# NORTHERN BOBWHITE POPULATION AND HABITAT RESPONSE TO PINE-GRASSLAND RESTORATION

By

DOUGLAS SCOTT CRAM

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Thesis Approved:

Ronald E. Masters

Thesis Advisor

Fred S. Guthery

David M. Engle

Alfred Carlozzi

Dean of the Graduate College

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# CHAPTER I

## INTRODUCTION

This thesis is composed of 2 manuscripts formatted for submission to 2 scientific journals. Chapter II is formatted for the *Journal of Wildlife Management*, and chapter III is formatted for the *Wildlife Society Bulletin*. Each manuscript is complete as written and requires no additional material for support. Because manuscripts submitted for publication will have multiple authors listed, first person plural pronouns were used throughout chapters II and III. Appendix follows the second manuscript.

# CHAPTER II

# NORTHERN BOBWHITE POPULATION AND HABITAT RESPONSE TO PINE-GRASSLAND RESTORATION

***Abstract:*** We compared northern bobwhite (*Colinus virginianus*) abundance and habitat characteristics in unmanaged mixed shortleaf pine (*Pinus echinata*)-hardwood stands and restored pine-grassland stands managed for the red-cockaded woodpecker (RCW, *Picoides borealis*) on the Ouachita National Forest (ONF), Arkansas. To determine bobwhite population response in untreated control, thinned, and thinned and burned stands either 1, 2, or 3 growing seasons post-burn, we used drive counts, whistling-male call counts, and covey-call counts as a measure of population abundance. We estimated woody stem density, understory and overstory canopy cover, conifer and hardwood basal area, and the disc of vulnerability to characterize habitat response. Whistling-male call counts provided the most useful index to relative abundance in our stands. Drive counts in the dormant season proved to be the least suitable. Relative abundance of whistling males in the spring was greatest in thinned stands 3 growing seasons postburn and in thinned but unburned stands. These stands had the smallest disc of vulnerability, and the greatest understory shrub cover <2 m in height compared to other treatments. A threshold-like increase of bobwhite abundance was observed as a function of woody structure <2 m. Pine-grassland restoration creates suitable structure for bobwhites in spring, summer, and fall, but may not be adequate in winter. Bobwhite management

efforts in similar shortleaf pine forests should include thinning to reduce midstory and overstory cover, and frequent fire to maintain park-like conditions. Furthermore, data suggest bobwhite density within a given stand is also related to the amount of suitable habitat surrounding the stand. Because isolated restored stands did not show the magnitude of response as stands with larger areas of surrounding suitable habitat, managers should concentrate restoration efforts in 1 or several core areas.

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***Key words:*** Arkansas, *Colinus virginianus*, disc of vulnerability, fire ecology, habitat, northern bobwhite, *Picoides borealis,* pine-grassland restoration, red-cockaded woodpecker, usable space.

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The northern bobwhite began experiencing a noticeable decline in the Midwest circa 1880 (Errington and Hamerstrom 1936), and has since declined across 77% of the states within its geographic range (Brennan 1991). Based on game surveys from Missouri and Iowa, Leopold (1933:52) hypothesized the "period of great [bobwhite] abundance" did not occur due to higher densities on populated areas, but rather due to "a higher proportion of populated acres" available. In the southeastern United States, bobwhite populations were reported to be declining at the same time quail "coverts" were deteriorating (Rosene 1956:126), and where habitat became scarce due to closing canopies in pine forests (Speake 1966:19). Bobwhite population declines are generally attributed to habitat changes resulting from wide-scale abandonment of small farms, clean farming, fire suppression, and industrial forest operations dominated by high basal areas and dense stocking rates (Baerg and Warren 1949, Vance 1976, Roseberry et al. 1979, Exum et al. 1982, Klimstra 1982, Landers and Mueller 1986).

Forest management practices, prescribed fire in particular, have proven to be beneficial for bobwhites on a variety of sites (Stoddard 1931, Speake 1966, Lewis and Harshbarger 1986). Moreover, some accounts have suggested bobwhite populations increase following intensive habitat management for the RCW (Brennan et al. 1995, Engstrom and Baker 1995, Wilson et al. 1995). The RCW, an endangered species endemic of open pine forests in the southeastern United States, is an indicator of pine-grassland habitats (Jackson 1988).

