herbicide winter disk treatments. Vertical structure was greatest in fall herbicide winter disking treatments. Fall herbicide applications increased vertical structure. Total vegetation cover and litter depth decreased while percent bare ground increased across all treatments. Forb cover was increased by all treatments with the greatest forb cover in fall glyphosate and fall herbicide winter disking treatments followed by fall imazapic and spring herbicide applications. Spring herbicide applications increased warm-season grass cover. Cool-season grass cover was decreased by all treatments. Vegetation height increased in fall herbicide winter disk treatments (Table 1.3).

Vegetation composition

One growing season post-treatment, 107 plant species were recorded along line transects. Plant species composition differed among treatments for 9 of 9 variables (Table 1.3). Tall fescue was decreased in all treatments. Cover of bobwhite food plants following spring herbicide applications was not different than control. Fall and spring applications of imazapic increased cover of desirable native grasses. Cover of undesirable grasses increased following spring glyphosate and fall glyphosate winter disk treatments. Species richness increased following fall glyphosate treatment.

Invertebrate abundance and biomass

Treatment differences were detected in order richness of invertebrates during the early growing season, 2004 (Table 1.4). Invertebrate order richness Fall glyphosate had more invertebrate order richness than spring herbicide treatments and control. Treatment differences were detected during the late growing season, 2004 (Table 1.4). The spring

Table 1.3 Mean tall fescue cover, vegetation composition characteristics, plant species richness, and vegetation height measured along 10-m line transects following treatments in three tall fescue fields, Tennessee, August 2004.

	Treatment																				
	Control			Fall imazapic			Fall glyphosate			Fall imazapic winter disk			Fall glyphosate winter disk			Spring imazapic			Spring glyphosate		
Variable[1]	$\bar{x}$[2]	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)	
Tall fescue	9.25	(0.36)	a	0.88	(0.29)	bc	0.50	(0.34)	cd	0.27	(0.10)	cd	0.05	(0.04)	d	2.03	(0.51)	b	1.99	(0.53)	b
Desirable nwsg	0.27	(0.05)	b	2.05	(0.43)	a	0.91	(0.16)	ab	0.39	(0.17)	b	0.23	(0.09)	b	2.03	(0.73)	a	1.13	(0.33)	ab
Bobwhite food plants	0.71	(0.27)	b	2.22	(0.67)	a	4.79	(1.18)	a	7.25	(1.66)	a	6.96	(1.24)	a	0.53	(0.32)	b	1.48	(0.65)	b
Undesirable grasses	0.31	(0.13)	c	1.14	(0.29)	bc	1.63	(0.30)	abc	1.61	(0.56)	bc	2.59	(0.91)	ab	0.93	(0.54)	bc	4.63	(1.24)	a
Undesirable forbs	1.20	(0.48)	b	4.15	(0.73)	ab	7.30	(2.05)	a	5.41	(2.43)	ab	4.67	(1.74)	ab	3.52	(0.69)	ab	2.36	(0.63)	ab
Bare	0.00	(0.00)	b	0.14	(0.04)	ab	0.10	(0.05)	ab	0.08	(0.03)	ab	0.32	(0.23)	a	0.17	(0.05)	a	0.07	(0.04)	ab
Litter	0.01	(0.01)	b	0.04	(0.03)	ab	0.02	(0.01)	b	0.00	(0.00)	b	0.00	(0.00)	b	0.24	(0.14)	a	0.09	(0.05)	ab
Species richness	19.56	(1.39)	b	24.33	(1.12)	ab	28.89	(1.31)	a	22.13	(2.29)	b	18.56	(1.97)	b	19.56	(0.87)	b	21.78	(1.78)	b
Vegetation height	0.44	(0.07)	cd	0.68	(0.09)	cd	0.87	(0.14)	bc	1.56	(0.16)	a	1.37	(0.17)	ab	0.38	(0.05)	d	0.54	(0.13)	cd

[1] Tall fescue = tall fescue (*Festuca arundinacea*) cover (m), Desirable nwsg = desirable native warm-season grass cover (m), Bobwhite food plants = cover (m) of plants producing seed eaten by bobwhites, Undesirable grasses = undesirable grass cover (m), Bare = bareground (m), Litter = litter (m), Species richness = number of species recorded per plot, Vegetation height = Average vegetation height (m).

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

Table 1.4 Mean density, biomass, and order richness of invertebrates following treatments in three tall fescue fields, Tennessee, June – August 2004.

	Treatment																				
	Control			Fall imazapic			Fall glyphosate			Fall imazapic winter disk			Fall glyphosate winter disk			Spring imazapic			Spring glyphosate		
Variable[1]	$\bar{x}$ [2]	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)	
Early growing season																					
Total biomass	0.10	(0.03)	a	0.18	(0.04)	a	0.11	(0.03)	a	0.16	(0.04)	a	0.12	(0.02)	a	0.08	(0.02)	a	0.25	(0.09)	a
Biomass preferred	0.05	(0.01)	a	0.15	(0.03)	a	0.08	(0.02)	a	0.11	(0.02)	a	0.11	(0.02)	a	0.07	(0.02)	a	0.17	(0.07)	a
Total density	11.25	(1.35)	a	20.44	(2.29)	a	15.56	(4.07)	a	24.56	(3.81)	a	18.00	(3.24)	a	18.56	(3.89)	a	18.00	(3.90)	a
Density preferred	8.56	(1.55)	a	17.78	(1.91)	a	13.44	(3.57)	a	20.56	(4.07)	a	16.11	(3.18)	a	15.38	(4.33)	a	15.22	(3.40)	a
Order richness	1.89	(0.17)	b	2.42	(0.15)	ab	2.97	(0.27)	a	2.00	(0.27)	ab	2.11	(0.26)	ab	1.91	(0.13)	b	1.92	(0.27)	b
Late growing season																					
Total biomass	0.30	(0.06)	ab	0.16	(0.04)	ab	0.12	(0.05)	b	0.14	(0.05)	b	0.11	(0.04)	b	0.50	(0.15)	a	0.18	(0.06)	ab
Biomass preferred	0.26	(0.05)	ab	0.15	(0.04)	ab	0.09	(0.04)	b	0.09	(0.02)	b	0.09	(0.03)	b	0.44	(0.13)	a	0.16	(0.05)	ab
Total density	18.67	(2.29)	a	12.17	(1.48)	ab	7.44	(2.03)	ab	9.71	(1.70)	b	8.25	(2.53)	b	20.00	(4.29)	a	13.19	(2.71)	ab
Density preferred	13.22	(2.84)	a	9.78	(1.69)	a	6.22	(1.72)	a	6.79	(1.25)	a	6.63	(1.97)	a	16.11	(4.64)	a	9.63	(2.68)	a
Order richness	2.08	(0.13)	a	1.81	(0.10)	a	1.28	(0.27)	a	1.50	(0.17)	a	1.41	(0.39)	a	2.14	(0.21)	a	1.92	(0.19)	a

[1] Total biomass = biomass (g /m^2) of all invertebrates, Biomass preferred = biomass (g /m^2) of invertebrates in orders preferred by foraging bobwhite chicks, Total density = density (invertebrates/m^2) of all invertebrates, Density preferred = density (invertebrates/m^2) of invertebrates in orders preferred by foraging bobwhite chicks, Order richness = number of invertebrate orders represented per sample.

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

imazapic treatment and control had greater total invertebrate density than fall herbicide spring disk treatments. The spring imazapic treatment had greater total invertebrate biomass and invertebrate biomass of preferred orders than fall glyphosate and fall herbicide winter disk treatments. While a treatment effect was detected for order richness, Tukey's HSD failed to produce a mean separation among treatments.

Dormant season following treatment (2004-2005)

Vegetation structure

Fall

Treatment differences were detected during fall (November – December) for 13 of 14 variables (Table 1.5). Ground sighting distance was increased by all treatments. Angle of obstruction was increased by fall imazapic and fall herbicide winter disk treatments. Visual obstruction distance was increased by all treatments. Vertical structure was increased by fall herbicide and fall herbicide winter disk treatments. Total vegetation cover was greatest in control followed by fall and spring herbicide applications and lowest in fall herbicide winter disk treatments. Bare ground was greatest in fall herbicide winter disk treatments and lowest in control. Litter depth was decreased by all treatments Forb cover was greatest in fall glyphosate and fall glyphosate winter disk treatments followed by fall imazapic and fall imazapic winter disk treatments. There was no difference in forb cover between spring herbicide applications and control. Cool-season grass cover was decreased by all treatments. Fall glyphosate and fall glyphosate winter disk treatments had the lowest cool-season grass cover. Warm-season grass cover was increased by all treatments.

Table 1.5 Mean vegetation structural characteristics following treatment application in three tall fescue fields, Tennessee, November 2004 – April 2005.

	Treatment																				
	Control			Fall imazapic			Fall glyphosate			Fall imazapic winter disk			Fall glyphosate winter disk			Spring imazapic			Spring glyphosate		
Variable^1	$\bar{x}^2$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)	
Fall																					
GSD	0.01	(0.00)	c	0.46	(0.09)	b	0.42	(0.05)	b	0.63	(0.08)	ab	0.78	(0.09)	a	0.37	(0.11)	b	0.36	(0.07)	b
AO	13.41	(1.93)	c	30.19	(3.82)	b	26.99	(2.77)	bc	47.37	(4.64)	a	45.87	(5.80)	a	23.53	(6.01)	bc	17.35	(2.89)	bc
VOD	0.01	(0.01)	c	0.46	(0.09)	ab	0.52	(0.05)	ab	0.62	(0.11)	ab	0.88	(0.15)	a	0.38	(0.11)	b	0.39	(0.07)	b
VOR	5.19	(0.49)	d	12.25	(0.83)	ab	11.63	(0.86)	bc	16.30	(1.02)	a	15.29	(1.54)	ab	7.83	(1.58)	cd	7.60	(1.17)	cd
Cover	99.09	(0.87)	a	88.37	(3.82)	b	87.74	(4.76)	b	70.80	(3.90)	c	70.55	(5.99)	c	85.28	(6.30)	b	88.72	(4.92)	b
Bare	0.07	(0.07)	c	6.81	(2.39)	b	5.24	(2.29)	b	27.88	(3.66)	a	29.18	(5.95)	a	6.98	(2.16)	b	3.26	(0.91)	b
Litter	0.28	(0.24)	a	4.94	(2.44)	a	6.39	(4.15)	a\	0.17	(0.17)	a	0.27	(0.27)	a	7.71	(5.37)	a	8.06	(4.46)	a
Ldepth	2.28	(0.45)	a	0.69	(0.18)	b	0.48	(0.35)	bc	0.00	(0.00)	c	0.02	(0.02)	c	0.70	(0.22)	b	0.69	(0.13)	b
Forb	7.42	(2.59)	c	47.01	(6.50)	b	89.83	(2.82)	a	67.08	(8.96)	b	90.98	(3.57)	a	24.17	(5.97)	c	21.19	(7.03)	c
Brambles	0.52	(0.32)	a	0.21	(0.10)	a	0.24	(0.24)	a	0.07	(0.07)	a	0.00	(0.00)	a	0.15	(0.12)	a	0.45	(0.17)	a
Sedges	0.00	(0.00)	a	0.00	(0.00)	a	0.03	(0.03)	a	0.00	(0.00)	a	0.00	(0.00)	a	0.00	(0.00)	a	3.54	(2.34)	a
Woody	0.97	(0.66)	a	0.52	(0.48)	a	1.18	(0.58)	a	0.03	(0.03)	a	0.08	(0.08)	a	1.04	(0.54)	a	1.49	(0.96)	a
CS grass	97.85	(0.79)	a	42.22	(10.59)	b	6.46	(2.86)	c	34.10	(9.69)	b	3.28	(1.63)	c	56.91	(9.26)	b	59.86	(9.15)	b
WS grass	2.56	(0.88)	c	24.76	(7.94)	ab	7.26	(2.38)	ab	8.33	(4.72)	ab	12.03	(6.14)	ab	28.75	(9.75)	a	28.72	(9.96)	a
Winter																					
GSD	0.17	(0.05)	d	0.84	(0.08)	abc	1.30	(0.14)	a	1.20	(0.16)	abc	1.24	(0.17)	ab	0.73	(0.18)	bcd	0.66	(0.11)	cd
AO	12.58	(1.76)	c	29.49	(2.77)	ab	23.85	(3.29)	abc	32.94	(3.53)	a	34.22	(4.28)	a	22.76	(5.53)	abc	16.42	(2.82)	bc
VOD	0.17	(0.05)	b	1.23	(0.12)	a	1.71	(0.29)	a	1.68	(0.34)	a	1.54	(0.38)	a	0.92	(0.16)	a	0.98	(0.18)	a
VOR	2.89	(0.35)	c	8.29	(0.68)	ab	6.66	(1.17)	abc	9.10	(1.74)	ab	10.12	(1.84)	a	5.63	(1.42)	abc	4.46	(0.80)	bc
Cover	93.19	(2.08)	a	70.90	(4.05)	bc	75.59	(3.71)	bc	64.17	(3.55)	bc	56.04	(6.92)	c	80.21	(4.58)	ab	71.88	(4.90)	bc
Bare	0.17	(0.12)	c	13.02	(2.74)	b	8.61	(1.87)	b	31.88	(2.46)	a	32.60	(5.28)	a	10.66	(3.92)	b	10.69	(2.53)	b
Litter	6.63	(2.02)	a	15.94	(4.17)	a	16.91	(3.26)	a	3.89	(1.88)	a	11.49	(6.63)	a	9.26	(2.80)	a	16.44	(5.76)	a

Table 1.5 (continued).

	Treatment																				
	Control			Fall imazapic			Fall glyphosate			Fall imazapic winter disk			Fall glyphosate winter disk			Spring imazapic			Spring glyphosate		
Variable	$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)	
Ldepth	3.17	(0.56)	a	0.76	(0.22)	b	0.98	(0.66)	bc	0.05	(0.03)	c	0.12	(0.07)	bc	0.76	(0.30)	bc	0.77	(0.22)	b
Forb	3.13	(1.06)	e	50.85	(6.31)	c	87.50	(2.89)	ab	68.44	(8.23)	bc	91.53	(2.40)	a	26.94	(6.18)	d	26.01	(7.32)	d
Brambles	1.25	(0.88)	a	1.01	(0.68)	a	0.56	(0.29)	a	0.00	(0.00)	a	0.14	(0.14)	a	0.56	(0.35)	a	0.52	(0.37)	a
Sedges	0.00	(0.00)	a	0.00	(0.00)	a	0.31	(0.21)	a	0.00	(0.00)	a	0.17	(0.17)	a	0.00	(0.00)	a	2.26	(2.26)	a
Woody	0.07	(0.07)	a	0.28	(0.19)	a	0.10	(0.07)	a	0.00	(0.00)	a	0.00	(0.00)	a	0.10	(0.07)	a	0.35	(0.18)	a
CS grass	98.78	(0.74)	a	33.89	(9.68)	b	5.42	(1.68)	c	37.88	(10.70)	b	5.87	(2.06)	c	56.74	(8.96)	b	53.09	(10.94)	b
WS grass	2.60	(1.23)	d	31.46	(8.19)	a	12.57	(4.07)	abcd	6.42	(2.58)	cd	8.82	(4.67)	bcd	29.72	(10.57)	abc	31.84	(10.75)	ab
Spring																					
GSD	0.10	(0.01)	b	0.46	(0.06)	ab	0.66	(0.15)	a	0.42	(0.05)	ab	0.57	(0.15)	a	0.43	(0.09)	ab	0.50	(0.05)	a
AO	17.62	(2.07)	b	30.64	(4.65)	a	23.77	(2.19)	ab	33.59	(2.76)	a	32.56	(2.75)	a	25.39	(5.08)	ab	15.55	(2.60)	b
VOD	0.34	(0.11)	b	0.99	(0.20)	a	1.09	(0.20)	a	0.74	(0.12)	ab	0.94	(0.25)	a	0.72	(0.11)	ab	1.01	(0.06)	a
VOR	3.99	(0.57)	a	5.95	(0.81)	a	5.35	(0.93)	a	5.50	(0.68)	a	6.52	(1.48)	a	4.78	(0.89)	a	2.87	(0.31)	a
Cover	89.53	(2.26)	a	82.40	(1.59)	ab	84.48	(1.72)	ab	82.99	(7.92)	ab	78.65	(3.73)	b	79.65	(3.18)	ab	78.75	(1.78)	ab
Bare	0.24	(0.21)	c	9.69	(2.62)	b	8.75	(1.34)	b	20.56	(2.18)	a	19.38	(3.06)	a	7.43	(2.13)	b	8.38	(1.65)	b
Litter	9.01	(1.48)	a	8.61	(1.96)	ab	6.42	(1.66)	abc	1.11	(0.52)	c	3.96	(2.07)	bc	12.99	(3.57)	b	12.88	(1.43)	b
Ldepth	5.87	(0.70)	a	0.97	(0.31)	bc	0.30	(0.09)	cd	0.04	(0.02)	d	0.78	(0.70)	cd	1.62	(0.55)	b	1.44	(0.22)	b
Forb	6.15	(1.85)	e	60.28	(8.21)	cd	88.02	(5.12)	ab	72.40	(7.91)	bc	96.53	(1.14)	a	43.02	(6.55)	d	42.60	(8.19)	d
Brambles	0.21	(0.14)	a	0.90	(0.68)	a	1.18	(0.37)	a	0.24	(0.18)	a	0.42	(0.28)	a	0.38	(0.21)	a	2.19	(2.03)	a
Sedges	0.69	(0.69)	a	0.10	(0.10)	a	3.06	(1.68)	a	0.59	(0.59)	a	2.08	(1.64)	a	0.03	(0.03)	a	1.18	(0.90)	a
Woody	0.63	(0.28)	a	2.40	(1.27)	a	3.30	(1.83)	a	0.83	(0.49)	a	0.03	(0.03)	a	3.16	(2.05)	a	0.38	(0.17)	a
CS grass	96.84	(1.38)	a	38.32	(12.00)	bcd	13.79	(6.08)	de	36.32	(10.02)	cd	4.47	(1.45)	e	61.15	(7.27)	bc	65.52	(6.32)	b
WS grass	1.98	(0.88)	b	16.35	(5.53)	a	3.75	(1.53)	ab	2.08	(0.76)	b	0.87	(0.37)	b	15.24	(5.98)	a	5.83	(2.00)	ab

Table 1.5 (continued).

[1] GSD = ground sighting distance (m), AO = angle of obstruction (0-90°), VOD = visual obstruction distance, VOR = visual obstruction reading or vertical structure, Cover = total vegetative cover (%), Bare = bareground (%), Litter = litter (%), Ldepth = litter depth (cm), Forbs = forb cover (%), Brambles = *Rubus* spp. Cover (%), Sedges = sedge cover (%), Woody = woody cover (%), CSgrass = cool-season grass cover (%), WSgrass = warm-season grass cover (%).

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

Winter

Treatment differences were detected during winter (February) for 11 of 14 variables (Table 1.5). Ground sighting distance increased in fall herbicide and fall herbicide winter disk treatments. Angle of obstruction was greatest following fall imazapic and fall herbicide winter disk treatments. Visual obstruction distance was increased by all treatments. Vertical structure was greatest in fall imazapic and fall herbicide winter disk treatments while spring herbicide treatments were similar to controls. Total vegetation cover was decreased by all treatments except spring imazapic. Bare ground was increased by all treatments and was greatest in fall herbicide winter disk treatments. Litter depth was decreased by all treatments. Forb cover was increased by all treatments. Fall glyphosate and fall glyphosate winter disk treatments had more forb cover than fall imazapic and spring herbicide treatments. Cool-season grass cover was decreased by all treatments. Warm-season grass cover increased in fall imazapic and spring herbicide treatments (Table 1.5).

Spring

Treatment differences were detected during spring (April – May) for 10 of 14 variables (Table 1.5). Ground sighting distance was increased by fall glyphosate, fall glyphosate winter disk, and spring glyphosate treatments. Angle of obstruction was increased by fall imazapic, fall imazapic winter disk and fall glyphosate winter disk treatments. Visual obstruction distance was increased by all treatments fall imazapic winter disk and spring imazapic. Total vegetation cover was decreased by the fall glyphosate winter disk treatment. Bare ground was increased by all treatments and was greatest following fall herbicide winter disk treatments. Litter was lower in fall herbicide winter disk and spring herbicide treatments. Litter depth was decreased by all treatments. Forb cover was increased by all treatments. Fall glyphosate and fall glyphosate winter disk treatments had more forb cover than fall imazapic and spring herbicide treatments. Cool-season grass cover was decreased by all treatments. Warm-season grass cover increased in spring and fall imazapic treatments (Table 1.5).