Low basal area pine-grassland communities composed of mature pines and an open midstory were historically maintained by frequent fire throughout the southeastern United States (Christensen 1981, Buckner 1989, Masters et al. 1995). Historical accounts, turn-of-the-century photographs, and analysis of General Land Office survey data from the Ouachita Mountains indicate shortleaf pine-grassland communities consisted of open park-like woodlands with a herbaceous understory comprised of bluestem grasses (*Andropogon* spp.), and on some sites woody resprouts (Foti and Glenn 1991, Masters et al. 1995). Fire suppression in the Ouachita Mountains allowed dense hardwood and pine midstories to develop and displace pine-grassland habitats (Masters et al. 1995). Consequently, suitable RCW habitat has became scarce.

For the past 2 decades the U.S. Forest Service (USFS) has been restoring pine-grassland communities for the RCW on the ONF using wildlife stand improvement (WSI) and prescribed fire. Wildlife stand improvement removes up to 1/3 of the overstory shortleaf pine and 2/3 of the hardwood midstory. Stands remain idle for 1–3 years following WSI and are then burned during the dormant season every 3 years.

We examined bobwhite abundance in untreated control, thinned, and thinned and burned stands 1, 2, and 3 growing seasons postburn. Following pine-grassland restoration we predicted the sequence of understory seral stage development beneath a canopy of lower conifer and hardwood basal area plus an increase in herbaceous and woody cover in the understory would result in an increase of bobwhite abundance. Our objective was to determine bobwhite population response to pine-grassland restoration and characterize relationships between bobwhite abundance and structural attributes of pine-grassland stands in various stages of restoration. Further, we sought to examine stand juxtaposition and its influence on bobwhite abundance relative to the amount of suitable habitat in surrounding stands.

**STUDY AREA**

Our study focus was the >60,000-ha pine-grassland renewal area in the west-central Ouachita Mountains on the Poteau Ranger District in the Ouachita National Forest, Scott County, Arkansas. Study stands were 16–100 ha and in different stages of restoration other than controls. The Ouachita Mountains cover an area about 380 km east to west by 100 km north to south in western Arkansas and southeastern Oklahoma. The region has ridge-and-valley topography. Ridges typically run east-west, having long north-facing and south-facing slopes (Foti and Glenn 1991). The forest was composed of mixed pine-hardwood stands with shortleaf pine dominating drier south-facing slopes, and hardwoods (primarily *Quercus* spp. and *Carya* spp.) dominating mesic north-facing slopes (Foti and Glenn 1991). Maximum average annual precipitation in the Ouachita

Mountains is >150 cm/yr and minimum average annual precipitation is <100 cm/yr. The climate is semi-humid to humid with hot summers and mild winters (Anonymous 1973). The study area, management, and vegetation of these stands was previously described by Masters et al. (1991), Wilson et al. (1995), and Sparks et al. (1999).

## METHODS

### Experimental Design

We used a completely randomized design over 2 years (1999, 2000), with 4 replications of 5 treatments in 20 stands in 1999, and 4 replications of 5 treatments in 20 stands in 2000 for a total of 40 stands ($n = 40$). Each year 20 stands $\geq$16 ha were randomly selected from a list of all suitable stands in the restoration area. Treatment stands in 1999 and 2000 were stratified based on number of burning cycles completed. Treatments ($n = 8$ for each) were as follows:

1. Control, unthinned and unburned;
2. WSI-no burn (WSI-NB);
3. WSI-burn, first growing season after dormant-season burn (WSI-B1);
4. WSI-burn, second growing season after dormant-season burn (WSI-B2);
5. WSI-burn, third growing season after dormant-season burn (WSI-B3).

### Vegetation Sampling

Woody stem density was estimated within 30 fixed-radius plots (radius 3.59 m) located at 30-m intervals on 2–4 randomly spaced parallel lines, perpendicular to the contour. Transect lines bisected bobwhite listening points. Sampling was conducted over a 2-week period in July 1999 and late-June 2000. To avoid bias from surrounding stands, no sampling was conducted within 50 m of stand edge (Mueller-Dombois and

Ellenberg 1974:123). Woody understory, shrub, and midstory species were divided into 3 height classes for analysis; 0–1, >1–3, and >3 m. To characterize forest structure, we estimated percent cover in 1-$m^2$ plots in the following categories; grass-like, forb, vine, legume, woody (0–1 and >1–2 m height classes), litter, rock, bare soil, woody live stem, and woody dead stem. Percent cover for categorical groups was estimated using a cover value scale modified after Daubenmire (1959). The cover value was based on the following scale:

| Cover value | Cover (%) | Midpoint value (%) |
|---|---|---|
| 0 | 0 | 0.0 |
| 1 | trace | 0.1 |
| 2 | >0–1 | 0.5 |
| 3 | >1–2 | 1.5 |
| 4 | >2–5 | 3.5 |
| 5 | >5–10 | 7.5 |
| 6 | >10–25 | 17.5 |
| 7 | >25–50 | 37.5 |
| 8 | >50–75 | 62.5 |
| 9 | >75–95 | 85.0 |
| 10 | >95–100 | 97.5. |

To characterize overstory stand conditions, we estimated conifer and hardwood basal area and canopy cover using a 10-factor prism (Avery 1967) and a spherical densiometer (Lemmon 1957). To index understory visual obstruction and structure, we estimated the disc of vulnerability (Kopp et al. 1998), the mean area of a circle within which a bobwhite might be visible to a terrestrial predator as judged from a human perspective. To estimate the mean disc area ($m^2$) we measured the distance at which a cylinder (15 x 2.5 cm) disappeared from view (100% visual obstruction) of a kneeling observer (height = 1 m), and then used average distance to calculate area. Obstruction type (herbaceous vegetation, woody stem, etc.) and distance were recorded along the cardinal radii. Estimates were made during a 2-week period in May 1999 and 2000. We used 4 sub-sampling plots around 3 points in the stand for a total of 12 sampling plots ($n = 3$) to estimate disc of vulnerability, basal area, and canopy cover. The first sampling plot was the point center. The second sampling plot was located in a random direction 30 m from point center. The remaining 2 sampling plots were located 120° and 240° from the second, and 30 m from point center. At each plot center we measured the disc of vulnerability, basal area, and canopy cover.

**Bobwhite Counts**

To estimate bobwhite abundance we used whistling-male call counts (hereafter, whistle counts) with playback recordings (Coody 1991) at 1–2 listening points/stand over a 2-week period in May 1999 and 2000. Points were centrally located ≥200 m from stand edge. Each point had an implied 200-m radius of audibility. This radius was determined by walking in the cardinal directions opposite the playback recording (Don Scott, Lake Charles, Louisiana, USA) (broadcast at 90 dB) and calculating the mean distance at which playback was no longer audible. To our knowledge the power at which bobwhites call has not been measured, however, based on the principles of physics, DeMaso et al. (1992) assumed bobwhites call midway between normal conversation (60 dB) and a noisy office (70 dB). Although a 400-m radius of audibility may be acceptable in rangelands, topography effects on the ONF reduced the distance sound waves could be detected by a human. Whistle counts were repeated 3 times by 3 different individuals between sunrise and 1100 hrs. Whistle counts were stratified during the morning to encompass peak calling periods. Wilson (2000) and Elder (1956) found peak-calling activity occurred, on average, within the hour after sunrise. However, Wilson (2000) and

Elder (1956) also found the second hour after sunrise to contain high calling activity. Repetition and stratification by peak calling time are recommended for a valid index of populations (Wilson 2000).

We recorded the number of different whistling males over a 6-minute listening period. Playback of an assembly call broadcast at 90 dB in the cardinal directions was used twice, once at the 3-minute mark and again after the 4.5-minute mark (Coody 1991). Relative abundance as indexed by whistle counts is reported by treatment as mean whistling males/point.