Second growing season post-treatment (2004)

Vegetation structure

Early growing season

Treatment differences were detected early in the second growing season post-treatment (June – July) for 10 of 14 variables (Table 1.6). Ground sighting distance was increased by fall glyphosate and spring herbicide fall disk treatments. Fall herbicide and fall herbicide winter disk treatments increased angle of obstruction. Spring glyphosate fall disk increased visual obstruction distance. Fall glyphosate and fall herbicide winter disk treatments increased vertical structure. Total vegetation cover and litter depth decreased while bare ground increased across all treatments. Forb cover was increased by all treatments. Fall glyphosate winter disk, fall glyphosate, and spring glyphosate fall disk treatments had greater forb cover than fall imazapic, spring imazapic, and spring glyphosate treatments. Cool-season grass cover was decreased by all treatments. Fall glyphosate and fall glyphosate winter disk treatments had less cool-season grass cover than fall and spring imazapic treatments, spring glyphosate, and spring herbicide fall disk treatments.

Table 1.6 Mean vegetation structural characteristics following treatments in three tall fescue fields, Tennessee, June – September 2005.

	Treatment																										
	Control			Fall imazapic			Fall glyphosate			Fall imazapic winter disk			Fall glyphosate winter disk			Spring imazapic			Spring glyphosate			Spring imazapic fall disk			Spring glyphosate fall disk		
Variable[1]	$\bar{x}$ [2]	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)	
Early growing season																											
GSD	0.05	(0.01)	c	0.36	(0.07)	bc	0.68	(0.28)	ab	0.47	(0.05)	abc	0.48	(0.08)	abc	0.31	(0.07)	bc	0.39	(0.07)	bc	0.76	(0.06)	ab	0.87	(0.06)	a
AO	28.56	(2.24)	b	49.67	(4.24)	a	55.52	(5.77)	a	55.19	(1.60)	a	54.88	(1.55)	a	37.97	(3.93)	ab	40.82	(3.07)	ab	41.85	(3.50)	ab	43.71	(9.02)	ab
VOD	0.06	(0.02)	b	0.31	(0.03)	b	0.43	(0.08)	ab	0.47	(0.06)	ab	0.58	(0.12)	ab	0.34	(0.09)	b	0.48	(0.10)	ab	0.69	(0.09)	ab	2.62	(2.02)	a
VOR	5.46	(0.60)	b	8.89	(0.78)	ab	10.73	(1.61)	a	11.01	(0.41)	a	10.98	(1.03)	a	9.03	(0.57)	ab	7.29	(0.56)	ab	6.71	(0.82)	b	6.53	(0.38)	b
Cover	96.60	(0.91)	a	88.26	(1.76)	b	84.24	(2.00)	bc	81.46	(3.33)	bc	76.56	(2.22)	bc	88.31	(3.27)	b	81.08	(3.69)	bc	77.66	(3.26)	c	83.28	(2.84)	c
Bare	0.10	(0.10)	d	6.94	(1.89)	c	10.21	(2.30)	bc	14.31	(3.17)	abc	18.13	(3.29)	ab	7.64	(2.39)	c	11.15	(3.55)	bc	21.48	(3.03)	a	16.72	(2.84)	ab
Litter	2.73	(0.68)	a	4.73	(1.16)	a	5.01	(0.88)	a	3.26	(0.59)	a	5.69	(2.20)	a	4.20	(1.48)	a	7.71	(1.38)	a	0.07	(0.07)	b	0.00	(0.00)	b
Ldepth	4.23	(0.56)	a	1.17	(0.71)	b	1.54	(0.93)	b	0.59	(0.50)	b	0.90	(0.61)	b	0.56	(0.19)	b	0.62	(0.12)	b	0.08	(0.08)	b	0.00	(0.00)	b
Forbs	9.79	(1.46)	e	47.85	(5.30)	dc	79.41	(4.92)	ab	70.24	(4.89)	abc	86.94	(3.85)	a	36.77	(8.48)	d	48.47	(7.02)	dc	57.08	(8.49)	bcd	75.42	(9.26)	ab
Brambles	1.04	(0.82)	a	1.11	(0.51)	a	4.13	(2.20)	a	0.87	(0.41)	a	4.34	(2.73)	a	0.49	(0.25)	a	0.21	(0.09)	a	0.10	(0.10)	a	0.83	(0.32)	a
Sedges	1.60	(0.75)	a	1.42	(0.63)	a	1.46	(0.54)	a	0.83	(0.32)	a	2.60	(1.20)	a	0.45	(0.25)	a	0.56	(0.24)	a	0.10	(0.10)	a	0.63	(0.40)	a
Woody	3.40	(1.31)	a	2.47	(1.13)	a	4.44	(2.22)	a	1.63	(0.82)	a	1.25	(0.50)	a	2.92	(1.53)	a	0.66	(0.41)	a	0.42	(0.31)	a	0.36	(0.36)	a
CS grass	97.57	(0.93)	a	41.22	(9.53)	bc	8.40	(2.51)	d	26.88	(7.86)	cd	5.17	(1.24)	d	59.17	(11.28)	b	51.67	(7.74)	bc	56.51	(8.08)	b	32.76	(8.23)	bc
WS grass	4.03	(1.17)	a	26.84	(9.46)	a	18.82	(6.06)	a	21.32	(7.40)	a	11.35	(2.58)	a	20.45	(7.86)	a	18.92	(4.64)	a	7.55	(3.23)	a	7.55	(3.84)	a
Late growing season																											
GSD	0.06	(0.02)	d	0.29	(0.07)	cd	0.48	(0.05)	abc	0.51	(0.04)	abc	0.59	(0.06)	ab	0.38	(0.07)	bc	0.42	(0.07)	bc	0.54	(0.11)	abc	0.70	(0.05)	a
AO	21.18	(1.58)	c	40.74	(4.27)	ab	43.05	(3.89)	ab	50.14	(2.94)	ab	50.66	(5.12)	ab	35.25	(2.81)	bc	37.41	(4.19)	bc	51.15	(6.45)	ab	55.56	(6.97)	a
VOD	0.08	(0.02)	b	0.34	(0.08)	a	0.51	(0.05)	a	0.35	(0.05)	a	0.44	(0.08)	a	0.46	(0.07)	a	0.43	(0.07)	a	0.35	(0.07)	a	0.36	(0.08)	a
VOR	3.91	(0.32)	b	7.64	(0.70)	ab	8.55	(1.11)	a	9.66	(0.74)	a	10.75	(1.35)	a	7.41	(0.79)	ab	7.14	(0.99)	ab	8.58	(0.96)	a	8.87	(1.45)	a
Cover	91.91	(2.67)	a	86.99	(1.95)	ab	82.93	(1.43)	ab	80.63	(3.09)	ab	78.54	(2.40)	b	87.92	(3.72)	ab	84.18	(2.91)	ab	86.24	(3.99)	ab	89.06	(2.27)	ab
Bare	0.07	(0.05)	d	6.88	(1.41)	bc	12.42	(1.54)	ab	15.12	(3.33)	ab	18.65	(2.56)	a	4.03	(1.08)	c	8.95	(1.96)	abc	13.81	(4.01)	ab	10.94	(2.27)	abc
Litter	5.31	(1.79)	a	6.13	(1.24)	a	5.63	(1.72)	a	3.63	(1.05)	ab	2.85	(1.37)	ab	8.06	(3.30)	a	6.68	(2.42)	a	0.00	(0.00)	b	0.00	(0.00)	b

Table 1.6 (continued).

	Treatment																										
	Control			Fall imazapic			Fall glyphosate			Fall imazapic winter disk			Fall glyphosate winter disk			Spring imazapic			Spring glyphosate			Spring imazapic fall disk			Spring glyphosate fall disk		
Variable	$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)	
Ldepth	4.73	(0.76)	a	1.18	(0.44)	bc	0.97	(0.36)	bc	0.40	(0.13)	bcd	0.32	(0.21)	cd	1.25	(0.31)	bc	1.25	(0.29)	b	0.06	(0.05)	d	0.00	(0.00)	d
Forbs	16.35	(3.21)	d	44.61	(9.17)	bc	67.54	(6.77)	ab	65.39	(6.71)	ab	74.93	(5.03)	a	36.18	(8.14)	cd	46.64	(6.67)	bc	63.88	(6.99)	ab	84.27	(7.37)	a
Brambles	0.45	(0.23)	a	1.91	(0.74)	a	5.39	(2.06)	a	2.54	(1.56)	a	4.79	(2.18)	a	1.32	(0.60)	a	2.07	(1.52)	a	0.50	(0.36)	a	1.82	(1.59)	a
Sedges	0.94	(0.33)	ab	0.16	(0.10)	b	2.73	(1.06)	a	0.23	(0.16)	b	1.04	(0.55)	ab	0.66	(0.44)	ab	0.78	(0.49)	ab	0.13	(0.13)	b	0.47	(0.36)	ab
Woody	1.56	(0.52)	abc	2.19	(0.69)	ab	1.99	(0.83)	ab	2.81	(1.09)	a	0.52	(0.27)	abc	0.52	(0.34)	abc	1.21	(0.63)	abc	0.06	(0.06)	bc	0.00	(0.00)	c
CS grass	92.12	(3.16)	a	33.52	(10.43)	bc	8.67	(3.47)	cd	26.96	(6.51)	bcd	2.88	(0.82)	d	55.90	(8.61)	b	41.99	(6.88)	b	48.06	(9.50)	b	23.75	(6.27)	bcd
WS grass	6.28	(1.40)	c	40.12	(12.13)	a	37.97	(6.93)	ab	27.77	(7.81)	ab	37.95	(6.41)	ab	24.44	(7.06)	abc	37.30	(7.19)	ab	24.25	(13.84)	abc	14.69	(7.23)	bc

[1] GSD = ground sighting distance (m), AO = angle of obstruction (0-90°), VOD = visual obstruction distance, VOR = visual obstruction reading or vertical structure, Cover = total vegetative cover (%), Bare = bareground (%), Litter = litter (%), Ldepth = litter depth (cm), Forbs = forb cover (%), Brambles = *Rubus* spp. Cover (%), Sedges = sedge cover (%), Woody = woody cover (%), CSgrass = cool-season grass cover (%), WSgrass = warm-season grass cover (%).

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

Late growing season

Treatment differences were detected late in the second growing season post-treatment (August – September) for 13 of 14 variables (Table 1.6). Treatment differences were also detected for average vegetation height (Table 1.7). Ground sighting distance was increased by all treatments except fall imazapic. Angle of obstruction was similar between spring herbicide treatments and control. Fall herbicide, fall herbicide winter disk, and spring herbicide fall disk treatments had greater angle of obstruction than control. Visual obstruction distance was increased by all treatments. Vertical structure was increased by fall glyphosate, fall herbicide winter disk, and spring herbicide fall disk treatments. Total vegetation cover was decreased by fall glyphosate winter disk. Litter depth was increased while bare ground decreased across all treatments. Forb cover was greater than control in all treatments except spring imazapic. Warm-season grass cover was greater in fall herbicide, fall herbicide winter disk, and spring glyphosate treatments than control. Cool-season grass cover was decreased by all treatments. Vegetation height was greater in fall glyphosate winter disk, and spring herbicide fall disk treatments than control.

Vegetation composition

Two growing seasons post-treatment 127 plant species were recorded along line transects. Plant species composition differed among treatments two growing seasons post-treatment (August) for 9 of 9 variables (Table 1.7). Orchardgrass cover was greater in fall imazapic, fall imazapic winter disk, and spring imazapic treatments than in fall glyphosate and fall glyphosate winter disk treatments. Cover of bobwhite food plants was increased by fall glyphosate, fall glyphosate winter disk, and spring herbicide fall disk treatments. Cover of desirable native grasses was greater in fall imazapic treatments than spring glyphosate fall disk and control. Fall imazapic winter disk and spring glyphosate fall disk increased cover of undesirable grass. Fall herbicide and fall herbicide winter disk treatments increased undesirable forb cover. Species richness increased in fall glyphosate, fall glyphosate winter disk, and fall imazapic winter disk treatments (Table 1.7).

At the HUBR site, treatment differences were detected for orchardgrass cover during winter, spring, and summer 2005 (Table 1.8). During winter and spring orchardgrass cover was less following fall glyphosate with and without disking than fall and spring imazapic. During summer 2005, orchardgrass cover was greater following fall imazapic with and without disking than in fall glyphosate with and without disking and control. Although tall fescue cover was less than control in fall imazapic plots (Table 1.9), ground sighting distance in plots with increased orchardgrass cover was similar to control (Table 1.10), during summer 2005.

Invertebrate abundance and biomass

No treatment differences were detected during June of the second growing season post-treatment for invertebrate abundance (Table 1.11). Treatment differences were detected during August of the second growing season post-treatment for total density of all invertebrate orders. While a treatment effect was detected for total density, Tukey's HSD failed to produce a mean separation among treatments (Table 1.11).

Table 1.7 Mean tall fescue cover, vegetation composition characteristics, plant species richness, and vegetation height measured along 10-m line transects in three tall fescue fields, Tennessee, August 2005.

	Treatment								
	Control	Fall imazapic	Fall glyphosate	Fall imazapic winter disk	Fall glyphosate winter disk	Spring imazapic	Spring glyphosate	Spring imazapic fall disk	Spring glyphosate fall disk
Variable[1]	$\bar{x}$[2] (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)
Tall fescue	9.48 (0.24) a	1.14 (0.58) c	0.17 (0.07) c	1.00 (0.34) c	0.20 (0.10) c	4.02 (1.15) b	4.21 (0.69) b	3.19 (1.05) b	2.83 (0.78) b
Desirable nwsg	0.78 (0.35) b	4.01 (1.16) a	2.52 (0.82) ab	2.36 (0.81) ab	1.13 (0.39) ab	2.99 (1.12) ab	2.74 (0.82) ab	0.52 (0.20) ab	0.83 (0.41) b
Bobwhite food plants	0.43 (0.17) d	1.19 (0.22) cd	2.83 (0.53) bc	2.18 (0.51) bcd	2.80 (0.78) bc	1.77 (0.44) cd	1.39 (0.44) cd	4.96 (0.87) ab	7.03 (1.39) a
Undesirable grasses	0.23 (0.06) b	0.66 (0.24) b	1.49 (0.46) ab	2.44 (0.67) a	1.71 (0.46) ab	0.39 (0.12) b	1.34 (0.35) ab	1.04 (0.39) ab	2.96 (1.03) a
Undesirable forbs	0.12 (0.07) c	2.33 (0.81) ab	4.44 (1.34) a	2.27 (0.75) ab	4.48 (1.26) a	1.18 (0.35) abc	1.21 (0.39) abc	1.74 (0.55) abc	0.83 (0.22) bc
Bare	0.00 (0.00) d	0.27 (0.11) abc	0.60 (0.15) a	0.37 (0.13) abc	0.39 (0.06) ab	0.08 (0.04) cd	0.08 (0.02) cd	0.27 (0.10) abc	0.12 (0.03) bcd
Litter	0.08 (0.05) ab	0.11 (0.04) ab	1.33 (0.75) a	0.21 (0.06) ab	0.37 (0.10) ab	0.15 (0.05) ab	0.18 (0.07) ab	0.00 (0.00) b	0.02 (0.01) b
Species richness	12.56 (1.11) b	19.11 (1.70) ab	22.44 (2.32) a	22.44 (1.60) a	24.33 (1.92) a	17.00 (1.73) ab	20.00 (2.01) ab	19.50 (1.06) ab	17.83 (1.82) ab
Vegetation height	0.35 (0.04) ab	0.55 (0.11) ab	0.57 (0.08) ab	0.62 (0.06) ab	0.80 (0.14) a	0.62 (0.09) ab	0.59 (0.07) ab	0.72 (0.14) ab	0.79 (0.19) a

[1] Tall fescue = tall fescue (*Festuca arundinacea*) cover (m), Desirable nwsg = desirable native warm-season grass cover (m), Bobwhite food plants = cover (m) of plants producing seed eaten by bobwhites, Undesirable grasses = undesirable grass cover (m), Bare = bareground (m), Litter = litter (m), Species richness = number of species recorded per plot, Vegetation height = average vegetation height (m).

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$)

Table 1.8 Mean orchardgrass cover along 10-m line transects following treatments in a tall fescue field, Spring City, Tennessee, 2004 – 2005.

	Orchardgrass cover				
	Summer 2004	Fall 2004	Winter 2005	Spring 2005	Summer 2005
Treatment	$\bar{x}$[1] (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)
Control	3.06 (1.82) a	3.75 (1.70) a	2.85 (1.63) ab	2.98 (2.00) ab	1.81 (0.82) cd
Fall imazapic	3.41 (1.34) a	4.79 (1.76) a	4.44 (1.21) a	5.64 (1.42) a	6.10 (1.40) a
Fall glyphosate	0.08 (0.04) a	0.25 (0.06) a	0.15 (0.06) b	0.25 (0.01) b	0.13 (0.02) d
Fall imazapic spring disk	0.70 (0.54) a	2.89 (0.67) a	3.12 (0.09) ab	4.56 (0.53) ab	4.99 (0.40) ab
Fall glyphosate spring disk	0.31 (0.31) a	0.09 (0.06) a	0.00 (0.00) b	0.05 (0.03) b	0.03 (0.03) d
Spring imazapic	4.17 (0.28) a	4.89 (0.65) a	5.56 (0.48) a	5.90 (0.50) a	4.25 (0.72) abc
Spring glyphosate	1.89 (0.99) a	3.44 (1.67) a	2.47 (0.81) ab	2.53 (1.01) ab	2.78 (0.81) bcd
Spring imazapic fall disk					1.52 (0.46) cd
Spring glyphosate fall disk					1.03 (0.45) cd

[1] Means within columns followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

Table 1.9 Mean orchardgrass cover, tall fescue cover, vegetation composition characteristics, plant species richness, and vegetation height measured along 10-m line transects in three tall fescue fields, Tennessee, August 2005.

	Treatment								
	Control	Fall imazapic	Fall glyphosate	Fall imazapic winter disk	Fall glyphosate winter disk	Spring imazapic	Spring glyphosate	Spring imazapic fall disk	Spring glyphosate fall disk
Variable[1]	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)
Orchardgrass	1.81 (0.82) cd	6.10 (1.40) a	0.13 (0.02) d	4.99 (0.40) ab	0.03 (0.03) d	4.25 (0.72) abc	2.78 (0.81) bcd	1.52 (0.46) cd	1.03 (0.45) cd
Tall fescue	8.90 (0.55) a	0.09 (0.02) c	0.02 (0.02) c	0.62 (0.13) bc	0.00 (0.00) c	1.30 (0.72) bc	2.54 (0.62) b	1.11 (0.15) bc	1.78 (0.65) bc
Desirable nwsg	0.73 (0.42) a	1.34 (0.42) a	1.15 (0.62) a	2.21 (0.11) a	0.91 (0.58) a	0.33 (0.04) a	0.98 (0.62) a	0.97 (0.08) a	1.63 (0.44) a
Bobwhite food plants	0.39 (0.13) b	1.96 (0.17) ab	3.04 (0.57) ab	2.18 (0.48) ab	4.14 (1.18) a	3.21 (0.75) ab	0.93 (0.42) ab	3.77 (1.22) ab	4.65 (1.92) a
Undesirable grasses	0.35 (0.11) b	0.83 (0.06) b	1.54 (0.67) ab	1.06 (0.40) b	1.98 (1.11) ab	0.78 (0.16) b	1.83 (0.98) ab	5.11 (0.79) a	1.77 (0.40) ab
Undesirable forbs	0.08 (0.04) b	2.84 (1.75) ab	4.14 (1.20) a	1.95 (0.25) ab	2.55 (0.70) ab	1.89 (0.66) ab	1.70 (1.04) ab	1.20 (0.75) ab	1.00 (0.34) ab
Bare	0.00 (0.00) c	0.19 (0.08) bc	0.99 (0.21) a	0.26 (0.09) bc	0.42 (0.21) ab	0.03 (0.03) bc	0.06 (0.05) bc	0.14 (0.09) bc	0.08 (0.00) bc
Litter	0.22 (0.10) b	0.18 (0.12) b	3.70 (1.59) a	0.05 (0.01) b	0.09 (0.04) b	0.29 (0.06) b	0.33 (0.17) b	0.00 (0.00) b	0.03 (0.02) b
Species richness	12.67 (1.33) c	22.00 (1.73) abc	24.00 (0.58) ab	24.67 (0.88) ab	27.67 (3.71) a	20.67 (2.60) abc	17.33 (1.20) bc	19.00 (1.53) abc	20.33 (2.85) abc
Height	0.18 (0.02) a	0.37 (0.11) a	0.66 (0.17) a	0.46 (0.10) a	0.54 (0.22) a	0.54 (0.08) a	0.38 (0.03) a	0.50 (0.14) a	0.39 (0.13) a

[1] Orchardgrass = orchardgrass (Dactylis glomerata) cover (m), Tall fescue = tall fescue (*Festuca arundinacea*) cover (m), Desirable nwsg = desirable native warm-season grass cover (m), Bobwhite food plants = cover (m) of plants producing seed eaten by bobwhites, Undesirable grasses = undesirable grass cover (m), Bare = bareground (m), Litter = litter (m), Species richness = number of species recorded per plot, Vegetation height = average vegetation height (m).

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

Table 1.10 Mean vegetation structural characteristics following treatments in a tall fescue field, Spring City, Tennessee, August – September 2005.

	Treatment								
	Control	Fall imazapic	Fall glyphosate	Fall imazapic winter disk	Fall glyphosate winter disk	Spring imazapic	Spring glyphosate	Spring imazapic fall disk	Spring glyphosate fall disk
Variable[1]	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)
GSD	0.11 (0.05) c	0.20 (0.07) bc	0.54 (0.08) a	0.43 (0.04) ab	0.70 (0.08) a	0.47 (0.07) ab	0.56 (0.07) a	0.43 (0.07) ab	0.60 (0.09) a
AO	16.47 (2.00) c	40.33 (2.70) ab	49.08 (3.65) a	43.85 (5.03) ab	44.54 (4.62) ab	32.38 (2.52) abc	29.85 (2.70) bc	40.72 (3.86) ab	47.92 (6.62) ab
VOD	0.10 (0.05) c	0.22 (0.07) bc	0.48 (0.08) ab	0.28 (0.04) abc	0.46 (0.08) ab	0.52 (0.06) a	0.58 (0.07) a	0.38 (0.07) ab	0.46 (0.09) ab
VOR	3.01 (0.35) d	8.54 (0.77) abc	11.02 (1.00) a	8.48 (0.98) abc	9.71 (1.15) ab	6.58 (0.98) bc	4.98 (0.40) c	6.59 (0.66) abc	7.41 (1.08) abc
Cover	88.13 (2.37) ab	83.33 (1.76) bc	82.71 (2.27) bc	84.58 (2.08) abc	82.60 (1.51) bc	75.52 (3.66) c	77.81 (2.21) c	88.72 (2.63) ab	91.98 (1.61) a
Bare	0.10 (0.10) c	6.88 (1.60) abc	9.27 (1.63) ab	13.75 (1.96) a	12.81 (2.25) a	4.90 (1.34) bc	8.54 (2.20) ab	11.41 (2.64) ab	8.02 (1.61) ab
Litter	11.96 (2.34) abc	9.79 (1.19) bcd	8.02 (2.82) bcd	1.67 (0.71) cd	4.58 (2.09) bcd	19.58 (4.54) a	13.65 (2.39) ab	0.00 (0.00) d	0.00 (0.00) d
Litter depth	6.56 (1.80) a	2.31 (0.62) b	1.50 (0.54) bcd	0.15 (0.08) cd	0.69 (0.32) bcd	1.98 (0.54) bc	1.65 (0.38) bcd	0.00 (0.00) d	0.00 (0.00) d
Forb	26.77 (3.47) d	64.58 (5.87) abc	78.44 (3.46) ab	77.40 (4.29) ab	86.77 (3.67) a	60.52 (4.01) bc	52.81 (7.47) c	55.78 (7.19) bc	71.98 (5.45) abc
Brambles	0.21 (0.21) a	2.08 (1.40) a	6.56 (2.72) a	6.46 (4.35) a	9.79 (5.16) a	3.33 (1.75) a	1.46 (1.25) a	0.00 (0.00) a	3.65 (3.20) a
Woody	1.15 (0.86) a	0.00 (0.00) a	0.63 (0.45) a	2.60 (2.60) a	0.21 (0.21) a	0.00 (0.00) a	0.73 (0.54) a	0.00 (0.00) a	0.00 (0.00) a
CSgrass	92.92 (1.52) a	45.94 (7.61) b	2.81 (0.92) c	31.27 (2.96) b	1.67 (0.82) c	46.46 (4.72) b	46.15 (7.03) b	33.44 (5.93) b	31.35 (4.58) b
WSgrass	6.67 (2.10) d	14.06 (2.79) bcd	25.63 (4.89) bc	8.85 (2.74) cd	22.60 (3.87) bcd	12.08 (2.18) bcd	16.67 (4.21) bcd	57.19 (7.45) a	27.50 (5.20) b

[1] GSD = ground sighting distance (m), AO = angle of obstruction (0-90°), VOD = visual obstruction distance, VOR = visual obstruction reading or vertical structure, Cover = total vegetative cover (%), Bare = bareground (%), Litter = litter (%), Ldepth = litter depth (cm), Forbs = forb cover (%), Brambles = *Rubus* spp. Cover (%), Sedges = sedge cover (%), Woody = woody cover (%), CSgrass = cool-season grass cover (%), WSgrass = warm-season grass cover (%).

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

Table 1.11 Mean density, biomass, and order richness of invertebrates following treatments in three tall fescue fields, Tennessee, June – August 2005.

	Treatment								
	Control	Fall imazapic	Fall glyphosate	Fall imazapic winter disk	Fall glyphosate winter disk	Spring imazapic	Spring glyphosate	Spring imazapic fall	Spring glyphosate fall disk
Variable[1]	$\bar{x}$[2] (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)
Early growing season									
Total biomass	0.08 (0.01) a	0.05 (0.01) a	0.16 (0.09) a	0.07 (0.01) a	0.07 (0.02) a	0.08 (0.02) a	0.08 (0.01) a	0.11 (0.05) a	0.07 (0.03) a
Biomass preferred	0.06 (0.01) a	0.03 (0.01) a	0.14 (0.09) a	0.06 (0.01) a	0.06 (0.01) a	0.05 (0.02) a	0.05 (0.01) a	0.08 (0.04) a	0.06 (0.02) a
Total density	20.22 (5.16) a	15.89 (5.54) a	10.89 (1.88) a	12.13 (3.60) a	16.00 (5.52) a	23.33 (8.23) a	13.56 (2.56) a	16.75 (2.72) a	19.00 (7.14) a
Density preferred	12.89 (3.27) a	8.67 (3.24) a	7.78 (1.02) a	7.88 (2.23) a	11.11 (3.65) a	14.00 (4.73) a	8.78 (1.72) a	12.63 (2.38) a	11.56 (3.95) a
Order richness	2.47 (0.42) a	2.11 (0.58) a	1.72 (0.26) a	2.03 (0.57) a	2.28 (0.63) a	2.47 (0.64) a	2.22 (0.37) a	2.50 (0.38) a	2.19 (0.52) a
Late growing season									
Total biomass	0.40 (0.12) a	0.30 (0.07) a	0.15 (0.02) a	0.28 (0.07) a	0.35 (0.18) a	0.37 (0.05) a	0.40 (0.09) a	0.23 (0.06) a	0.24 (0.12) a
Biomass preferred	0.35 (0.10) a	0.28 (0.07) a	0.12 (0.02) a	0.26 (0.08) a	0.32 (0.17) a	0.34 (0.05) a	0.35 (0.09) a	0.16 (0.07) a	0.14 (0.10) a
Total density	25.57 (3.18) a	20.20 (2.78) a	15.86 (2.26) a	21.00 (4.04) a	25.33 (3.94) a	30.57 (4.72) a	19.71 (2.66) a	29.80 (5.51) a	35.72 (11.17) a
Density preferred	15.43 (3.04) a	11.20 (1.46) a	9.57 (2.64) a	14.67 (2.91) a	17.17 (3.44) a	17.86 (3.36) a	10.14 (1.61) a	14.00 (3.65) a	9.50 (1.12) a
Order richness	2.32 (0.28) a	2.60 (0.17) a	2.25 (0.17) a	2.25 (0.25) a	3.25 (0.20) a	3.39 (0.29) a	2.64 (0.37) a	3.10 (0.29) a	3.04 (0.20) a

[1] Total biomass = biomass (g /m^2) of all invertebrates detected, Biomass preferred = biomass (g /m^2) of invertebrates in orders preferred by foraging bobwhite chicks, Total density = density (invertebrates/m^2) of all invertebrates detected, Density preferred = density (invertebrates/m^2) of invertebrates in orders preferred by foraging bobwhite chicks, Order richness = number of invertebrate orders represented per sample.

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

DISCUSSION

Tall fescue eradication

Residual tall fescue cover two growing seasons following fall glyphosate application (< 3 %) was similar to results from similar treatments in Tennessee (Fribourg et al. 1998), Georgia (Hoveland et al. 1986, Smith 1989), Kentucky (Washburn and Barnes 2000), Kansas (Moyer and Kelly 1989), and Nebraska (Vogel and Waller 1990). Residual tall fescue one and two growing seasons following spring glyphosate application (19 and 42% respectively) is comparable to results reported by Madison et al. (2001; 10 and 32% respectively) and Washburn et al. (2000; 17 % one growing season post treatment). Defelice and Henning (1990) found spring glyphosate applications were more effective than fall glyphosate applications in eliminating tall fescue coverage in Missouri; however, the authors noted fall herbicide applications may be more effective in the South due to a longer growing season and greater annual precipitation. Although research conducted in Mississippi found lower residual tall fescue coverage (5%) one growing season following spring glyphosate application, controls had much less tall fescue coverage (44%; Greenfield et al. 2001) than controls in this study (> 93%). Conflicting results were found in Kentucky, where spring applications of glyphosate, imazapic, and tank mixes containing both imazapic and glyphosate were successful in reducing residual tall fescue to less than 10% one growing season following treatment (Washburn and Barnes 2000, Washburn et al. 2000). In one study, tall fescue cover was reduced from more than 88% to less than 14% one growing season following treatment by applying imazapic alone and imazapic/glyphosate tank mixes during the spring vegetative, boot, summer dormancy, and fall vegetative growth stages (Washburn and Barnes 2000). Washburn et al. (2000) reported glyphosate applied during the summer dormancy stage followed by imazapic applied in the fall vegetative stage was not as effective as imazapic applied in the spring vegetative stage, then again in the summer dormancy stage.

In this study, a single fall application of either glyphosate or imazapic reduced tall fescue cover to less than 10% two growing seasons following treatment. No difference was detected in residual tall fescue cover between fall applications of glyphosate and imazapic; however, imazapic does not control other undesirable non-native cool-season grasses, such as orchardgrass, timothy, or bluegrass. Fall applications of glyphosate provided the best orchardgrass control. Furthermore, glyphosate is less expensive and more widely available than imazapic.

Disking following fall herbicide applications did not reduce tall fescue cover more than fall herbicide applications alone. Disking following spring herbicide applications resulted in greater reduction of tall fescue coverage; however, this is likely because plots were only measured one growing season following fall disking. Other studies found an initial reduction in tall fescue coverage one growing season following disking, but no difference from control by the second growing season (Madison et al. 2001, Greenfield et al. 2002).

Bobwhite habitat response

Nesting

Bobwhite populations in the mid-South are often limited by the availability of quality nesting and brood-rearing habitat (Dimmick et al. 2002). Bobwhites appeared to be limited by the presence of nesting and brooding cover in fields in the Virginia Piedmont, while the amount of winter feeding habitat was a poor predictor of actual bobwhite abundance (Tonkovich 1995). Puckett et al. (1995) concluded a lack of early succession nesting cover associated with modern agricultural practices likely limited recruitment of bobwhite populations in North Carolina. In an agricultural area in west Tennessee, Exum et al. (1982) noted a decrease in bobwhite populations as acreage devoted to soybean production increased and idle lands decreased. Because soybeans were identified as an important source of food for bobwhites in that area (Eubanks and Dimmick 1974), the decline in bobwhite populations was attributed to loss of escape and nesting cover once provided by idle areas (Exum et al. 1982).

Micro-habitat characteristics around bobwhite nests have been described in the mid-South (Lee 1994, Taylor and Burger 2000, Harris 1995, Smith 2001, Szukaitis 2001) and throughout the bobwhite range (Burger et al. 1995, Taylor et al. 1999, Lusk et al. 2006). While bobwhite nest site selection likely takes place at multiple spatial scales (Taylor et al. 1999), this discussion is limited to micro-habitat characteristics in habitats similar to those found in Tennessee and the mid-South.

Taylor and Burger (2000) described vegetation at bobwhite nest sites in old-fields in northeast Mississippi as 36% grass cover, 33% forb cover, and 26% woody cover with 24% bare ground. Tall fescue control areas in this study did not provide habitat for nesting because they contained too much grass cover and too little forb cover and bare ground. Additionally, tall fescue controls contained little desirable warm-season grass, such as broomsedge bluestem, a commonly used nesting substrate for bobwhites in Tennessee (Dimmick 1972).

It is unlikely any treatment produced adequate bobwhite nesting habitat one growing season following treatment, as bobwhites generally nest in areas with residual dead grass from the previous growing season (Stoddard 1931, Rosene 1969, Dimmick 1972). In the second growing season following treatment application, fall imazapic applications resulted in the greatest increase in desirable warm-season grass cover. Fall imazapic, fall glyphosate, fall imazapic winter disk, spring imazapic and spring glyphosate treatments provided nwsg cover (2 – 4 m) similar to grass cover in areas used by nesting bobwhites (20 – 50%; Taylor and Burger 2000, Smith 2001, Szukaitis 2001). Bobwhites avoid nesting in areas with dense grass cover (Dimmick 1972, Roseberry and Klimstra 1984), but often use areas with sparse coverage of native grasses, such as broomsedge bluestem (Dimmick 1972, Roseberry and Klimstra 1984, Harris 1995). Fall imazapic, spring imazapic, and spring glyphosate treatments provided forb cover similar to the 33% used by nesting bobwhites in Mississippi (Taylor and Burger 2000). Fall glyphosate, fall herbicide spring disk, and spring herbicide fall disk treatments produced forb cover greater than that used by nesting bobwhites. No treatment contained woody vegetation cover more than 5%. While cover of woody plants showed statistically significant increases, it is unlikely that increases of less than 5 % are biologically significant. Although woody cover was much less than the 20 – 25% recommended by Taylor and Burger (2000), desirable brushy cover, such as blackberries and sumac, were present in treated plots and would likely increase over time as plant succession progresses. Treatment differences were detected in visual obstruction distance across all sampling periods, but no treatment resulted in visual obstruction distance above the range at which Cram et al. (2002) observed a decline in bobwhite population as a result of a lack of cover (> 75 m^2 cone of vulnerability or > 4.9 m visual obstruction distance). Only disked treatments produced bare ground similar to the amounts described by Taylor and Burger (2000); however, bare ground two years after fall glyphosate application (12%) was comparable to that reported at bobwhite nest sites in Mississippi (16%; Smith 2001). Methods for estimating bare ground often differ across studies and may be deceiving.

Undesirable forbs and grasses increased one and two growing seasons following fall glyphosate applications. Imazapic or other selective herbicides may be applied in the spring following fall glyphosate application to control problem plants and increase desirable grass cover. Spring burning (April) may also help control undesirable weeds and stimulate desirable plants in the seedbank. Applications of imazapic alone in the fall are not recommended if orchardgrass, timothy, bluegrass are present.

Brood-rearing

Specific habitat-use patterns of juvenile bobwhites in the South have been difficult to explain (DeVos and Muller 1993, Yates et al. 1995, Taylor and Burger 2000, Puckett et al. 2000); however, it is well documented that invertebrates are important to bobwhite chicks (Handley and Cottam 1931, Nestler 1942, Rosene 1969, Hurst 1972). Arthropods compose > 80% of bobwhite chick diets during the first 2 weeks after hatching (Handley 1931, Nestler 1942). Vegetation structure at the ground level is critical to bobwhite broods (Stoddard 1931, Rosene 1969). Bobwhite chicks may become entangled in dense vegetation and exhaust themselves (Hurst 1972). In addition to open structure at ground level, bobwhites require vegetation with dense overhead cover to provide protection from predators as well as shade to escape high daytime temperatures in the summer (Hiller and Guthery 2005). Tall fescue control areas and imazapic treated plots dominated by orchardgrass did not provide desirable habitat for bobwhite broods because they contained dense vegetation at the ground level. Tall fescue control plots provided little vertical structure and overhead cover.

During the first growing season following treatment, fall herbicide winter disk and fall glyphosate treatments improved bobwhite brood-rearing habitat. Fall herbicide winter disk treatments were more open at ground level (ground sighting distance) and provided greater overhead canopy (angle of obstruction) and vertical cover (vertical structure) for bobwhite broods. Fall glyphosate and fall herbicide winter disk treatments increased forb cover. While bare ground increased one growing season following fall herbicide winter disking treatments, no treatment produced bare ground amounts as great as those (18 – 31%) used by bobwhite broods recorded in the South (Puckett et al. 2000, Taylor and Burger 2000, Carver et al. 2001).

It is important to note, methods for visually estimating percent vegetation cover, bare ground, and litter are rarely consistent across studies. In this study, bare ground was estimated by a standing observer looking directly down on the vegetation canopy. This study uses measured variables to account for vegetation structure at ground level (ground sighting distance) and overhead cover (angle of obstruction). Measuring ground level structure and overhead cover separately may better characterize “umbrella cover,” often recommended for brood cover. For instance, the structure underneath a group of ragweed plants would have a longer ground sighting distance and a greater angle of obstruction than the structure in a sward of sod forming perennial grass.

Abundant, diverse invertebrate communities are often associated with diverse plant communities (Southwood et al. 1979, Shelton and Edwards 1983). During the first growing season following treatment (2004), increased invertebrate richness during the early growing season following fall glyphosate treatments may have resulted from increased plant species richness. During the late growing season, disked treatments contained the lowest amount of invertebrates. These results contradict previous studies where invertebrates were collected using sweep nets (Yates et al. 1995, Madison et al. 1995) or vacuum sampling methods different than this study (Lee 1994, Manley et al. 1994). Disking decreased litter and litter depth and likely negatively affected invertebrate communities associated with the litter layer. Although phytophagous insects are often cited as the most important arthropod food resource for bobwhite chicks (Handley and Cottam 1931, Hurst 1972, Eubanks and Dimmick 1974, Jackson et al. 1987), Palmer (1995) found increased foraging rate of chicks in no-till soybean fields was related to the presence of crop residue rather than vegetation cover.

Disking increased vegetation canopy height and vertical structure. The sampling method used in this study targeted invertebrates near ground level that were available to foraging chicks. Although the efficacy of invertebrate sampling techniques varies greatly with relation to vegetation structure (Harper and Guynn 1998, Palmer et al. 2001, Randel et al. 2006), sampling invertebrates important to bobwhite chicks with a sweep net is not recommended because invertebrates on the ground are missed completely (Whittaker 1952). Increases in the abundance of foliage-dwelling invertebrates (as determined by sweep net sampling) following disking may not be representative of what is available to bobwhite chicks depending on vegetation height and density. Invertebrates in the vegetation canopy above 0.25 m (20 in) were not sampled in this study as they were considered unavailable to foraging chicks.