Covey-call counts were conducted 3 times by 3 different observers 45 minutes before sunrise to 1100 hrs over a 2-week period in October 1999 and 2000. Listening-point locations and assembly-call broadcast methodology were unchanged from whistle-count procedures. The 6-minute listening periods were stratified by observer to encompass peak calling times. We recorded the number of different calling coveys and reported relative abundance by treatment as mean coveys/point.

Drive counts, as described by Guthery (1986:141–142), covering 100% of stand area were conducted in all 20 stands between 16 and 20 March 1999. Drive counts started at 0900 and finished at 1600 hrs. Crews of 4–15 counters walked abreast at 10-m intervals and recorded the number of birds flushed.

**Data Analysis**

We used the Kruskal-Wallis nonparametric test (Steel et al. 1997:177) to detect treatment differences in bobwhite abundance, basal area, overstory canopy cover, disc of vulnerability, woody stem density, and herbaceous and woody cover. Specific orthogonal contrasts were used to separate effects of WSI and fire by comparing control versus thinned stands, and thinned unburned stands versus thinned burned stands. Stand means were tested for homogeneity of variance among treatments using Levene's test (Snedecor and Cochran 1980). Stand (year × treatment) type III mean square was the error term (SAS Institute 1985:651). We used multiple comparisons between mean ranks with the Least Significant Difference (LSD) test with $P = 0.050$ (Steel et al. 1997:178). Pearson product-moment correlation analysis (SAS Institute 1985) was used as a starting point to index relationship strengths between bobwhite relative abundance and habitat characteristics. Regression analysis (SAS Institute 1985) was used to model relationships between bobwhite relative abundance and habitat variables.

We modeled mean whistling-male response to habitat variables using artificial neural network (ANN) models. Neural Connection software (SPSS Inc., Chicago, Illinois, USA) was used to conduct modeling. Neural models are used in many areas of research including physics, chemistry, and ecology (Lek and Guegan 1999). We used ANN models to detect relationships between mean whistling-male abundance and habitat structure and composition following treatment. Habitat variables were selected based on significant $r$ values ($P < 0.05$) from correlation analysis and specific variables of interest such as forb cover and Orthopteran mass. Our model used 6 input nodes (independent variables), 1 hidden node, and 1 output node (dependent variable). The input nodes were year and stand means for forb cover, Orthopteran mass (Cram 2001), hardwood basal area, conifer basal area, and disc of vulnerability. The output node was predicted whistling males/point. The ANN model was trained using a randomly drawn data set comprising 80% of the data ($n = 32$); validation was conducted on the remaining 20% of the data ($n = 8$).

We used regression analysis to determine if the area (ha) of suitable structural habitat (hereafter, suitable habitat) surrounding whistle points affected bobwhite abundance. Habitat data were obtained from the USFS stand inventory database. Habitat surrounding listening points was classified as suitable or marginal. Based on whistle-count results suitable habitat was defined as WSI-NB, WSI-B2, or WSI-B3 stands, and marginal habitat was defined as WSI-B1 and control stands. Remaining habitat types such as regeneration stands were also classified as marginal (J. B. James, unpublished data). Using Arc-Info software (Environmental Systems Research Institute, Redland, California, USA), habitat suitability coverages were created and intersected with whistle-count points buffered at 400 and 800-m radii. We buffered points at 400 and 800 m (50 and 201 ha, respectively) to encompass bobwhite home ranges (41 ha on the ONF, J. B. James, unpublished data), and to test for a threshold effect. Area of suitable and marginal habitat within each buffered circle was calculated using Arc-View software (Environmental Systems Research Institute, Redland, California, USA).