Palmer (1995) determined bobwhite chicks 2 – 5 and 7 – 10 days old required 3 – 4 and 5 – 6 g (0.10 – 0.15 and 0.17 – 0.21 oz; dry matter) of invertebrates per day respectively. Based on this information, the lowest density of preferred invertebrates detected in any treatment (0.06 g/m^2; 0.002 oz/yd^2) would contain enough invertebrates to meet the daily requirements of a bobwhite brood consisting of 10 chicks in approximately 0.1 ha (0.25 ac), a small fraction of reported daily brood ranges (DeVos and Muller 1993, Puckett et al. 2000). Certainly, chicks would not be able to forage with 100% efficiency; however, invertebrate abundance should have been adequate for bobwhite broods within any treatment. Although abundance of invertebrate orders preferred by bobwhite chicks was lower in disking treatments than tall fescue control areas, disking increased openness at ground level and likely resulted in increased availability of invertebrates.

During the second growing season following treatment (2005), spring herbicide fall disk and fall glyphosate with and without disking improved bobwhite brood-rearing habitat most. Spring herbicide fall disk plots improved bobwhite brood-rearing habitat by increasing openness at ground level, over head cover, and vertical structure; however, these improvements were measured only one growing season following disking. The fall glyphosate winter disk treatment also effectively eliminated tall fescue, and increased plant species richness. Bare ground in fall glyphosate winter disk plots (19%) was similar to areas used by bobwhite broods in the South (18 – 31%; Taylor and Burger 2000, Puckett et al. 2000, Carver et al. 2001). Fall glyphosate and fall imazapic winter disk had 12 and 15% bare ground respectively. No difference in abundance of invertebrates preferred by bobwhites or invertebrate richness was detected between treatments in the second growing season.

Fall applications of glyphosate and fall herbicide winter disk treatments improved bobwhite brood-rearing habitat in tall fescue fields. Although fall glyphosate and fall herbicide winter disk treatments are recommended, no treatment resulted in vegetation characteristics, one and two growing seasons post treatment, identical to habitats used by broods in the South (DeVos and Muller 1993, Taylor and Burger 2000, Puckett et al. 2000, Carver et al. 2001). Fall herbicide winter disk plots were dominated by forbs with little desirable grass or shrub cover. Carver et al. (2001) found broods rarely used disked fields which were often dominated by a few plant species and lacked the diversity found in areas frequently used by bobwhite broods. In contrast, Yates et al. (1995) reported broods frequently used fall disked areas dominated by ragweed. In Mississippi, undisturbed old-fields with abundant cover of forbs, broomsedge bluestem, and native shrubs and strip-disked old-fields were preferred by adult bobwhites during the breeding season (Manley 1994).

Fall glyphosate and fall herbicide winter disk treatments contained undesirable forbs and grasses one and two growing seasons following treatment. Undesirable plants may dominate areas quickly. Dense vegetation limits brood travel within a field. Undesirable plants should be eliminated using appropriate management practices.

Feeding

Bobwhite food habits in the South have been described thoroughly (Rosene and Freeman 1969, Eubanks and Dimmick 1974, Landers and Johnson 1976, Buckner and Landers 1979, Hurst and Brennan 1995). Bobwhite feeding habitat generally consists of early succession plant communities, supporting plants producing seed preferred by bobwhites, with adequate bare ground for birds to forage freely, but with enough overhead cover to avoid predation (Stoddard 1931, Rosene 1969). Discrepancies exist as to the precise amounts of food plants, cover, and bare ground optimal for bobwhite feeding habitat (Tonkovich and Stauffer 1993). Tall fescue controls failed to provide adequate feeding habitat because vegetation was too dense at ground level for bobwhites to effectively forage. Coverage of preferred bobwhite food in controls was less than 7% across both years of the study.

During the first growing season following treatment (2004), fall herbicide winter disk treatments contained greater coverage of bobwhite food plants than controls or plots where cool-season grass elimination was less successful. During the 2005 growing season, coverage of bobwhite food plants was greatest in spring herbicide fall disk treatments. Fall glyphosate and fall glyphosate winter disk treatments resulted in 50 – 70% and 20 – 25% coverage of bobwhite food plants one and two growing seasons following treatment. While Schroeder (1985) suggested bobwhites require 25 – 75% cover of desirable food plants for optimal feeding habitat, bobwhites in Virginia frequently used fields with desirable food plants covering as little as 18% (Tonkovich and Stauffer 1993).

During the second growing season following treatment (2005), fall glyphosate winter disk increased plant species richness, an important complement to the diverse food habits of bobwhites in the South (McRae et al. 1979). Cover of desirable food plants was less in the second year following disturbance, while cover of undesirable forbs and grasses increased. Openness at ground level and overhead cover remained somewhat similar one and two growing seasons following treatment.

Plant community response was similar in the first growing season following disking conducted in November (fall) or early-March (winter). Studies conducted in the coastal plain found fall disking produced greater bobwhite habitat benefits than spring disking (Yates et al. 1995, Carver et al. 2001). Disking in February or March is reported to produce similar plant communities to areas disked in the fall (Jones et al. 1993, Olinde 2000, Gruchy and Harper 2006). Gruchy and Harper (2006) found undesirable plant cover did not increase until disking was implemented in April. Disking after March is not recommended in areas with seedbanks and containing johnsongrass, crabgrass, broadleaf signalgrass, and other undesirable warm-season grasses (Gruchy and Harper 2006).

Winter cover

During winter, bobwhites require woody or brushy escape cover, feeding areas, and a grassland or annual forb community for roosting (Roseberry and Klimstra 1984). Bobwhite coveys often use brushy areas that provide overhead cover and avoid areas with little cover, such as harvested crop fields (Yoho and Dimmick 1972). While large amounts of bare ground are beneficial for winter feeding habitats (Tonkovich and Stauffer 1993), areas with dense overhead cover are necessary for predator avoidance and thermal cover (Dixon et al. 1996, Chamberlain et al. 2002, Hiller and Guthery 2005). Coveys in the mid-South prefer old-field habitats with native shrubs and early succession vegetation (Yoho and Dimmick 1972, Dixon et al. 1996). Tall fescue control areas did not provide sufficient winter cover because they did not provide adequate overhead and vertical cover for bobwhites in winter.

During the dormant season following treatment application, fall herbicide winter disk treatments provided the greatest improvements in bobwhite winter cover compared to tall fescue control. Vertical structure, openness at ground level, overhead cover, and bare ground were increased. It is possible for overhead cover (angle of obstruction) and bare ground to simultaneously increase in habitats with sufficient vertical cover. Total vegetative canopy cover was reduced, but was still within the range used by bobwhites in the winter (Tonkovich and Stauffer 1993). Further, winter food resources were greater in disked areas as coverage of desirable seed producing plants was increased in those areas. Fall herbicide applications lacked vertical structure and overhead cover provided by the residual annual forb stems in fall herbicide winter disk treatments. Bobwhites in Missouri selected winter roost sites with more vertical cover than random sites (Chamberlain et al. 2002). Fall imazapic treatments increased desirable nwsg cover, including broomsedge bluestem which rmains upright providing good vertical cover throughout winter. Fall imazapic applications failed to eliminate some undesirable cool-season grasses (orchardgrass, timothy, bluegrass), and are not recommended when these grasses are present. Areas with dense cool-season grass cover do not provide adequate food or cover for wintering bobwhites (Barnes et al. 1995).

Fall glyphosate applications and fall applications of glyphosate followed by winter disking decreased cool-season grass cover more effectively than fall imazapic. While early succession vegetation is desirable for nesting, brooding, and feeding bobwhites, later seral stage plant communities with interspersed brushy cover provide ideal bobwhite winter cover. Roosting habitat with more nwsg and litter provide important thermal cover for bobwhites (Chamberlain et al. 2002). Overhead cover similar to bobwhite winter coverts in areas with more brushy cover (Hiller and Guthery 2005) may develop on treated areas as succession progresses.

CONCLUSIONS

Habitat for bobwhites in fields dominated by non-native perennial cool-season grasses may only be improved over the long term if the undesirable grasses are eliminated using herbicides. A single application of glyphosate in the fall (October – mid-November) is recommended for renovating tall fescue fields in Tennessee. While a fall imazapic application was effective in eliminating tall fescue, other undesirable cool-season grasses, such as orchardgrass, were "released" from the seedbank. Orchardgrass and tall fescue were structurally similar. A single application of either herbicide in the spring (April – May) reduced tall fescue coverage compared to control; however, > 40% tall fescue remained two growing seasons following spring herbicide applications.

Eliminating tall fescue using a fall glyphosate application improved nesting, brood-rearing, and feeding habitat for bobwhites two growing seasons following herbicide application. Disking following fall glyphosate application improved brood-rearing, feeding, and wintering habitat for bobwhites. Based on these results, plant communities emerging from the seedbank following tall fescue elimination may provide quality bobwhite habitat without the need for seeding. Planting nwsg and associated forbs may only be necessary in areas where desirable plant communities are absent from the seedbank.

In addition to desirable plant response following tall fescue elimination, several undesirable plants emerged from the seedbank. Undesirable plants should be managed using herbicides or mechanical methods. Undesirable grasses, if present in the seedbank, may be reduced by avoiding late-spring and summer soil disturbance. Many undesirable warm-season grasses, such as johnsongrass, crabgrass, and broadleaf signalgrass, are controlled using a pre-emergence application of imazapic. Imazapic applications increased desirable nwsg cover. Undesirable forbs, such as horseweed, thistles, sicklepod, and cocklebur, can be controlled using broadleaf-selective herbicides or mowing. Herbicide applications may result in a short term loss of diversity and/or desirable plants. However, failure to address undesirable plants aggressively as soon as they appear may allow them to accumulate in the seedbank, and present an overwhelming problem when managing for bobwhites.

Although disking improved feeding and brood-rearing habitat, disking following herbicide application may not be necessary to improve bobwhite habitat. Disking following herbicide applications did not result in greater reduction of tall fescue cover than fall herbicide applications alone. Further, fall glyphosate applications resulted in acceptable brood-rearing and feeding habitat during the first growing season following treatment. Disking may be implemented if necessary in fall/winter following the first growing season after fall glyphosate application. Disking as conducted in this study (> 50% aboveground residue incorporated), resulted in little or no desirable grass or shrub cover one and two growing seasons following treatment. Grasses and shrubs are important for nesting, brooding, and roosting cover. In areas were grasses and shrubs are lacking, disking should not be conducted.

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PART II

EFFECTS OF MANAGEMENT PRACTICES ON BOBWHITE HABITAT IN ESTABLISHED NATIVE WARM-SEASON GRASS FIELDS

ABSTRACT

The loss of quality early successional habitat has a negative impact on several wildlife species in Tennessee, including northern bobwhites (*Colinus virginianus*). To address this problem, native warm-season grasses (nwsg) have been promoted. However, if left unmanaged, nwsg grow dense over time and habitat benefits are reduced. Six management practices (November disk, March disk, March burn, March mowing, strip herbicide application, and September burn) and control were implemented on a previously unmanaged nwsg field 2003 – 2004. Vegetation structure was measured during the growing season and in fall of 2004, then in winter, spring, and in the growing season of 2005. Vegetation composition and invertebrate abundance were measured during the growing season 2004 and 2005. November disk, March disk, and March burn increased forb cover, overhead cover, and openness at ground level and decreased litter during the first growing season following treatment. Nwsg cover was reduced by disking, but remained similar to control or greater than control across all other treatments. In the second growing season following treatment, March burn decreased undesirable grasses and increased nwsg cover. March mowing was structurally similar to control. Differences were observed in invertebrate density and richness between treatments. Disking applied prior to April is recommended for improving dense stands of nwsg for bobwhites. Burning in March may be used to maintain established nwsg.

INTRODUCTION

Early successional plant communities provide habitat for a variety of wildlife including northern bobwhites (*Colinus virginianus*; hereafter bobwhites). Quality bobwhite habitat is characterized by a diverse suite of forbs and grasses, with scattered brushy cover, creating a community structure open at the ground level with abundant plant and macroinvertebrate food resources (Roseberry and Klimstra 1984, Burger et al. 1990). Native warm-season grasses (nwsg) such as, big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), broomsedge bluestem (*Andropogon virginicus*), indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), and sideoats grama (*Bouteloua curtipendula*), are commonly recommended to enhance early successional habitats for bobwhites (Burger et al. 1990, Warner and Brady 1994), especially when renovating sod-forming grasses (Washburn et al. 2000). The benefit of nwsg, compared to non-native perennial cool-season grasses, such as tall fescue (*Festuca arundinacea*) and orchardgrass (*Dactylis glomerata*), is an open structure at ground level and overhead cover. Additionally, bareground space between grass bunches allows desirable native forbs to germinate and produce high-quality forage and seed resources for wildlife.

In the past decade, knowledge of nwsg establishment has increased considerably. Improved no-till seeding methods and herbicides for weed control have greatly enhanced establishment success (Harper et al. 2002). However, nwsg are often planted at high rates (> 6.7 kg pure live seed [PLS]/ha, 6.0 lbs PLS/acre), which results in a rank field of grass within two years (Jones et al. 2004). Even when planted at low rates, the density of grass bunches will increase over time. As nwsg become dense, plant species richness declines (Millenbah et al. 1996, Gill et al. 2006) and wildlife habitat benefits are reduced (Burger et al. 1990, Millenbah et al. 1996, McCoy et al. 2001a). Studies in Nebraska, Missouri, and Kentucky failed to detect differences in breeding bird richness between fields planted in dense nwsg or perennial cool-season grass (King and Savage 1995, Desile and Savage 1997, McCoy et al. 2001a, Larkin et al. 2001), indicating the habitat provided by monotypic stands of grass is similarly lacking regardless of species composition (Burger et al. 1994, McCoy et al. 2001a, Larkin et al. 2001, Fettinger et al. 2002).

Prescribed fire and disking are commonly recommended when managing early succession habitats for bobwhites. Periodic burning and disking increase bare ground, improve plant community structure, and may increase desirable food plants and invertebrates (Stoddard 1931, Rosene 1969, Hurst 1972, Buckner and Landers 1979, Manley et al. 1994). Although prescribed fire is an essential component of early succession habitat management, periodic dormant-season fire does little to alter plant composition in fields dominated by perennial grasses (Whitehead and McConnell 1979, Towne and Owensby 1984, Manley 1994, Howe 1994). Growing-season fire has been used to reduce nwsg density (Howe 2000). Relatively heavy disking reduces perennial grass density; however, the resulting plant community composition and structure is affected by the timing of disking application (Olinde 2000, Carver et al. 2001, Madison et al. 2001, Greenfield et al. 2003). The plant community directly influences the availability of food and cover for wildlife. Therefore, timing of soil disturbance affects the quality of wildlife habitat.

The objective of this research was to determine the effects of management practices and timing of disturbance in an unmanaged nwsg field with dense grass growth. Management practices were evaluated based on their ability to reduce planted grass cover and improve bobwhite habitat. Additionally, recommendations for field management practices in areas where burning is not possible will be provided.

METHODS

Study area

Treatments were implemented on a privately owned 15.8-ha (38-ac) field in McMinn County, Tennessee. Elevation within the field ranged from 287 – 293 m (940 – 960 ft). Soils were Dewey silty clay loams of the Fullerton-Clarksville-Greendale soil association (Bacon et al. 1948) with pH ranging from 5.4 – 5.8 (based on soil test). The field was planted in a nwsg seed mixture consisting of big bluestem, indiangrass, switchgrass, and little bluestem at 6.7 kg PLS/ha (6.0 lbs PLS/acre), with the primary objective of improving bobwhite habitat. Prior to nwsg establishment, the field was dominated by tall fescue. Tall fescue was sprayed with glyphosate (2.2 kg active ingredient (ai)/ha; Roundup 2 qt/ac) in May 2000, and grasses were planted in June 2000 using a no-till drill. The portion of the field used in this study had not been managed since establishment. Dominant plants within the field prior to treatment were big bluestem, indiangrass, switchgrass, nimblewill (*Muhlenbergia shreberi*), brambles (*Rubus* spp.), pokeweed (*Phytolacca americana*), and sumac (*Rhus* spp.). Tall fescue, orchardgrass, smooth brome (*Bromus inermis*), and thistles (*Cirsium* spp.) also were present.

Treatment application

Seven treatments with control were applied to 0.2-ha (0.5-ac) plots in a completely randomized design with 3 plots per treatment from November 2003 – May 2004 and in September 2004 depending on treatment. Treatments included November disk, March disk, March burn, March mow, strip-herbicide application, and September burn. November disk was conducted 11 November 2003 using a 3.1-m (10-ft) offset disk.

Plots were disked 3 – 6 passes, or until > 50% of the aboveground residue was incorporated into the soil. The same equipment and procedures were used for March disk. March burn, March disk, and March mow treatments were conducted 11 March 2004. September burn was conducted 28 September 2004. Average flame heights were > 2 m (6 ft) for all burns. Strip herbicide was conducted 5 May 2004 by closing off alternating nozzle tips of an agricultural spray coupe with a 6.5-m (21-ft) spray boom and applying a grass-selective herbicide (clethodim 1.8 kg ai/ha; Select 2 EC 10 oz/ac) using a using a total solution volume of 235 L/ha (25 gal/ac). Non-ionic surfactant was added at 0.25% total solution volume to improve herbicide uptake. Control plots did not receive any treatment.

Data collection

Vegetation structure and composition

Total vegetation cover, bare ground, litter and cover of vegetation canopy classes including forbs, warm-season grasses, cool-season grasses, brambles, sedges, and woody species were estimated to the nearest 5% using a 1-m^2 sampling frame (Bonham 1989). Litter depth was measured in the center of each sampling frame. Sampling frames were systematically placed within each 0.2-ha plot. Each plot was subdivided into 4 quadrants and subsampled 4 times for a total of 16 1-m^2 frames per plot (i.e., 48 subsamples/ treatment/sampling period). Ground sighting distance, angle of obstruction, visual obstruction distance, and visual obstruction reading, were also measured. Ground sighting distance is an index of openness at ground level. Angle of obstruction is an index of overhead vegetation canopy cover for bobwhites (Kopp et al. 1998). Visual obstruction distance is an index of meso-mammal predator avoidance cover for bobwhites (Kopp et al. 1998). Visual obstruction reading is and index of vertical structure (Robel et al. 1970). Vegetation structural parameters were recorded in the growing season (July), and fall (November – December) 2004 and winter (February), spring (April), growing season (July) 2005. Plant species composition was characterized along a 10-m line transect (Canfield 1941) placed along the cardinal azimuth passing through the center of each plot. The distance along each transect occupied by each plant species was measured. Vegetation height was measured at 0, 5, and 10 m along each line transect. Vegetation composition was measured during the growing season (June – August) 2004 and 2005.

Invertebrate abundance

Invertebrate samples were collected using a 0.25-m^2 bottomless box and modified hand held blower-vac (Harper and Gyunn 1998). Four subsamples were collected within each 0.2-ha plot by systematically locating the sampling box near the center of each cardinal quadrant (i.e., 12 subsamples/treatment/sampling period). The modified blower-vac was used to vacuum the vegetation and substrate within the sampling box into cloth bags. Samples were collected when vegetation was dry and daytime temperature was > 80° F (Palmer 1995). Invertebrate samples were collected once during the growing season (June) 2004 and 2005and stored at a constant temperature of -20 C to prevent decomposition (Murkin et al 1996). Invertebrates were sorted and dried for 48 hours in a forced air oven at a constant temperature of 60 C (140 F) (Murkin et al. 1996). Dry weight and abundance for each invertebrate order were recorded.

Data analysis

A one-way analysis-of-variance (ANOVA) was used to test for differences in vegetation structure and composition among treatments (Montgomery 1997). Vegetation composition and invertebrate abundance were analyzed by grouping plant species and invertebrate taxa into biologically meaningful associations in order to avoid increased Type I error rates that may result from running multiple ANOVAs on the same data set (Neter et al. 1996). Statistical tests were preformed on cover of planted nwsg species (big bluestem, indiangrass, switchgrass, and little bluestem), unplanted desirable nwsg (primarily broomsedge bluestem), bobwhite food plants (described in Part I), undesirable warm-season grasses (primarily nimblewill, johnsongrass, and crabgrass [*Digitaria* spp.]), undesirable cool-season grasses (tall fescue, smooth brome, and orchardgrass), undesirable forbs (primarily thistles), desirable brushy cover (blackberries and sumacs), and species richness within each plot.

Variables used to quantify invertebrates included total density, total biomass, density of orders preferred by bobwhite broods, and biomass of orders preferred by bobwhite broods. In foraging trials using pen-reared bobwhite chicks in different habitat types, several invertebrate orders, including Aranea (spiders), Coleoptera (beetles), Diptera (flies), Hemiptera (true bugs), Homoptera (leafhoppers), Hymenoptera (ants and wasps), Lepedoptera larva (butterfly and moth larva), and Orthoptera (grasshoppers), have been reported preferred (Hurst 1972, Jackson et al. 1987, Palmer 1995, Smith 2004, Doxon 2006). For this analysis, invertebrates considered preferred by bobwhite chicks included Coleoptera, Hemiptera, Homoptera, and Orthoptera because these orders are consistently cited as preferred (Burger et al. 1993, Devos and Muller 1993).

The assumptions of ANOVA, normality of residuals and homogeneity of variances, were assessed by the Shapiro-Wilk test ($W \geq 0.90$) and Levene's test ($P \leq 0.05$) respectively, using PROC UNIVARIATE (SAS Institute 2003). Within each sampling period, several variables used to describe vegetation structure and composition failed to meet the assumptions of ANOVA. Following transformation using arcsine square root and natural log plus 0.5 transformations most variables met the assumptions of ANOVA. Some variables within each sampling period failed to meet the assumption of heterogeneity of variances following transformation. Kruskal-Wallis tests were performed on variables failing to meet the assumptions of ANOVA. Additionally, vegetation composition variables litter and bare ground were unable to be amended and were excluded from analysis as both were estimated by vegetation structure variables. Statistical tests were preformed on 14 variables for vegetation structure, 9 variables for vegetation composition, and 5 variables for invertebrate abundance. If *F*-tests were significant ($P < 0.05$), pair-wise differences between treatments were tested using Tukey's Honest Significant Difference (HSD) test. ANOVAs were performed using PROC GLM in the SAS® system (Littell et al. 2002).

RESULTS

Vegetation structure and composition

Growing season 2004

Treatment differences were detected for 12 of 14 vegetation structure variables (Table 2.1). Mow plots were similar to control for all structural variables. November and March disk were similar for all variables except visual obstruction reading. Disking increased openness at ground level as indicated by increased ground sighting distance and bare ground. The strip herbicide application successfully decreased vegetation density as indicated by decreased vegetation cover, and visual obstruction reading as well as

Table 2.1 Mean vegetation structural characteristics following management practices in a previously unmanaged field planted to native warm-season grasses June 2000, McMinn County, Tennessee, July – August 2004 and 2005.

	Treatment						
	Control	Bushhog	Strip herbicide	March burn	September burn[3]	Novemeber disk	March disk
Variable[1]	$\bar{x}$[2] (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)
2004							
GSD	0.05 (0.02) c	0.16 (0.05) bc	0.28 (0.04) ab	0.21 (0.03) ab	NT	0.32 (0.04) a	0.43 (0.07) a
AO	54.23 (2.74) ab	53.00 (1.79) ab	46.85 (2.90) b	56.40 (4.22) ab	NT	58.81 (2.37) a	60.71 (2.63) a
VOD	0.07 (0.02) b	0.10 (0.03) b	0.33 (0.04) a	0.08 (0.02) b	NT	0.13 (0.03) b	0.10 (0.03) b
VOR	18.19 (0.67) a	19.13 (0.25) a	14.71 (1.08) b	19.13 (0.40) a	NT	10.18 (0.73) c	16.99 (0.68) ab
Cover	94.17 (1.30) a	95.63 (0.70) a	86.88 (1.23) b	92.19 (1.98) ab	NT	89.27 (0.95) b	91.88 (1.51) ab
Bare	0.83 (0.28) c	0.31 (0.31) c	4.17 (0.99) b	7.71 (1.88) ab	NT	10.73 (0.95) a	7.75 (1.52) ab
Litter[4]	6.25 (2.12)	4.17 (0.69)	9.17 (1.67)	0.10 (0.10)	NT	0.00 (0.00)	0.00 (0.00)
Litter depth[4]	5.25 (0.66)	2.63 (0.10)	1.21 (0.11)	0.00 (0.00)	NT	0.00 (0.00)	0.00 (0.00)
Forb	40.31 (5.51) cd	30.31 (4.57) d	47.92 (2.20) bc	60.10 (6.68) b	NT	95.94 (1.40) a	95.83 (1.20) a
Woody	14.17 (3.14) a	7.08 (3.24) ab	7.40 (2.23) ab	10.31 (4.59) ab	NT	1.56 (0.67) b	2.29 (1.59) b
Brambles	10.00 (4.86) a	8.65 (5.64) a	2.29 (1.16) a	4.58 (2.75) a	NT	0.00 (0.00) a	3.96 (2.67) a
Sedges	0.73 (0.50) a	0.85 (0.83) a	1.04 (0.55) a	0.21 (0.21) a	NT	0.10 (0.10) a	0.83 (0.58) a
CS grass	3.33 (1.83) a	0.42 (0.42) ab	1.35 (1.04) ab	0.00 (0.00) b	NT	2.71 (1.09) ab	0.31 (0.22) ab
WS grass	82.60 (4.55) ab	90.52 (3.43) a	73.02 (4.35) b	65.42 (7.08) b	NT	20.73 (2.70) c	16.98 (2.24) c
2005							
GSD	0.23 (0.07) b	0.39 (0.08) ab	0.36 (0.08) ab	0.31 (0.07) ab	0.46 (0.06) ab	0.43 (0.06) ab	0.58 (0.08) a
AO	71.94 (2.37) ab	69.94 (1.44) b	71.13 (1.88) b	78.13 (0.92) a	73.54 (1.57) ab	68.58 (1.73) b	74.00 (1.08) ab
VOD	0.06 (0.03) b	0.11 (0.05) ab	0.18 (0.05) ab	0.08 (0.04) ab	0.09 (0.03) ab	0.25 (0.05) a	0.18 (0.04) ab
VOR	16.04 (0.58) ab	15.38 (0.97) ab	13.13 (0.53) bc	17.31 (0.63) a	14.77 (0.63) abc	10.90 (0.93) c	12.00 (0.80) c
Cover	93.02 (2.62) a	92.71 (3.11) a	93.65 (1.45) a	95.00 (1.58) a	93.33 (0.96) ab	88.13 (2.58) ab	81.88 (2.48) b
Bare	0.00 (0.00) c	0.21 (0.21) c	0.63 (0.63) c	1.25 (0.92) bc	6.35 (1.09) a	4.17 (1.27) ab	10.10 (3.10) a
Litter[4]	6.98 (2.62)	5.00 (1.59)	7.60 (2.08)	3.98 (1.53)	0.31 (0.31)	7.71 (2.37)	8.23 (2.94)
Litter depth[4]	5.10 (1.10)	4.52 (0.70)	3.40 (1.01)	2.13 (0.51)	0.00 (0.00)	0.23 (0.08)	0.60 (0.21)

Table 2.1 (continued).

	Treatment																				
	Control			Bushhog			Strip herbicide			March burn			September burn			Novemeber disk			March disk		
Variable	$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)	
Forb	31.46	(6.77)	c	24.69	(4.23)	c	35.65	(6.97)	c	34.58	(6.04)	c	58.54	(6.64)	b	77.40	(5.98)	ab	87.92	(2.86)	a
Woody	7.39	(3.39)	a	3.10	(1.16)	ab	1.56	(0.86)	ab	1.77	(1.06)	ab	3.75	(1.93)	ab	0.31	(0.22)	b	0.21	(0.21)	b
Brambles[4]	15.83	(4.33)		10.21	(4.03)		3.85	(1.84)		3.75	(1.85)		5.00	(2.74)		1.67	(1.67)		1.15	(0.81)	
Sedges	5.94	(2.78)	ab	0.83	(0.56)	b	10.00	(3.05)	a	2.71	(2.71)	b	1.56	(1.06)	b	0.83	(0.47)	b	0.21	(0.21)	b
CS grass	7.81	(3.31)	abc	9.48	(3.97)	abc	20.10	(7.87)	ab	1.25	(1.25)	c	1.35	(0.93)	c	25.94	(7.38)	a	14.48	(3.70)	ab
WS grass	71.46	(6.96)	a	80.21	(4.75)	a	64.58	(6.07)	a	79.48	(6.32)	a	62.60	(5.88)	a	17.29	(2.20)	b	20.94	(5.03)	b

[1] GSD = ground sighting distance (m), AO = angle of obstruction (0-90°), VOD = visual obstruction distance, VOR = visual obstruction reading or vertical structure, Cover = total vegetative cover (%), Bare = bareground (%), Litter = litter (%), Litter depth = litter depth (cm), Forbs = forb cover (%), Brambles = *Rubus* spp. Cover (%), Sedges = sedge cover (%), Woody = woody cover (%), CS grass = cool-season grass cover (%), WS grass = warm-season grass cover (%).

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

[3] NT = no test performed because treatment had not been completed at time of data collection.

[4] Kruskal-Wallis test ($P > 0.05$), at least one ANOVA assumption was violated, no pair-wise comparisons were preformed.

increased visual obstruction distance and ground sighting distance. March burn increased forb cover and decreased cool-season grass cover. Disking resulted in the greatest reduction in warm-season grass cover and increase in forb cover. Disking and burning decreased litter and litter depth. Woody cover was greater in control than in disked treatments.

Treatment differences were detected for 7 of 9 vegetation composition variables (Table 2.2). March mowing was similar to control for all variables. November and March disk treatments had less planted nwsg and more bobwhite food plants than all other treatments. Planted nwsg cover was less in strip herbicide than March mow, but similar to control. All treatments except March mowing decreased undesirable warm-season grasses. November disk had more undesirable forb cover than March burn or mow treatments. Burning and disking decreased desirable brushy cover. Species richness was greater in strip herbicide than control. November disk and strip herbicide treatments had lower vegetation height than control, March mow, and March disk.

Dormant season (November 2004 – April 2005)

Treatment differences were detected for all vegetation structure variables (Table 2.3). March mow and control were similar through the entire dormant season for all but angle of obstruction in winter. Strip herbicide was similar to control for all but total vegetation cover and angle of obstruction in winter and spring. November disk was similar to March disk for all but vertical cover in fall, angle of obstruction in winter and spring and bare ground in winter. Disking and March burn treatments improved both vertical and overhead cover throughout the dormant season as evident by increased visual obstruction reading and angle of obstruction respectively. Disking increased visual

Table 2.2 Mean vegetation composition characteristics measured along a 10-m line transect following management practices in a previously unmanaged field planted to native warm-season grasses June 2000, McMinn County, Tennessee, August 2004 and 2005.

	Treatment						
	Control	Bushhog	Strip herbicide	March burn	September burn[3]	Novemeber disk	March disk
Variable[1]	$\bar{x}$ [2] (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)
2004							
Planted nwsg	5.27 (1.41) ab	8.00 (0.88) a	4.64 (0.57) bc	7.95 (0.43) ab	NT	0.86 (0.26) c	0.77 (0.24) c
Unplanted nwsg	0.16 (0.05) ab	0.08 (0.08) ab	0.29 (0.13) a	0.06 (0.03) ab	NT	0.00 (0.00) b	0.02 (0.02) ab
Bobwhite food plants	2.46 (0.49) b	2.21 (0.86) b	2.20 (0.58) b	4.09 (1.35) b	NT	9.96 (0.87) a	10.60 (0.96) a
Undesirable wsg	4.68 (1.24) a	3.00 (0.67) ab	1.77 (0.70) b	1.67 (0.45) b	NT	0.81 (0.26) b	1.23 (0.41) b
Undesirable csg	0.69 (0.40) a	0.57 (0.33) a	1.48 (0.78) a	0.14 (0.07) a	NT	1.31 (0.54) a	0.40 (0.21) a
Undesirable forbs	0.38 (0.12) ab	0.32 (0.07) b	0.52 (0.12) ab	0.31 (0.12) b	NT	1.48 (0.57) a	1.05 (0.21) ab
Brushy cover[4]	1.65 (0.63)	1.30 (0.53)	1.43 (0.61)	0.67 (0.35)	NT	0.05 (0.03)	0.40 (0.21)
Species richness	13.67 (1.12) b	15.11 (0.48) ab	18.56 (1.20) a	17.33 (1.77) ab	NT	17.44 (1.00) ab	18.00 (0.93) ab
Vegetation height	1.47 (0.14) a	1.48 (0.04) a	1.08 (0.11) b	1.24 (0.03) ab	NT	1.03 (0.04) b	1.50 (0.11) a
2005							
Planted nwsg	5.43 (1.29) b	7.12 (1.12) ab	4.56 (0.64) b	9.64 (0.59) a	6.27 (0.57) ab	1.80 (0.29) c	0.96 (0.28) c
Unplanted nwsg[4]	0.01 (0.01)	0.02 (0.02)	0.69 (0.34)	0.00 (0.00)	0.13 (0.09)	0.10 (0.05)	0.31 (0.10)
Bobwhite food plants	0.76 (0.24) ab	0.73 (0.21) ab	0.54 (0.18) b	0.26 (0.06) b	2.45 (0.79) a	1.83 (0.60) ab	1.35 (0.51) ab
Undesirable wsg	3.18 (0.81) a	2.12 (0.69) abc	0.67 (0.27) bcd	0.15 (0.15) d	0.25 (0.13) cd	1.49 (0.44) abcd	1.89 (0.57) ab
Undesirable csg	1.17 (0.42) ab	0.37 (0.24) bc	2.05 (0.60) a	0.00 (0.00) c	0.05 (0.04) c	1.84 (0.53) a	0.60 (0.20) abc
Undesirable forbs	0.93 (0.22) bc	1.00 (0.31) bc	0.82 (0.24) c	1.14 (0.62) c	2.09 (0.41) bc	3.00 (0.73) ab	5.73 (0.84) a
Brushy cover	2.59 (1.24) ab	3.58 (0.74) a	0.30 (0.15) bc	0.09 (0.07) c	1.51 (0.79) abc	0.58 (0.16) bc	1.16 (0.52) bc
Species richness	12.75 (0.49) abc	10.22 (0.92) c	15.22 (0.86) a	9.50 (0.98) c	14.22 (1.15) ab	12.56 (0.80) abc	10.67 (1.18) bc
Vegetation height	1.25 (0.18) a	1.25 (0.09) a	0.97 (0.06) a	0.98 (0.12) a	0.97 (0.15) a	1.00 (0.14) a	1.19 (0.12) a

[1] Planted nwsg = cover of planted nwsg including big bluestem, little bluestem, indiangrass, and switchgrass (m), Unplanted nwsg = cover of unplanted nwsg including broomsedge bluestem, Bobwhite food plants = cover (m) of plants producing seed eaten by bobwhites, Undesirable wsg =

Table 2.2 (continued).

undesirable warm-season grass cover (m), Undesirable csg = undesirable cool-season grass cover (m), Undesirable forbs = undesirable forb cover (m),

Brushy cover = cover of desirable brushy species such as, sumac and blackberry (m), Species richness = number of species recorded per plot,

Vegetation height = average vegetation height (m).

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

[3] NT = no test performed because treatment had not been completed at time of data collection.

[4] Kruskal-Wallis test ($P > 0.05$), at least one ANOVA assumption was violated, no pair-wise comparisons were preformed.

obstruction distance in fall and winter. Disking and March burn treatments increased bare ground. Disking decreased litter and litter depth. During April, September burning increased vegetation cover and bare ground, but provided similar visual obstruction distance and angle of obstruction to control.

Growing season 2005

Treatments differed for all variables tested (Table 2.1). As in the first growing season following treatment, March mow was similar to control for all variables. November and March disk were similar for all variables. March disk treatments maintained greater ground sighing distance and less vegetation cover than control. Disking and September burn treatments improved bare ground compared to control. Angle of obstruction was greater in the March burn treatment than mow, strip herbicide, or November disk treatments. Visual obstruction reading was lower in disked treatments than control. Forb cover was greater in disking and September burn treatments than all other treatments. March burn, strip-herbicide, and mow treatments had forb cover similar to control. Woody cover and brambles were greater in control than disked plots. Cool-season grass cover was greater in strip-herbicide and disking treatments than in March and September burn treatments. Warm-season grass cover remained low in disked treatments.

Treatment differences were detected for all vegetation composition variables except vegetation height (8 of 9; Table 2.2). Control and March mow were similar for all variables. November and March disking were similar for all variables. March burn increased the density of planted grass, compared to control. Planted grass remained lower in disking treatments than all other treatments. September burn had more bobwhite food

Table 2.3 Mean vegetation structural characteristics following management practices in a previously unmanaged field planted to native warm-season grasses June 2000, McMinn County, Tennessee, November 2004 - April 2005.

	Treatment						
	Control	Bushhog	Strip herbicide	March burn	September burn[3]	Novemeber disk	March disk
Variable[1]	$\bar{x}$ [2] (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)
Fall							
GSD[4]	0.19 (0.07)	0.29 (0.08)	0.39 (0.08)	0.38 (0.06)	NT	0.78 (0.07)	1.03 (0.08)
AO	25.52 (2.74) d	28.91 (3.32) cd	34.17 (2.60) bcd	39.10 (2.74) bc	NT	43.88 (2.44) ab	51.60 (2.19) a
VOD	0.15 (0.08) c	0.33 (0.10) c	0.35 (0.10) bc	0.28 (0.07) c	NT	0.71 (0.06) ab	0.86 (0.08) a
VOR	8.19 (1.22) c	8.11 (0.98) c	9.99 (0.58) bc	13.04 (0.81) b	NT	13.18 (0.90) b	16.93 (0.79) a
Cover	80.31 (3.81) ab	84.48 (2.25) ab	83.13 (3.36) ab	91.35 (1.10) a	NT	88.13 (1.50) ab	77.81 (3.26) b
Bare[4]	1.35 (1.04)	0.10 (0.10)	1.04 (0.57)	7.50 (1.07)	NT	12.29 (1.41)	21.15 (3.34)
Litter	16.25 (3.50) ab	15.42 (2.24) a	15.31 (3.44) a	1.04 (0.57) b	NT	0.00 (0.00) b	1.04 (0.72) b
Litter depth	3.29 (0.67) a	2.35 (0.26) a	1.96 (0.23) a	0.13 (0.07) b	NT	0.00 (0.00) b	0.04 (0.03) b
Winter							
GSD	0.55 (0.04) b	0.48 (0.06) b	0.61 (0.13) b	0.43 (0.05) b	NT	1.11 (0.07) a	1.07 (0.07) a
AO	20.73 (2.91) c	31.46 (2.43) b	37.52 (2.31) b	41.56 (2.00) ab	NT	35.69 (2.75) b	50.23 (2.60) a
VOD	0.98 (0.10) b	0.93 (0.09) b	0.84 (0.13) b	0.75 (0.06) b	NT	2.86 (0.56) a	2.29 (0.19) a
VOR[4]	4.94 (0.93)	6.49 (0.85)	6.31 (0.84)	10.58 (0.53)	NT	10.18 (0.71)	15.44 (1.47)
Cover	56.77 (7.18) b	56.77 (3.18) b	75.10 (2.97) a	72.92 (3.86) ab	NT	85.73 (1.27) a	71.35 (4.02) ab
Bare	0.00 (0.00) c	2.50 (1.66) c	2.19 (1.01) c	8.33 (1.72) b	NT	14.17 (1.26) b	27.81 (3.93) a
Litter[4]	43.23 (7.18)	38.29 (3.85)	22.50 (2.80)	17.19 (3.90)	NT	0.10 (0.10)	0.83 (0.64)
Litter depth[4]	2.50 (0.39)	2.04 (0.33)	1.00 (0.12)	0.42 (0.13)	NT	0.00 (0.00)	0.00 (0.00)
Spring							
GSD	0.65 (0.12) a	0.68 (0.09) a	0.44 (0.06) ab	0.50 (0.07) a	0.68 (0.12) a	0.12 (0.05) c	0.20 (0.05) bc
AO	17.10 (1.44) e	23.94 (2.29) cde	26.15 (1.64) bcd	30.33 (2.38) bc	21.06 (2.60) de	34.17 (1.93) b	43.31 (2.03) a
VOD	0.83 (0.12) a	0.88 (0.09) a	0.65 (0.08) a	0.62 (0.08) a	0.79 (0.12) a	0.23 (0.10) b	0.26 (0.09) b

Table 2.3 (continued).