## RESULTS

### Stand Response

Control stands were characterized by dense pine-hardwood midstories with a closed canopy, and extensive leaf-litter cover (Table 1, 2). Following thinning and burning, stands were park-like with open midstories and canopies. Stand understory following thinning was characterized by a dense ground cover of slash, shrubs, vines, grasses, and forbs. Woody cover <1 m and dead stem cover (resulting from slash following WSI) increased following thinning in WSI-NB stands (Table 2). In the growing season following fire, woody cover <2 m was less than thinned and thinned and burned stands 2 and 3 growing seasons following fire (Table 2). Grass, forb, and legume ground cover characterized WSI-B1 stands (Table 2). Woody sprouts increased in the second growing season following fire, and an herbaceous understory dominated by woody sprouts <2 m characterized stands 3 growing seasons following fire.

Stands with both woody and herbaceous cover, WSI-NB and WSI-B3, had the lowest disc of vulnerability (Table 1). The dominant visual obstruction in WSI-NB and WSI-B3 stands was woody vegetation; 57% and 60%, respectively, followed by dead stems (20%) in WSI-NB stands and forbs (15%) and grass (13%) in WSI-B3 stands.

**Population Response**

According to spring whistle counts, the greatest relative abundance of bobwhites occurred in unburned, thinned stands and in thinned stands in the third growing season following fire (Table 3). Bobwhite relative abundance increased 13-fold and 19-fold in WSI-NB and WSI-B3 stands, respectively as compared to control stands. Bobwhite relative abundance in stands during the first and second growing season following fire was less than thinned stands (WSI-NB) (Table 3). There was no difference in bobwhite relative abundance between 1999 and 2000 ($P = 0.157$). Call-playbacks resulted in an increase of 0.9 males/point and 0.4 males/point in 1999 and 2000, respectively (Fig. 1A, B)

Based on covey-call counts, relative abundance of covey calls was similar in nature to whistle counts; relative abundance of covey calls was greatest in unburned, thinned stands (WSI-NB) and in thinned stands 3 growing seasons following fire (WSI-B3) (Table 3). No coveys were detected in control stands using covey-call counts. We flushed 1 covey of 10 birds in an unburned thinned stand in 1999 using drive counts (650 total ha censused) (Table 3). No other coveys were observed using the drive-count method; therefore drive counts were not repeated in 2000.

**Habitat Relationships**

We found 9 of 24 habitat characteristics were correlated to mean whistling males (Table 4). Negative relationships with mean whistling males included conifer basal area, total basal area, canopy cover, disc of vulnerability, and marginal habitat area within a 400 and 800-m radius of listening points (Table 4). Positive relationships with mean whistling males included woody stem density 1–3 m, and suitable habitat area within a 400 and 800-m radius of listening points (Table 4). Multiple regression analysis indicated forb cover (%), woody cover (%) 1–2 m in height, suitable habitat (ha) within a 400-m radius, and overstory canopy cover (%) best explained bobwhite relative abundance (Y = 2.81 + 0.06[forb cover] + 0.14[woody cover 1–2 m in height] + 0.01[ha of suitable habitat within 400-m radius] – 0.04[overstory canopy cover]) ($P < 0.001$, $r^2 = 0.461$). Regression analysis demonstrated an exponential increase in bobwhite relative abundance as the disc of vulnerability decreased below a threshold of 75 $m^2$ (Fig 2).

The ANN model explained 37% of the variation in the training data and 19% of the variation in the validation data (Fig. 3A, B). Multivariate ANN graphs showed a collapse of predicted whistling males as a function of habitat structure. A decrease in conifer basal area had a greater impact on bobwhite relative abundance as compared with a decrease in hardwood basal area (Fig. 4A). A decrease in both conifer basal area and disc of vulnerability predicted an increase in bobwhite relative abundance (Fig. 4B).

Linear regression indicated an increase in suitable habitat within a 400-m radius of listening points explained 21% of the variation in mean whistling-male abundance

(Fig. 5). Within a 400-m radius of control, WSI-NB, WSI-B1, WSI-B2, and WSI-B3 listening points ($n$ = 8 for each treatment), mean suitable habitat was 1.3 ha (SE = 0.9), 32.2 ha (SE = 3.0), 0.8 ha (SE = 0.5), 28.9 ha (SE = 2.8), and 32.1 ha (SE =3.3), respectively. Mean area of suitable habitat within a 400-m radius of listening points with $\geq$2 mean whistling males/point was 32.7 ha (SE = 3.5).