	Treatment						
	Control	Bushhog	Strip herbicide	March burn	September burn	Novemeber disk	March disk
Variable	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)
VOR	3.76 (0.37) c	5.11 (0.62) c	6.08 (0.50) bc	8.00 (0.51) ab	3.82 (0.45) c	6.38 (0.43) bc	8.63 (0.52) a
Cover	59.69 (6.15) d	69.79 (4.19) cd	80.63 (2.59) abc	78.75 (2.75) bc	75.73 (3.27) c	94.48 (1.15) ab	91.04 (1.97) a
Bare	1.77 (1.66) d	0.00 (0.00) cd	1.77 (0.79) cd	3.44 (0.89) bc	24.27 (3.27) a	5.52 (1.16) b	8.96 (1.97) b
Litter[4]	38.33 (6.04)	30.21 (4.19)	16.88 (2.74)	17.81 (3.10)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Litter depth[4]	4.29 (0.48)	2.63 (0.47)	2.38 (0.33)	1.38 (0.33)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

[1] GSD = ground sighting distance (m), AO = angle of obstruction (0-90°), VOD = visual obstruction distance, VOR = visual obstruction reading or vertical structure, Cover = total vegetative cover (%), Bare = bareground (%), Litter = litter (%), Litter depth = litter depth (cm).

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

[3] NT = no test performed because treatment had not been completed at time of data collection.

[4] Kruskal-Wallis test ($P > 0.05$), at least one ANOVA assumption was violated, no pair-wise comparisons were preformed.

plants than March burn or strip herbicide. Undesirable warm-season grasses were decreased by March and September burn. November disk and strip herbicide had more undesirable cool-season grass than in burn treatments. Desirable brushy cover was reduced following March burn, compared to mowing and control. Disked plots had less brushy cover than mowed plots. Strip herbicide had greater species richness than March mow, March burn, and March disk.

Invertebrate abundance

No treatment differences were detected in 2004 for biomass, density, or order richness (Table 2.4). Treatment differences were detected in 2005 for total density and order richness of invertebrates (Table 2.4). March mow contained more invertebrates than November disk or strip herbicide treatments. March disk had greater order richness than strip herbicide.

DISCUSSION

Dykes (2005) evaluated the effectiveness of planted nwsg fields on Farm Bill program lands in Tennessee for providing habitat for grassland birds, including bobwhites. Bobwhites were present in 87% and 72% of fields evaluated in 2002 and 2003 respectively (Dykes 2005). While these figures are encouraging, Burger et al. (1990) observed bobwhite habitat declined as fields in Missouri aged. Without some type of management to set back succession, fields quickly become rank with grass and provide little else than potential nesting cover for bobwhites (Burger et al. 1990, Millenbah et al. 1996). Dykes (2005) reported 70% of nwsg fields evaluated in Tennessee were unmanaged or managed by mowing alone. Results from this study as well as others

Table 2.4 Mean invertebrate density, biomass, and ordinal richness following management practices in a previously unmanaged field planted to native warm-season grasses June 2000, McMinn County, Tennessee, July 2004 and 2005.

	Treatment						
	Control	Bushhog	Strip herbicide	March burn	September burn[3]	Novemeber disk	March disk
Variable[1]	$\bar{x}$ [2] (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)
2004							
Total densisty	33.67 (7.06) a	41.67 (8.08) a	39.67 (8.66) a	25.67 (4.47) a	NT	25.33 (4.07) a	18.33 (4.68) a
Density preferred	18.00 (4.47) a	30.67 (6.72) a	17.67 (4.01) a	19.67 (3.46) a	NT	21.33 (3.86) a	16.67 (4.37) a
Total biomass	0.26 (0.06) a	0.27 (0.08) a	0.47 (0.19) a	0.16 (0.03) a	NT	0.09 (0.03) a	0.22 (0.08) a
Biomass preferred	0.06 (0.01) a	0.20 (0.06) a	0.34 (0.17) a	0.14 (0.03) a	NT	0.08 (0.02) a	0.19 (0.08) a
Order richness	3.42 (0.57) a	3.67 (0.31) a	4.17 (0.49) a	3.25 (0.51) a	NT	2.92 (0.38) a	2.33 (0.40) a
2005							
Total densisty	20.67 (1.96) ab	34.33 (8.63) a	12.33 (3.05) b	19.33 (3.65) ab	16.67 (4.82) ab	12.00 (2.51) b	24.67 (5.02) ab
Density preferred	13.00 (1.71) a	8.67 (1.62) a	5.67 (2.28) a	11.00 (1.57) a	11.67 (4.79) a	5.67 (1.43) a	13.00 (2.92) a
Total biomass	0.13 (0.04) a	0.09 (0.02) a	0.12 (0.04) a	0.10 (0.03) a	0.09 (0.02) a	0.10 (0.04) a	0.14 (0.05) a
Biomass preferred	0.08 (0.03) a	0.04 (0.01) a	0.05 (0.02) a	0.05 (0.01) a	0.07 (0.03) a	0.03 (0.01) a	0.08 (0.04) a
Order richness	3.00 (0.28) ab	3.58 (0.38) ab	1.92 (0.42) b	3.08 (0.29) ab	2.33 (0.33) ab	2.17 (0.46) ab	3.83 (0.73) a

[1] Total biomass = biomass (g /m^2) of all invertebrates detected, Biomass preferred = biomass (g /m^2) of invertebrates in orders preferred by foraging bobwhite chicks, Total density = density (invertebrates/m^2) of all invertebrates detected, Density preferred = density (invertebrates/m^2) of invertebrates in orders preferred by foraging bobwhite chicks, Order richness = number of invertebrate orders represented per sample.

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

[3] NT = no test performed because treatment had not been completed at time of data collection.

[4] Kruskal-Wallis test ($P > 0.05$), at least one ANOVA assumption was violated, no pair-wise comparisons were preformed.

indicate mowing provides little if any improvement in bobwhite habitat (Puckett et al. 1995, McCoy et al. 2001b).

The primary objective of this research was to determine the effects of management practices and timing of disturbance in an unmanaged field with dense grass growth; however, the field used in this study contained reasonable amounts of nwsg (~ 50% cover; 5.3 – 5.4 m). Undesirable warm-season grasses were the vegetative component responsible for reducing habitat for bobwhites. The dominant undesirable warm-season grass was nimblewill. Although seed from nimblewill has been reported as a low preference bobwhite food (Landers and Johnson 1976), the density present in this field, reduced openness at ground level (ground sighting distance) and likely reduced bobwhite brood-rearing habitat. March burn reduced the cover of nimblewill and increased nwsg density. By the second growing season after treatment, nwsg cover was > 80% in March burn plots. Increased nwsg cover following dormant-season fire is consistent with studies conducted in the South (Whitehead and McConnell 1979, Manley 1994) and other regions (Towne and Owensby 1984, Howe 2000). Disking in November or March were the only treatments that significantly reduced planted nwsg density. Strip-herbicide applications failed to reduce planted nwsg cover. September burn failed to reduce nwsg density; however, repeated burns may yield different results (Howe 1994, 2000).

Adequate nesting cover is often limiting for bobwhites (Dimmick et al. 2002). Important components for bobwhite nesting cover include senescent grass for nesting substrate and vertical cover for nest concealment (Roseberry and Klimstra 1984). Vertical structure was adequate for nest concealment across all treatments. Nwsg cover in disked plots (13 – 19%) was less than in areas used by nesting bobwhites (20 – 50%; Taylor and Burger 2000, Smith 2001, Szukaitis 2001). Planted nwsg cover was approximately 50% prior to treatment.

Bobwhites tend to nest in areas with scattered grass clumps rather than homogeneous swards (Roseberry and Klimstra 1984, Harris 1995). Research conducted in Tennessee observed greater nest success in fields with sparse broomsedge cover compared to fields dominated by broomsedge (Harris 1995). March burn increased nwsg cover; however, nesting habitat is influenced by the interspersion and juxtaposition of other cover types (Guthery and Bingham 1992). Increased grass cover may have limited the arrangement of cover types for nesting. Additionally, prescribed fire consumes senescent grass leaves, and usually results in a short term loss of nesting habitat (Rosene 1969, Dimmick 1971). Female bobwhites avoided recently burned old fields during the nesting season in Mississippi, while strip-disked fields and unmanaged old fields were preferred for nesting (Manley 1994). Unmanaged controls likely provided adequate nesting cover. Mowed and strip-herbicide plots may not have provided nesting cover during the first growing season following treatment because of a lack of overhead cover the initial presence of dense thatch.

Disking and March burn treatments reduced undesirable wsg cover, increased forb cover, decreased litter and litter depth and improved openness at ground level during the brooding period for bobwhites in 2004. Strip-herbicide application also improved ground level structure. Although vertical structure and overhead cover were improved by some treatments, both were adequate for bobwhite brood-rearing across all treatments and control.

Invertebrate availability is an important component of bobwhite brood-rearing habitat (DeVos and Muller 1993, Burger et al. 1993). Bobwhite chicks and laying females require macroinvertebrate food resources to meet daily protein requirements (Nestler 1942, Brennan and Hurst 1995). Abundant invertebrate communities are often associated with increased forb cover and plant species richness (Southwood 1979, Shelton and Edwards 1983, Jackson et al. 1987, Burger et al. 1993, Doxon 2005). Previous studies report increased invertebrate abundance following disking (Lee 1994, Manley et al. 1994, Yates et al. 1995, Madison et al. 1995), burning (Hurst 1972), and herbicide application (Madison et al. 1995). No increases in invertebrate density, biomass, or ordinal richness were detected following disking, burning, or herbicide treatment in this study. While burning and disking increased forb cover compared to control, no increases were detected in plant species richness. Increased plant species richness following strip herbicide application was the result of increases in unplanted nwsg, sedges, and undesirable cool-season grasses, rather than desirable forbs associated with greater invertebrate abundance.

Lack of treatment effects on invertebrate abundance or biomass may be attributed to several factors. Significant *P*-values are a function of a false null hypothesis and an adequate sample size (Johnson 1999). Biologically significant differences may not have been detected because of a small sample size, which increases the probability of Type II error. Furthermore, invertebrate response to some management practices may be short lived. Cancelado and Yonke (1970) found favorable effects of grassland invertebrates to burning lasted only a few weeks. Brief responses immediately following treatments would not have been detected in this study. Alternatively, previous studies used different methods to sample invertebrates. Samples collected using sweep nets may be biased by several factors (Whittaker 1952). Although vacuum sampling equipment, may provide a more representative estimate of invertebrate populations (Race 1960, Byerly et al. 1978), efficacy of invertebrate sampling techniques varies greatly with relation to vegetation structure (Southwood 1979, Palmer et al. 2001, Randel et al. 2006). The sampling method used in this study targeted invertebrates near ground level that were available to bobwhite chicks (Harper and Guynn 1998). Increases in the abundance of foliage dwelling invertebrates following disking would not have been detected if those invertebrates were present in the vegetation canopy, above the reach of foraging chicks.

Invertebrate abundance is unimportant if bobwhite chicks cannot forage effectively because of vegetation density. Based on an assessment of the nutritional requirements of bobwhites 1 – 14 days old (Palmer 1995), invertebrate abundance was sufficient for bobwhite broods within all treatments and control. Invertebrate *availability*, however, may have been limiting in areas with little openness at ground level. Management practices such as disking and burning improve vegetation structure and may increase foraging efficiency of bobwhite chicks, and therefore increase the availability of invertebrates, irregardless of abundance. Measuring openness at ground level (ground sighting distance) and overhead cover (angle of obstruction) may quantify the structure of "umbrella cover," often recommended for bobwhites, more accurately than estimating percent cover of vegetation, bare ground, and litter using a sampling frame.

Although disking and burning decreased desirable brushy cover, forb cover, vertical structure, overhead cover, and openness at ground level were improved. Bobwhites are hypothesized to exhibit some degree of interchangeability of function in cover types (Leopold 1933, Guthery 1999). Thus, some types of herbaceous cover, such as ragweed, partridge pea (*Chamaecrista fasciculata*), beggar's ticks (*Bidens* spp.) and pokeweed, may provide adequate loafing habitat in the absence of brushy cover, just as brushy cover, in turn, may provide feeding cover. The herbaceous cover in disked plots (primarily ragweed) likely provided adequate shade and concealment to function as thermal and escape cover during the growing season; however, adequate brushy cover is essential for predator avoidance during the winter.

Improvements in cover of bobwhite food plants one growing season following disking reflect the response of annual forbs, primarily common ragweed (*Ambrosia artemisifolia*). While cover of bobwhite food plants was likely sufficient across all treatments and control, improved bare ground and overhead cover following disking, may improve foraging efficiency and predator avoidance during winter. Cover of food plants appeared to decline within all treatments and control from 2004 to 2005. This may be a function of several factors. Above average rainfall may have improved food plant cover in 2004. In addition, food plants tend to decline as annual forbs are replaced by perennial forbs and grasses (Burger et al. 1990). Cover of food plants was reduced following increase in perennial nwsg in March burn, thistles and perennial cool-season grasses in disking treatments, and cool-season grasses and sedges in strip herbicide plots during the second growing season following treatment. In fact, the greatest cover of food plants in 2005 was in September burn, the most recently completed treatment.

CONCLUSIONS

Disking is recommended for decreasing nwsg cover in fields that have become rank. Plant community response to disking applied in fall and winter is relatively similar. Disking applied after mid-March may stimulate undesirable plants such as johnsongrass, crabgrass, and sicklepod (Carver et al 2001, Gruchy and Harper 2006). Undesirable plants such as thistles, Canadian horseweed (*Conyza canadensis*), and sericea lespedeza (*Lespedeza cuneata*) are stimulated by disturbance such as disking and burning. These plants present a paradox in early succession habitat management. The objective of management is to perpetuate or improve native plant communities through natural disturbance regimes; however, many non-native plants are adapted to exploit disturbed areas. Early succession habitat management requires disturbance through management practices. Therefore, non-native plants should be addressed aggressively using chemical, mechanical, or cultural methods to restore the function of the native plant community.

Burning fields during the dormant season is recommended for increasing nwsg density in fields with grass cover too sparse to provide adequate nesting structure. Additionally, burning improves habitat structure and may reduce cover of some undesirable plants. Mowing is not recommended for improving early succession habitat for bobwhites. Strip herbicide applications may produce more desirable results in areas with different seedbanks or following a prescribed fire. Although no change in grass density was detected following September burn, effects of growing-season fires on plant communities and subsequent wildlife response should be studied more closely on early succession habitat in the mid-South.

In areas where prescribed fire is not permitted, disking can be used to reduce litter and stimulate desirable plant communities. Fire serves an important biological role in early succession habitats. Managers should attempt to mimic natural disturbance regimes, including fire regimes, in wildlife management plans wherever possible. Management practices should be distributed through time and space over multiple spatial scales to maximize benefits to bobwhites as desirable responses to management may be short-lived.

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PART III

METHODS FOR CONTROLLING WOODY INVASION INTO OLD-FIELDS

ABSTRACT

Woody cover is an important component of northern bobwhite (*Colinus virginianus;* hereafter bobwhite) habitat; however, some species such as red maple (*Acer rubrum*), green ash (*Fraxinus pennsylvanica*), and sweetgum (*Liquidambar styraciflua*) grow aggressively and may become dominant. Six treatments with controls were implemented in a completely randomized design on an old-field planted to tall fescue, with extensive invasion by sweetgum, red maple, and other woody saplings to determine the most effective method for reducing coverage of undesirable woody plants. Treatments included August 2004 mowing, March 2004 burn, September 2004 burn, and July 2004 applications of triclopyr, imazapyr, and glyphosate. Resulting vegetation structure and composition were measured in July 2005. Woody cover was reduced by all treatments except mowing compared to control. Imazapyr, growing-season burn, and triclopyr were most effective at reducing woody cover. Cover of desirable legumes (*Chamaecrista* spp., *Desmodium* spp., *Lespedeza* spp.) was greatest in growing-season burn, imazapyr, and dormant-season burn treatments. Imazapyr increased coverage of blackberries (*Rubus* spp.), while triclopyr increased coverage of warm- and cool-season grasses. Results suggest growing-season fire in September was best at reducing woody plants and enhancing habitat for northern bobwhites. Growing-season fire resulted in the greatest coverage of desirable legumes, reduced litter depth and increased percent bare ground. If burning is not possible, applications of imazapyr or tryclopyr may be suitable alternatives.

INTRODUCTION

Managing woody cover for bobwhites can be difficult. In general, optimal cover for bobwhites consists of an annual forb community for feeding and brood-rearing, a perennial grass component for nesting structure, and early successional shrubs to provide cover and mast (Stoddard 1931, Rosene 1969). These plant communities occur along a successional gradient that may be manipulated by management practices (Rosene 1969). While it is widely understood burning is an effective management practice used to control the structure and composition of early successional vegetation, the effects of season, intensity, and frequency of fire are not completely understood.

In the South, desirable early successional "brushy" cover may include sumacs (*Rhus spp.*), plums (*Prunus spp.*), and blackberries. Unfortunately, "late successional species" (Lorimer 2001) commonly invade fields without management. Species such as sweetgum, green ash, winged elm (*Ulmus alata*), and red maple (*Acer rubrum*) do not provide optimal structure for bobwhites and may shade out desirable plant species. Undesirable woody plants can be controlled by using fire or disking, but these techniques may become less effective once plants advance past the seedling stage. Also, in some areas, use of fire is not a management option.

Advances in forest herbicides may provide managers with a means to control undesirable woody vegetation and improve bobwhite habitat (Jones and Chamberlain 2004, Miller and Miller 2004, Welch et al. 2004). Past research evaluated the use of herbicides and fire on wildlife habitat in power line rights-of-way (Arner et al. 1976, Bramble and Byrnes 1976). Several studies examined the effects of forest herbicides and fire used to manage encroaching hardwoods on wildlife habitat in pine stands in the

South (Jones and Chamberlain 2004, Welch et al. 2004, Edwards et al. 2004). Research in Mississippi and Georgia tested the effects of forest herbicides for improving bobwhite habitat and controlling bermudagrass (*Cynodon dactylon*) on retired pasture sites (Hamrick et al. 2005, Bond et al. 2005). However, no study has examined the effectiveness of herbicide application on reducing undesirable woody plants in CRP fields and compared those treatments with different applications of prescribed fire. The objectives of this study were to determine the effects of late growing-season prescribed fire, dormant-season prescribed fire, mowing, and applications of three herbicides on encroaching hardwoods and resulting habitat for bobwhites in a CRP old-field.

METHODS

Study area

Treatments were implemented on a privately owned 18-acre field in Benton County, Tennessee. The area was sown to tall fescue (*Festuca arundinacea*) when it was enrolled into the CRP in 1985. Tall fescue coverage was reduced as undesirable woody species pioneered into the field from an adjacent hardwood stand. The field had been mowed annually since the early 1990s in an attempt to control invading hardwoods. The portion of the field used in this study was uniformly covered by invading hardwoods.

Treatment application

Treatments were applied to 0.1 ha plots (0.25-ac) in a completely randomized design with four replicates per treatment (28 plots total) in March 2004. Treatments included August 2004 mowing, March 2004 burn, September 2004 burn, and July 2004 applications of triclopyr (Garlon-4 at 5.60 kg ai/ha; 5qts/acre), imazapyr (Arsenal AC at

0.84 kg ai/ha; 24 oz/acre), and glyphosate (Gly-4 at 4.48 kg ai/ha; 4qts/acre). Treatment blocks were rectangular (15.2 × 67 m; 50 × 200 ft) to facilitate herbicide applications. Average flame heights were > 1 m (3 ft) for March burns and < 1 m (3 ft) for September burns. Herbicides were applied using an agricultural spray coupe with a 15.2-m (50-ft) boom and a total spray volume of 190.2 L/ha (20 gal/ac). All plots were mowed prior to the study in August 2003, so herbicides could be applied using ground equipment in July 2004. Non-ionic surfactant was added to each herbicide application at 0.25% total spray volume to improve herbicide uptake. Control blocks did not receive any treatment after mowing in August 2003.

Data collection

Total vegetation cover, litter, bare ground, and coverage of vegetation canopy classes, including desirable legumes, other forbs, warm-season grases, cool-season grasses, brambles, sedges, and woody plants, were estimated to the nearest 5% using a 1-m^2 subsample plot (Bonham 1989) at 3 locations within each treatment plot. Desirable legumes included members of *Desmodium*, *Lespedeza*, and *Chamaecrista*. Legumes considered undesirable (i.e, *Lespedeza cuneata*) were counted as forbs. Additionally, the total number of woody stems within each subsample plot was recorded and litter depth at plot center was measured. Plant species composition was characterized along a 10-m line transect (Canfield 1941) bisecting each plot. The distance along each transect occupied by each plant species was measured. Vegetation height was measured at 0, 5, and 10 m along each line transect.

Data analysis

A one-way analysis-of-variance (ANOVA) with subsampling error was used to test for differences in vegetation structure and composition among treatments (Montgomery 1997). Vegetation composition was analyzed by grouping plant species into biologically meaningful associations in order to avoid increased type I error rates that may result from running multiple ANOVAs on the same data set (Neter et al. 1996). Statistical tests were preformed on cover of undesirable woody species (sweetgum, red maple, winged elm), desirable woody species (blackberries and sumacs), bobwhite food plants (described in Part I), desirable native warm-season grasses (broomsedge bluestem [*Andropogon virginicus*]), undesirable cool-season grasses (tall fescue, cheatgrass [*Bromus tectorum*], little barley [*Hordeum pusillum*]), undesirable warm-season grasses (johnsongrass [*Sorghum halepense*] and crabgrass [*Digitaria* spp.]), undesirable forbs (thistles [*Cirsium* spp.]and Canadian horseweed [*Conyza canadensis*]), and species richness within each plot. Mean vegetation height was collected and analyzed with the vegetation composition dataset.

The assumptions of ANOVA, normality of residuals and equality of variances, were assessed by the Shapiro-Wilk test ($W \geq 0.90$) and Levene's test ($P \leq 0.05$) respectively, using PROC UNIVARIATE (SAS Institute 2003). Variables failing to meet the assumptions of ANOVA were amended using appropriate transformations. Statistical tests were preformed on 12 variables characterizing vegetation structure and 9 variables characterizing vegetation structure. If F-tests were significant ($P < 0.05$), pair-wise differences between treatments were tested using Tukey's Honest Significant Difference. All tests were performed using PROC GLM in the SAS® system (Littell et al. 2002).

RESULTS

Vegetation Structure

Percent cover differed among treatments for total vegetative cover, litter, bare ground, forbs, legumes, woody species, cool-season grasses, warm-season grasses, litter depth, and total woody stems (Table 3.1). Vegetation height was also different among treatments (Table 3.2). Woody cover and number of woody stems were reduced by all treatments except August mowing compared to control. Imazapyr, September burn, and triclopyr most effectively reduced woody cover. Desirable legume cover was highest in growing-season burn and imazapyr treatments. Bare ground was greatest in September burn. Triclopyr increased cool- and warm-season grass cover. Herbicide applications increased litter, while September burn increased bare ground. Litter depth was greater in glyphosate than control or burn treatments.

Vegetation composition

Forty-seven plant species were recorded across all treatments in July 2005. Mean species richness did not differ among treatments. Treatments differences were detected for coverage of undesirable woody species, desirable woody species, bobwhite food plants, desirable native warm-season grasses, undesirable cool-season grasses, and vegetation height. Cover of undesirable woody species was reduced by all treatments except mowing compared to control. Desirable woody cover was lower in imazapyr than triclopyr treatments. Cover of bobwhite food plants was greater in Imazapyr and September burn treatments than control, mowing, and triclopyr treatments. While a treatment effect was detected for desirable native warm-season grass cover, Tukey's HSD test failed to separate the means. Undesirable cool-season grasses were greatest following

Table 3.1 Mean vegetation structural characteristics following treatments in an old-field, Benton County, Tennessee, July 2005.

	Treatment						
	Control	August mow	March burn	September burn	Imazapyr	Glyphosate	Triclopyr
Variable[1]	$\bar{x}$ [2] (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)
Cover	97.5 (1.7) a	91.7 (2.1) ab	90.0 (2.4) ab	84.5 (3.4) bc	81.7 (2.0) bc	73.8 (2.7) c	82.5 (3.6) bc
Bare	0.0 (0.0) c	1.7 (1.3) bc	5.8 (1.8) b	14.5 (3.3) a	1.7 (1.1) bc	2.5 (1.3) bc	1.7 (1.1) bc
Litter	3.3 (1.7) cd	7.5 (1.9) bc	4.6 (5.3) cd	0.8 (0.8) d	16.7 (2.5) ab	23.7 (2.7) a	15.8 (3.4) ab
Litter depth	1.5 (0.4) b	1.8 (0.3) ab	0.3 (0.2) ab	0.1 (0.1) c	1.8 (0.3) ab	3.3 (0.8) a	2.3 (0.2) ab
Forb	25.8 (5.6) b	40.0 (6.7) ab	39.2 (7.1) ab	39.2 (7.1) ab	62.5 (6.6) a	55.0 (6.1) a	51.2 (8.3) ab
Legume	6.2 (2.9) c	14.6 (3.8) bc	24.5 (5.2) b	54.2 (6.7) a	28.3 (5.9) b	15.0 (4.1) bc	13.3 (4.1) bc
Woody	80.4 (7.6) a	65.8 (7.0) ab	50.4 (6.1) bc	14.2 (3.1) d	13.3 (2.6) d	32.1 (6.4) cd	15.8 (3.5) d
Brambles	15.0 (5.7) a	15.4 (3.2) a	19.1 (5.2) a	19.2 (5.3) a	28.8 (7.4) a	13.8 (4.0) a	0.0 (0.0) b
CS grass	3.7 (2.5) bc	7.0 (3.0) bc	4.5 (1.6) bc	0.0 (0.0) c	4.5 (1.6) bc	11.7 (3.1) b	29.6 (7.2) a
WS grass	5.8 (2.8) b	7.1 (2.6) b	4.1 (2.0) b	10.8 (3.4) b	1.3 (1.3) b	5.4 (3.7) b	29.6 (8.8) a
Woody stems	4.8 (0.6) a	4.5 (0.5) a	2.6 (0.4) b	1.5 (0.4) b	1.5 (0.3) b	2.7 (0.5) b	1.5 (0.3) b

[1] Cover = total vegetative cover (%), Bare = bareground (%), Litter = litter cover (%), Litter depth = litter depth (cm), Forb = forb cover (%), Legume = desirable legume cover (%), Woody = woody cover (%), Brambles = cover of *Rubus* spp. (%), CS grass = cool-season grass cover (%), WSgrass = warm-season grass cover (%), Woody stems = number of woody stems per m^2.

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

triclopyr application. Vegetation height was greater in control than in all treatments except dormant season burn (Table 3.2).

DISCUSSION

Woody cover is important to bobwhites (Cram et al. 2002). Taylor and Burger (2000) reported bobwhite broods in Mississippi selectively used habitats with greater canopy coverage of woody species (44.3%) than random sites (21.7%). Bobwhites in Illinois nested in old-fields with 20% woody cover (Roseberry and Klimstra 1984). Cram et al. (2002) observed a threshold-like increase in bobwhite abundance relative to woody cover < 2m; however, Guthery (1999) hypothesized an upper threshold to woody cover likely exists where too little herbaceous cover is present, resulting in a loss of usable space for bobwhites. Welch et al. (2003) defined severe woody invasion in pine uplands in Florida as areas with woody stem densities > 5 stems/m^2. Our study area was severely invaded by undesirable woody species (4.8 stems/m^2) and as a result, provided suboptimal bobwhite habitat.

The Northern Bobwhite Conservation Initiative states adequate nesting and brood rearing habitat often limit bobwhite populations in the South (Dimmick et al. 2002). Suitable bobwhite nesting habitat generally consists of 40 – 60% vegetative canopy cover of grasses suitable for nesting, 40 – 60 cm in height (Schroeder 1985). Additionally, bare ground is an important component of bobwhite nesting habitat (Rosene 1969). Triclopyr applications maintained greater warm-season grass coverage than all other treatments. Warm-season grasses, such as broomsedge, provide important nesting cover for bobwhites (Dimmick 1974, Roseberry and Klimstra 1984). panicgrass (*Dichanthelium*

Table 3. 2 Mean vegetation composition characteristics measured using 10-m line transects following treatments in an old-field, Benton County, Tennessee, July 2005.

	Treatment																				
	Control			August mow			March burn			September burn			Imazapyr			Glyphosate			Triclopyr		
Variable[1]	$\bar{x}$ [2]	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)		$\bar{x}$	(SE)	
Undesirable woody	8.93	(0.22)	a	6.15	(0.56)	ab	2.66	(1.18)	bc	1.04	(0.42)	c	1.90	(0.20)	bc	2.18	(0.73)	bc	1.34	(0.50)	c
Desirable woody	0.87	(0.43)	ab	0.43	(0.43)	ab	1.16	(0.66)	ab	0.85	(0.85)	ab	4.50	(1.01)	a	0.37	(0.37)	ab	0.00	(0.00)	b
Bobwhite food plants	0.98	(0.42)	c	1.66	(0.71)	c	1.98	(0.83)	bc	5.50	(0.47)	ab	6.40	(1.22)	a	2.43	(0.51)	bc	1.07	(0.83)	c
Desirable nwsg	0.37	(0.22)	a	0.45	(0.33)	a	1.90	(1.48)	a	1.63	(0.67)	a	0.07	(0.07)	a	0.00	(0.00)	a	1.45	(0.52)	a
Undesirable csg	0.00	(0.00)	b	0.05	(0.05)	b	0.08	(0.08)	b	0.00	(0.00)	b	0.00	(0.00)	b	0.00	(0.00)	b	0.43	(0.13)	a
Undesirable grasses	0.20	(0.13)	a	0.13	(0.09)	a	0.13	(0.13)	a	0.07	(0.07)	a	0.00	(0.00)	a	0.53	(0.29)	a	0.67	(0.48)	a
Undesirable forbs	0.07	(0.07)	a	0.07	(0.03)	a	0.03	(0.03)	a	0.15	(0.15)	a	0.20	(0.20)	a	0.92	(0.42)	a	0.20	(0.20)	a
Species richness	11.33	(0.67)	a	10.67	(0.33)	a	12.00	(1.15)	a	14.67	(1.20)	a	9.67	(1.20)	a	10.33	(0.88)	a	12.00	(3.00)	a
Vegetation height	1.62	(0.19)	a	1.04	(0.08)	b	1.30	(0.09)	ab	0.92	(0.13)	bc	0.94	(0.03)	bc	0.52	(0.04)	c	0.84	(0.06)	bc

[1] Undesirable woody = cover of undesirable woody plants (m), Desirable woody = cover of desirable brushy cover (m), such as blackberries and sumac, Bobwhite food plants = cover (m) of plants producing seed eaten by bobwhites, Desirable nwsg = cover of desirable native warm-season grasses, such as broomsedge bluestem (m), Undesirable csg = undesirable cool-season grass cover (m), Undesirable wsg = undesirable warm-season grass cover (m), Undesirable forbs = undesirable forb cover (m), Species richness = number of species per plot, Vegetation height = average vegetation height (m).

[2] Means within rows followed by unlike letters are different by one-way ANOVA and Tukey's HSD test ($P < 0.05$).

Warm-season grasses recorded on the study area included, broomsedge bluestem, beaked panicgrass (*Panicum anceps*), low panicgrass (*Dichanthelium* spp.), fall panicgrass (*Panicum dichotomiflorum*), and johnsongrass. Triclopyr applications also increased coverage of undesirable cool-season grasses. Non-native cool-season grasses, such as tall fescue, do not provide adequate bobwhite habitat (Barnes et al. 1995).

Burger et al. (1990) described optimal bobwhite brood cover as fields with diverse annual forb communities produced by recent (< 3 years) soil disturbance (i.e., disking or burning). Bobwhite broods feed heavily on invertebrates (Stoddard 1931); therefore, bobwhite brood habitat quality is directly related to invertebrate availability (Hurst 1972, Jackson et al. 1987, DeVos and Mueller 1993). Although invertebrate availability may be highly variable, greater invertebrate abundance and diversity may be associated with diverse plant communities (Shelton and Edwards 1983). Grass monocultures, regardless of type, support relatively few invertebrates (Fettinger et al. 2002). Availability of invertebrates to chicks is determined largely by vegetation density at ground level, which determines foraging efficiency of chicks (Hurst 1972).

All treatments increased percent forb cover relative to control. Although no treatment effects were observed in this study for plant species richness, all treatments met species richness requirements for bobwhite brood-rearing habitat (Schroeder 1985). Increase in desirable legumes by burning and imazapyr treatments likely enhanced brood-rearing habitat (Jones and Chamberlain 2003). Arner et al. (1976) found desirable legume response after burning in power line rights-of-ways was inconsistent and depended on soil fertility and past land use. Bobwhite broods in Mississippi and Florida used areas with mean bare ground cover > 20% (Taylor and Burger 2000, DeVos and Mueller

1993). Late growing-season burning produced the most cover of bare ground in our study; however no treatment produced adequate amounts of bare ground to be considered optimal brood rearing habitat (Schroeder 1985). Although dormant-season burning did not provide the greatest decrease in woody cover (the primary objective of this study), coverage of undesirable woody plants such as sweetgum was reduced, and bobwhite brooding habitat benefits were likely increased because sweetgum out-competes desirable forbs and legumes (Jones and Chamberlain 2003).

Growing-season fire has been used to control undesirable hardwoods in pine stands in the South. Rosene (1969) stated growing-season fire would destroy nests, eggs, and broods of birds and should be used only when necessary to control invading hardwoods. Fields with severe woody invasion similar to the one used in our study do not provide suitable nesting or brood rearing habitat for bobwhites because of a lack of nesting structure, annual plant communities, and adequate bare ground. Growing-season fire in September is recommended in areas where bobwhite nesting and brood-rearing is limited by undesirable woody encroachment.

While September burning is recommended to manage CRP fields invaded by undesirable woody species, burning may not be possible in many areas. In that case, applications of imazapyr or tryclopyr provide a suitable management alternative for woody control. Imazapyr may provide greater brood-rearing and feeding habitat benefits than triclopyr because it has less adverse effects on legumes and blackberry. Although triclopyr applications increased desirable warm-season grass coverage, bobwhite habitat benefits are reduced when cool-season grasses such as tall fescue (Barnes et al. 1995) and orchardgrass (*Dactylis glomerata*) are present. Invasive plants such as sericea lespedeza, tall fescue, and undesirable woody species should be treated aggressively, as negative effects of these plants will only worsen over time. Once invasive plants are controlled, prescribed fire and disking may be used to set back succession in old-fields and maintain desirable plant communities for bobwhites.

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PART IV

MANAGEMENT RECOMMENDATIONS

ABSTRACT

I studied the effects of various management practices on tall fescue (*Festuca arundinacea*) fields, a planted native warm-season grass (nwsg) field, and a field invaded by undesirable woody species 2004 – 2005. I found biologically meaningful treatment differences in all three types of fields. I recommend fall applications of a glyphosate herbicide for eliminating tall fescue and other undesirable cool-season grasses, such as orchardgrass, timothy, and bluegrass. Applications of imazapic controlled undesirable grasses, such as johnsongrass (*Sorghum halepense*), and increased cover of broomsedge bluestem, a desirable native warm-season grass (nwsg). I recommend disking in fall or winter to reduce nwsg cover where grasses are too dense. Burning in September reduced undesirable woody cover and stimulated desirable legumes. When a desired composition of native grasses, desirable forbs, and brushy cover are present, I recommend burning in late March/early April on a 2 – 4-year rotation to maintaining desirable vegetation structure.

INTRODUCTION

I studied the effects of various management practices on tall fescue (*Festuca arundinacea*) fields, a planted native warm-season grass (nwsg) field, and a CRP field originally planted in tall fescue with nearly complete coverage of tree saplings during 2004 – 2005. These results provide insight across the entire range of seral stages comprising early succession habitat in Tennessee. Management recommendations are discussed in terms of improving habitat quality for bobwhites. I assume the goal of habitat management is to manipulate plant species composition to maximize useable space, or suitable, permanent cover, available to bobwhites (Guthery 2002).

RECOMMENDATIONS

Eliminating tall fescue

I found fields planted in tall fescue did not provide usable space in the form of brood-rearing, feeding, winter roosting, or summer loafing cover for bobwhites. Because usability of nesting cover is influenced by the interspersion and juxtaposition of other cover types (Guthery and Bingham 1992), nesting cover was also lacking in tall fescue fields. To improve fields for bobwhites, tall fescue must be eliminated using herbicides.

I recommend fall applications of a glyphosate herbicide (2 qts/acre) or imazapic (Plateau 12 oz/acre) for eliminating tall fescue. To improve herbicide uptake, fields should be hayed, grazed, or burned to remove tall fescue thatch prior to herbicide application. If fields must be mowed to prepare for spraying, I recommend mowing several times throughout the growing season to avoid building a dense thatch layer that will prevent herbicide contact with tall fescue leaves. Herbicides should be applied when tall fescue is actively growing at a height of 6 – 12 in. Addition of a nonionic surfactant (0.025% total solution by volume) or crop oil concentrate (1 qt/acre) will increase herbicide uptake.

I found disking in winter following fall herbicide application did not reduce tall fescue cover more than fall herbicide applications alone. Winter disking following fall herbicide application improved resulting plant communities for feeding and brood-rearing; however, fall herbicide applications without disking also provided useable space for feeding and brood-rearing. Disking improved winter cover one year following treatment because residual stems from annual forbs stimulated by disking, such as common ragweed (*Ambrosia artemisifolia*), remained upright throughout the dormant season. Although fallow field vegetation does provide winter roosting habitat for bobwhites, it is unlikely any treatment provided usable space in the first winter following treatment application because desirable grass and shrub cover were lacking. Thus, I do not recommend disking during the first winter following herbicide application. Delaying disking until subsequent years following herbicide application may be more beneficial in terms of bobwhite habitat quality and cost effectiveness.

I found desirable nwsg, primarily broomsedge bluestem (*Andropogon virginicus*), in each field during the first and second growing season following fall herbicide applications. Little bluestem (*Schizachyrium scoparinum*), big bluestem (*Andropogon gerardii*), split-beard bluestem (*Andropogon ternarius*), indiangrass (*Sorghastrum nutans*), and bushy bluestem (*Andropogon glomeratus*) were also recorded, though not at each study area. I contend commonly planted nwsg, such as big bluestem, little bluestem, indiangrass, switchgrass (*Panicum virgatum*), and sideoats gramma (*Bouteloua curtipendula*), provide no better structure for bobwhites than broomsedge bluestem because broomsedge remains upright upon senescence, providing vertical cover throughout winter and excellent nesting substrate the following growing season.

These results indicate cover of desirable nwsg > 20% (2 m of 10-m transect) can be achieved two growing seasons following tall fescue eradication without planting. Nwsg response will vary based on localized seedbanks. Managed old-fields with < 20% nwsg cover may also provide usable space for bobwhites, though nesting cover may be limiting. While these results, as well as those from other studies, indicate imazapic is effective in controlling undesirable plants and increasing desirable nwsg cover (Harper et al. 2002), I found imazapic did not remove, and in fact increased, cover of orchardgrass, timothy, and bluegrass. I found orchardgrass structurally identical to tall fescue. I recommend fall applications of glyphosate for eliminating non-native cool-season perennial grasses. Glyphosate will kill actively growing grasses; however, nwsg should not be affected by glyphosate applied in the fall when they are dormant.

Managing the seedbank

Management prescriptions following perennial cool-season grass eradication should be determined based on seedbank response. Undesirable warm-season grasses, such as johnsongrass, broadleaf signalgrass (*Brachiaria platyphylla*), goosegrass (*Eleusine indica*), and crabgrass (*Digitaria* spp.), and forbs, such as thistles (*Cirsium* spp.), Canadian horseweed (*Conyza canadensis*), pigweeds (*Amaranthus* spp.), and sericea lespedeza (*Lespedeza cuneata*), may dominate fields quickly, inhibiting more desirable plants and reducing the diversity of cover types in a field. Although a small number of undesirable plants may be controlled using cultural methods (i.e., mowing, burning, altering timing of disturbance), most require herbicide applications. Successful weed control strategies often include using a combination of techniques. For instance, disking or burning to stimulate undesirable plants in the seedbank for herbicide application. Properly timing herbicide applications and using selective or preemergence herbicides may improve control of various undesirable plants and may not harm various desirable native plants. Multiple herbicide applications are often required to purge undesirable plants from the seedbank (Harper et al. 2007).