**DISCUSSION**

Wildlife stand improvement and fire were used to effectively restore pine-grassland dominated stands with open midstory conditions preferred by RCW and bobwhites. Fire played a major ecological role in the evolution, distribution, and maintenance of pine-grassland forests in the Ouachita Mountains (Foti and Glenn 1991). Historically, pine-grassland sites were probably not continuous across the landscape, but were dissected by hardwood dominated north slopes and hardwood drainages. Fire suppression after settlement allowed encroachment of pine and hardwood trees into the midstory resulting in widespread habitat changes and the loss of habitat for a number of species (Neal and Montague 1991, Wilson et al. 1995, Masters et al. 1998). The reintroduction of fire following WSI reduced the accumulation of pine and hardwood leaf litter in the understory, prepared the seedbed for an herbaceous reponse, and maintained an open midstory by suppressing woody stems.

Pine-grassland restoration created distinct successional conditions characterized by differing structure with each additional growing season following fire. A prolific woody stem response dominated the understory after WSI and then 3 growing seasons following fire. Without frequent fire woody stems quickly encroach into pine midstory. Understory woody response appeared to be a major factor dictating bobwhite occurrence.

## Population Response

Pine-grassland restoration resulted in a positive bobwhite population response. Unfortunately, we do not have empirical data or even antidotal evidence for presettlement bobwhite population levels as a basis for comparison. Treated stands had greater bobwhite relative abundances as compared to control stands in the spring and fall. However, relative abundance in spring and fall decreased following fire and suppression of woody sprouts and did not increase above prefire abundance levels until the third growing season following fire. Wilson et al. (1995) found a decrease in bobwhite density and frequency of occurrence following fire in the ONF; however, they found bobwhite response remained below prefire population levels 1, 2, and 3 growing seasons after fire. The difference in bobwhite response following fire may be attributed to some combination of cumulative effects over time on the plant community, number of fire cycles completed, or an increase of pine-grassland treatment hectares.

Because restoration efforts have been under way for a relatively short period of time, bobwhites may be responding to shifts in the plant community as additional burning cycles are completed (Masters et al. 2001). As increased hectares are treated with WSI and fire, suitable habitat is created and made available to bobwhites. Wilson et al. (1995) conducted their study in 1992 and 1993 with a total of 1057 ha in pine-grassland restoration. Since that time 3913 additional ha have undergone pine-grassland restoration treatment. Time is also a determinant in bobwhite population response. Population response to management practices, particularly in low-density populations, takes 3–5 years to ameliorate. The mean finite rate of increase for bobwhite populations in the Southeast was reported as 1.13 (Guthery et al. 2000).

**Habitat Relationships**

Wildlife stand improvement followed by prescribed fire every 3 years created and maintained park-like woodlands with an understory characteristic of an early to mid-seral stage. As predicted, bobwhites on the ONF increased with a set back in understory seral stage following disturbance, WSI and fire in this case. A change in successional stage following disturbance is often recognized as the fundamental reason for alterations in bobwhite populations (Ellis et al. 1969). The appropriate seral stage for bobwhites varies inversely with the primary site productivity (Spears et al. 1993). Furthermore, creation of the appropriate successional stage maximizes usable space (Guthery 1997). The usable space hypothesis, formalized by Guthery (1997), contends as suitable habitat structure increases on an area of fixed size, mean bobwhite density will increase. Following pine-grassland restoration we found 4 habitat variables combined to best describe suitable habitat: percent forb cover (%), percent woody cover (%) <2 m in height, overstory canopy cover (%), and ha of suitable surrounding habitat.