If johnsongrass, crabgrass, goosegrass, broadleaf signalgrass, or yellow nutsedge (*Cyperus esculentus*) are known to be present in the seedbank, imazapic should be applied preemergence for maximum effectiveness (Plateau 6 – 10 oz/acre, Journey 16 – 32 oz/ac). Imazapic (Plateau 6 – 12 oz/acre) or sulfosulfuron (Outrider 2 oz/ac) may be applied post-emergence, with the addition of a non-ionic surfactant (0.25% total solution by volume), for undesirable grass control. Bermudagrass (*Cynodon dactylon*) should be eliminated using a single postemergence application of imazapyr (Arsenal AC 24 oz/ac; Bond et al 2006). Nimblewill (*Muhlenbergia schreberi*) and dallisgrass (*Paspalum dilatatum*) can be controlled using glyphosate. Undesirable forbs, such as cocklebur (*Xanthium strumarium*), sicklepod (*Senna obtusifolia*), pigweeds, horseweed, and thistles, may be controlled using 2-4,D (2 – 3 pt/ac), 2-4,DB (Butyrac 2 – 3 qt/ac), dicamba (Banvel 8 – 16 oz/ac), or other broadleaf selective herbicides. Some undesirable plants, such as sericea lespedeza, require more specialized herbicide applications (e.g., triclopyr, metsulfuron methyl, aminopyralid, etc.). Occasionally, nwsg and desirable forbs may be negatively impacted because no herbicide can selectively remove some undesirable plants (i.e., bermudagrass, nimblewill) without harming various nwsg and forbs. If desirable plant communities including nwsg, forbs, and shrubs, do not emerge from the seedbank following elimination of tall fescue, planting may be necessary.

I do not recommend planting nwsg and desirable forbs until the second growing season following tall fescue elimination. Waiting at least two growing seasons to plant allows the seedbank adequate time to respond and increases weed control options. Eliminating undesirable plants, such as bermudagrass and sericea lespedeza, which may respond following tall fescue elimination, is especially important because many undesirable plants cannot be selectively removed without harming desirable nwsg and forbs once they have been planted. Effective weed control is especially important when native grasses are planted at low rates (< 6 PLS lb/ac), because bare ground space between grass bunches, necessary for bobwhite habitat, is quickly exploited by aggressive undesirable plants.

Managing established native warm-season grass fields

Once nwsg and associated forbs are established, either through seedbank response or planting, I recommend managing plant communities using prescribed fire and disking. Dormant-season fire can be used to increase nwsg cover when it is too sparse, stimulate desirable forbs, reduce litter, increase bareground, and in some instances, reduce undesirable plants. Disking November – March reduces nwsg cover when it is too dense, improves ground level structure, increases bobwhite food plants, and may improve winter cover in the absence of desirable brushy cover. Late-growing season fire (September) reduces undesirable woody cover and stimulates desirable legumes in the seedbank.

In areas where prescribed fire cannot be conducted, herbicides and mechanical practices can be used to manage habitats. Imazapic applications may increase nwsg cover, while disking can stimulate desirable forbs in the seedbank. Strip herbicide application (conducted by spraying a grass-selective herbicide from alternating nozzle tips) did not result in significant habitat improvements. Triclopyr (Garlon 4 qt/ac) or imazapyr (Arsenal AC 24 oz/ac) may be applied to control unwanted woody species.

I found plots with dense big bluestem and indiangrass provided limited useable space in winter after grasses fell over in the absence of forbs and shrubs to lodge against. Broomsedge bluestem and switchgrass remained upright throughout the winter. Although late growing season burning and fall disking produce desirable plant communities the following growing season, both practices result in temporary reduction of winter cover. I recommend disking applied later in the dormant season (February – March), as it may produce similar habitat benefits and leave more undisturbed cover for a longer period during winter. Likewise, burns conducted later in the dormant season (March – April) have less of an impact on useable space in the winter than burns conducted early in the dormant season (January – February).

I recommend management practices be applied based on their ability to increase usable space within a field. For example, disking strips in a field with dense nwsg increases usable space by interspersing feeding cover throughout the field and juxtaposing nesting and brooding cover within the field. In contrast, burning an entire field with dense nwsg in March may not improve habitat quality because grass density will limit usable space. Mowing early succession habitats did not increase, and likely decreased, useable space. Mowing should only be used in early successional habitats to control undesirable annual plants in areas where problems are severe and selective herbicide applications are not possible. Late-growing season fire or herbicide applications reduce undesirable woody cover, such as sweetgum (*Liquidambar styraciflua*) and red maple (*Acer rubrum*), and may increase useable space in fields where feeding and nesting resources are limiting. Desirable brushy cover, such as blackberry (*Rubus* spp.) thickets and sumac (*Rhus* spp.) mottes, provide fully usable space (year-round cover) and should be relished by bobwhite managers.

My recommendations are based on plant community responses to management practices in the context of bobwhite habitat. Not all of these recommendations are permitted under provisions of various Farm Bill programs (i.e., CRP, WHIP, GRP), based on soil conservation policies set forth by state technical committees. Policy should not dictate wildlife management practices. Although previous research found low intensity disturbance did not result in unacceptable soil loss on CRP in Mississippi and Missouri (Greenfield et al. 2002), I recommend further research examining the effects of management techniques (heavy seasonal disking, using the seedbank instead of planting after tall fescue eradication) on soil loss. If the soil conservation objectives of Farm Bill programs are compatible with effective bobwhite management practices, and I suspect they are, Farm Bill policies should be adapted to suit wildlife biology.

IMPLICATIONS

Landscape-scale habitat management efforts are necessary to reverse the bobwhite population decline (Brennan 1991, Williams et al. 2004). While my recommendations are fine-scaled, implications from this research are intended to influence field management on private lands, federally subsidized and otherwise. One goal of the Northern Bobwhite Conservation Initiative (NBCI), a comprehensive management plan designed to restore bobwhite populations, is the establishment of nwsg and associated forbs on private lands (Dimmick et al. 2002). In Tennessee, the NBCI calls for the establishment of more than 600,000 acres of nwsg on Conservation Reserve Program (CRP) fields and improvable agricultural lands (including row crops and hay/pasture; Dimmick et al. 2002). Planting nwsg is expensive and often logistically taxing. Results of this study indicate usable space for bobwhites may be created without planting nwsg where desirable plants such as broomsedge are present in the seedbank.

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APPENDICES

APPENDIX A

Additional Tables from Part I: EFFECTS OF HERBICIDES AND DISKING ON TALL FESCUE RENOVATION AND RESULTING HABITAT FOR BOBWHITES

Appendix A.1 Scientific and common names of plants considered to produce seed preferred by bobwhites encountered along 10-m line transects across multiple treatments in three fields in Tennessee, 2004 - 2005.

Scientific name	Common name
Acalypha virginica	three seeded mercury
Ambrosia artemisiifolia	common ragweed
Bidens spp.	beggar's ticks
Chamaecrista fasciculata	partridge pea
Desmodium spp.	beggar's lice
Dichanthelium spp.	low panic grass
Helianthus spp.	sunflower spp.
Kummerowia striata	kobe lespedeza
Lespedeza spp.	lespedezas[1]
Panicum spp.	panic grasses[2]
Paspalum spp.	paspalums[3]
Phytolacca americana	American pokeweed
Polygonum pensylvanicum	Pensylvania smartweed
Rubus spp.	blackberry
Trifolium pratense	red clover
Trifolium repens	white clover
Vica spp.	vetch spp.

[1] Does not include sericea lespedeza

[2] Does not include fall panicum

[3] Does not include dallisgrass

Appendix A.2 Scientific and common names of native warm-season grasses considered adequate nesting substrate for bobwhites encountered along 10-m line transects across multiple treatments in three fields in Tennessee, 2004 - 2005.

Scientific name	Common name
Andropogon virginicus	broomsedge bluestem
Andropogon glomeratus	bushy bluestem
Schizachyrium scoparium	little bluestem
Sorghastrum nutans	indiangrass

Appendix A.3 Scientific and common names of plants considered undesirable forbs encountered along 10-m line transects across multiple treatments in three fields in Tennessee, 2004 - 2005.

Scientific name	Common name
Amaranthus spp.	pigweeds
Cirustium spp.	thistles
Conyza canadensis	horseweed
Erechtites hieraciifolia	American burnweed
Plantago lanceolata	narrowleaf plantain
Rumex crispus	curly dock
Solanum carolinense	horse nettle
Sonchus asper	spiny sow thistle
Xanthium strumarium	cocklebur

Appendix A.4 Scientific and common names of plants considered undesirable grasses encountered along 10-m line transects across multiple treatments in three tall fescue fields, Tennessee, 2004 - 2005.

Scientific name	Common name
Brachiaria platyphylla	broadleaf signal grass
Digitaria spp.	crabgrasses
Holcus lanatus	velvetgrass
Microstegium vimineum	Japanese stilt grass
Muhlenbergia schreberi	nimblewill
Panicum dichotomiflorum	fall panic grass
Paspalum dilatatum	dallisgrass
Phleum pratense	timothy
Poa annua	bluegrass
Sorghum halepense	johnsongrass

Appendix A.4 Scientific and common names of all plants recorded in multiple treatments in three tall fescue fields, Tennessee, 2004 – 2005.

Scientific name	Common name
Acalypha virginica	three seeded mercury
Acer negundo	boxelder
Acer rubrum	red maple
Acer saccharinum	silver maple
Achillea millefolium	common yarrow
Agalinis tenuifolia	slenderleaf false foxglove
Agrimonia parviflora	harvestlice
Agrostis ascicula	red top
Amaranthus spp.	Pigweed spp.
Ambrosia artemisiifolia	common ragweed
Ambrosia trifida	giant ragweed
Andropogon virginicus	broomsedge bluestem
Andropogon glomeratus	bushy beardgrass
Apocynum cannabinum	Indian hemp
Artemisia spp.	Mugwort
Asclepias spp.	Milkweed spp.
Aster spp.	Aster spp.
Aster pilosus	oldfield aster
Barbarea spp.	Yellow rocket
Bidens spp.	Devil’s beggars ticks
Boehmeria asciculate	smallspike false nettle
Brachiaria platyphylla	broadleaf signal grass
Capsella bursa-pastoris	sheppards purse
Cardamine ascicu	hairy bitter cress
Cardiospermum halicacabum	ballon vine
Carex spp.	Sedge spp.
Celtis spp.	Hackberry spp.
Cerastium glomeratum	mouse ear chickweed
Chamaecrista asciculate	partridge pea
Chamaesyce spp.	Sandmat spp.
Cirsium vulgare	bull thistle
Cirustium spp.	Thistle spp.

Appendix A.4 (continued).

Scientific name	Common name
Clematis virginiana	devil's darning needles
Conoclinium coelestinum	blue mistflower
Conyza canadensis	horseweed
Coreopsis tinctoria	golden tickseed
Cornus spp.	dogwood spp.
Cyperus esculentus	yellow nutsedge
Dactylis glomerata	orchardgrass
Daucus carota	Queen Anne's lace
Desmodium spp	beggar's ticks
Dichanthelium clandestinum	deertounge
Dichanthelium spp.	low panic grass
Digitaria spp.	crabgrass spp.
Diodia teres	poorjoe
Diodia virginiana	Virginia buttonweed
Diospyros virginiana	persimon
Duchesnea indica	Indian strawberry
Echinochloa crus-galli	barnyardgrass
Elephantopus carolinianus	Carolina elephants foot
Elymus virginicus	Canada wild rye
Erechtites hieraciifolia	American burnweed
Erigeron spp.	fleabane spp.
Eupatorium purpureum	sweetscented joe pye weed
Eupatorium rotundifolium	roundleaf boneset
Eupatorium serotinum	late flowering thoroughwort
Festuca arundinacea	tall fescue
Fraxinus pennsylvanica	green ash
Gnaphalium obtusifolium	rabit tabbacoo
Helianthus spp.	sunflower spp.
Helianthus annuus	annual sunflower
Helianthus hirsutus	hairy sunflower
Holcus lanatus	velvetgrass
Hypericum multilum	dwarf St. John's wort
Hypericum punctatum	spotted Saint Johnswort
Ipomoea spp.	morning glory
Juncus spp.	rush spp.

Appendix A.4 (continued).

Scientific name	Common name
Juncus effusus	common rush
Kummerowia stipulacea	korean lespedeza
Kummerowia striata	kobe lespedeza
Lactuca serriola	prickly lettuce
Lepidium virginicum	virgina pepperweed
Lespedeza cuneata	sericia lespedeza
Leucanthemum vulgare	oxeye daisy
Ligustrum sinense	Chinese privet
Liquidambar styraciflua	sweetgum
Liriodendron tulipifera	yellow poplar
Lobelia inflata	lobelia infalata
Lonicera japonica	Japanese honeysuckle
Ludwigia alternifolia	seedbox
Microstegium vimineum	Japanese stilt grass
Mikania scandens	climbing hemp vine
Mollugo verticillata	carpetweed
Muhlenbergia schreberi	nimblewill
Oenothera spp.	primrose spp.
Oxalis stricta	common yellow oxalis
Panicum anceps	beaked panic grass
Panicum dichotomiflorum	fall panic grass
Panicum rigidulum	redtop panicgrass
Parthenocissus quinquefolia	virgina creeper
Paspalum spp.	paspalum spp.
Paspalum dilatatum	dallisgrass
Passiflora incarnata	passion flower
Phleum pratense	timothy
Physalis virginiana	Virgina ground cherry
Phytolacca americana	American pokeweed
Plantago lanceolata	narrowleaf plantain
Plantago rotudifolia	broadleaf plantain
Plantago virginica	Virginia plantain
Pluchea camphorata	stink weed
Poa annua	bluegrass
Polygonum pensylvanicum	Pensylvania smartweed

Appendix A.4 (continued).

Scientific name	Common name
Potentilla simplex	common sinquefoil
Prunella vulgaris	common selfheal
Prunus serotina	black cherry
Pycnanthemum spp.	wild mint
Ratibida pinnata	yellow coneflower
Rhexia virginica	meadow beauty
Rhus copallinum	winged sumac
Rosa multiflora	multiflora rose
Rubus spp.	blackberry spp.
Rudbeckia hirta	black eyed Suzan
Rumex spp.	dock spp.
Rumex acetosella	common sheep sorrel
Rumex crispus	curly dock
Satureja vulgaris	wild basil
Schizachyrium scoparium	little bluestem
Scutellaria spp.	skull cap spp.
Setaria faberi	giant foxtail
Setaria glauca	yellow bristle grass
Setaria viridis	green foxtail
Sida spinosa	prickly sida
Smilax spp.	greenbrier spp.
Solanum carolinense	horse nettle
Solidago spp.	goldenrod spp.
Sonchus asper	spiny sow thistle
Sorghastrum nutans	indiangrass
Sorghum halepense	johnsongrass
Symphoricarpos orbiculatus	coralberry
Taraxacum officinale	dandelion
Thlaspi arvense	field penny cress
Toxicodendron radicans	poison ivy
Tridens flavus	purpletop
Trifolium campestre	field clover
Trifolium pratense	red clover
Trifolium repens	white clover
Ulmus alata	winged elm

Appendix A.4 (continued).

Scientific name	Common name
unknown forb	unknown forb
unknown grass	unknown grass
unknown unknown	unknown unknown
Verbascum thapsus	mullen
Verbena urticifolia	white vervein
Vernonia gigantea	ironweed
Vica spp.	vetch spp.
Viola bicolor	field pansy
Vitis spp.	wild grape
Xanthium strumarium	cocklebur

Appendix A.6 Definition of variables used to quantify vegetation composition across three fields in Tennessee, 2004 - 2005.

Variable	Definition
Tall fescue	Mean distance of vegetative canopy along a 10-m line transect covered by tall fescue.
Orchardgrass	Mean distance of vegetative canopy along a 10-m line transect covered by orchardgrass.
Bobwhite food plant	Mean distance of vegetative canopy along a 10-m line transect covered by desirable bobwhite food plants.
Desirable native warm-season grasses	Mean distance of vegetative canopy along a 10-m line transect covered by native-grasses that provide some type of nesting, food or cover resource for bobwhites.
Forb weed	Mean distance of vegetative canopy along a 10-m line transect covered by invasive, non-native, or noxious broadleaf herbaceous plants.
Grass weed	Mean distance of vegetative canopy along a 10-m line transect covered by invasive, non-native, or noxious grasses. Does not include tall fescue or orchardgrass.
Bare	Mean distance along a 10-m line transect not covered by any type of vegetative canopy or litter.
Litter	Mean distance along a 10-m line transect covered by non-living vegetation in some state of decomposition.
Species richness	Total number of plant species encountered on line transects within each plot (experimental unit).
Vegetation height	Mean of vegetation height measurements recorded at 0, 5, and 10 m along a 10-m line transect.

Appendix A.7 Definition of variables used to quantify vegetation structure across three tall fescue fields,Tennessee, 2004 - 2005.

Variable	Definition
Visual obstruction reading (vertical structure)	Number of 0.1 m segments of Robel pole obstructed from view of an observer 4 m from pole at a height of 1 m. Measured in 5 cm increments.
Angle of obstruction	Angle of Robel pole with base anchored at sampling point and top portion placed against highest vegetation. Measured to nearest degree.
Visual obstruction distance	Distance (m) at which the lower 15 cm of robel pole is obstructed from the view of an observer at a height of 1 m.
Ground sighting distance	Distance (m) at which the lower 15 cm of robel pole is obstructed from the view of an observer looking through tube at a height of 15 cm.
Percent total canopy cover	Percent of sampling frame covered by vegetation. Estimated to the nearest 5 percent.
Percent bare ground	Percent of bare ground visible within a sampling frame. Estimated to the nearest 5 percent.
Percent litter	Percent of sampling frame covered by litter. Estimated to the nearest 5 percent.
Litter depth	Depth of litter (cm) in the center of the sampling frame.
Percent canopy forb	Percent of sampling frame covered by forbs. Estimated to the nearest 5 percent.
Percent canopy woody	Percent of sampling frame covered by woody vegetation. Estimated to the nearest 5 percent.
Percent canopy brambles	Percent of sampling frame covered by *Rubus* spp. Estimated to the nearest 5 percent.

Appendix A.7 (continued).

Variable	Definition
Percent canopy sedge/rush	Percent of sampling frame covered by *Juncus* spp. And *Carex* spp. Estimated to the nearest 5 percent.
Percent canopy warm-season grass	Percent of sampling frame covered by desirable and undesirable warm-season grasses. Estimated to the nearest 5 percent.
Percent canopy cool-season grass	Percent of sampling frame covered by all cool-season grasses including tall fescue. Estimated to the nearest 5 percent.

Appendix A.8 Definition of variables used to quantify invertebrate abundance across three tall fescue fields, Tennessee, 2004 – 2005.

Variable	Definition
Total density	Mean number of invertebrates in all orders collected per m^2 sample.
Total density preferred	Mean number of invertebrates in orders preferred collected per m^2 sample.
Total biomass	Mean biomass (g) of invertebrates in all orders collected per m^2 sample.
Biomass preferred	Mean biomass (g) of invertebrates in orders preferred by bobwhites collected per m^2 sample .
Order richness	Mean number of orders present in per m^2 sample.

VITA

John was born in Vicksburg, MS, just a stones throw from the Mississippi River. Though he was raised near Starkville, MS, he learned to love the outdoors hunting and fishing on his family's farm near Vicksburg. Upon graduating from Starkville High School in 1998, he spent two years as a biology major and varsity football player at Mississippi College. John transferred to Mississippi State University to study wildlife science in 2000. While at MSU, he worked as a technician on projects examining bobwhite habitat use in agricultural landscapes. John was a research intern at Tall Timbers Research Station in Tallahassee, FL in 2002, where he participated in various bobwhite management research activities. He received his Bachelor of Science in Wildlife and Fisheries Science from MSU in 2003. John worked as a technician on a quality deer management project at the Ames Plantation before attending graduate school at the University of Tennessee. He earned his Master of Science degree in Wildlife and Fisheries Science in 2007. While in graduate school at UT he worked as a research associate providing technical assistance for private landowners establishing native warm-season grasses for livestock forage and wildlife habitat improvement. John is married to the lovely Kristy Gale. They have a son, John Colter, and a Labrador retriever, Daisy Duke. Occasionally, Daisy "earns her dinner" in the duck blind.