We found the disc of vulnerability to be a reasonable habitat response variable for predicting usable space in the ONF. Thinned stands and thinned stands 3 growing seasons following fire had lower discs of vulnerability and the highest bobwhite abundance among all stands. As the disc of vulnerability increased above 75 $m^2$ a threshold-like collapse of bobwhite abundance occurred (Fig. 2). Kopp et al. (1998) found similar bobwhite responses to an increasing disc of vulnerability in a study of bobwhite habitat selection in subtropical rangeland in Texas. Kopp et al. (1998) concluded larger disc areas avoided by bobwhites were deficient in woody screening cover. Bobwhite screening cover, particularly that proportion comprised of woody vegetation <2 m, can be indexed quantitatively using the disc of vulnerability. Large disc areas (i.e., control and WSI-B1 stands) were void of suitable screening cover at the ground level (<1 m). The disc of vulnerability, however, was not an omnibus habitat variable. For example, 6 stands with disc areas $\leq 75$ $m^2$ had no measure of relative abundance (Fig. 2). Closer examination indicated these stands had other unsuitable structural and landscape attributes the disc of vulnerability did not measure, in particular overstory canopy cover and ha of suitable structural habitat.

For example, in the random selection of stands for the ANN validation model, an outlier stand (1282) was included resulting in an $r^2$ value of 0.277 (without the point $r^2$ = 0.528) (Fig. 3A). Our model predicted stand 1282 to have 1.5 whistling males/point whereas we observed no whistling males. Although understory attributes of input nodes for stand 1282 seemed to indicate structurally suitable habitat, landscape characteristics suggested the stand to be an outlier. A threshold of suitable habitat surrounding 1282 and other similar stands (<20 ha) may have affected relative bobwhite abundance. Stand 1282 (WSI-B2) had 19.8 and 23.8 ha of suitable habitat within a 400 and 800-m radius area of the whistling point, respectively. The mean suitable habitat surrounding WSI-B2 stands at a 400 and 800-m radius was 28.9 and 71.9 ha, respectively. Small isolated treatment stands with little suitable surrounding habitat in the ONF are in essence "graveyard" habitats (Guthery 2000:140). Graveyard habitats offer suitable habitat, but are too small to support viable bobwhite populations.

Regression analysis predicting whistling males as a function of suitable habitat indicated 33 ha of suitable habitat resulted in the addition of 1 whistling male/point up to 50 ha (400-m radius) (Fig. 5). This provides limited evidence small landowners wishing to manage for bobwhites in similar habitat conditions can expect a threshold-like response when total usable space exceeds 33 ha. Caution, however, should be used when interpreting results. The low $r^2$-value (0.210) for the linear regression model indicates a single habitat variable did not fully explain variation in bobwhite abundance. In hindsight we feel the criterion for suitable habitat may have been too narrow in scope. The suitable habitat criterion was based primarily on the response of whistling males to the disc of vulnerability, previously discussed to have oversights. Furthermore, census results seemed to indicate bobwhites were often adjacent to or within regeneration stands. We also feel whistle-call counts conducted in 2000 occurred before the peak of seasonal calling activity thereby increasing the variation in relative abundance that existed among sites.

Predicted bobwhite abundance showed an increase commensurate with decreasing basal area (Fig. 4A). Current WSI prescriptions on the ONF target 13.8 $m^2$/ha for conifer basal area with an additional limited hardwood component; similar to presettlement total basal area of 14.4 $m^2$/ha (Foti and Glenn 1991). Historically, however, stand composition was different with a conifer basal area of 8.4 $m^2$/ha and a hardwood basal area of 6.0 $m^2$/ha (Foti and Glenn 1991). As previously noted, we do not have historical data on bobwhite population levels in pine-grassland communities as a basis for comparison. Furthermore, pine-grassland communities historically had a significant grazing component from elk (*Cervus elaphus*) and bison (*Bison bison*). These species, which are no longer present in the Ouachita Highlands, would have affected understory herbaceous structure and, in turn, bobwhite habitat. There remains a need to understand how, under current landscape conditions, a lower basal area incorporating ecosystem management principles, that allow for timber harvest, would affect bobwhites. Further, investigation into bobwhite-habitat relationships with regeneration stands is also necessary.

## MANAGEMENT IMPLICATIONS

Bobwhite habitat management theory suggests a wide set of patch configurations may be optimal for bobwhites (Guthery 1999). Under this premise, the goal of habitat management for bobwhites should be to identify where usable space through time begins to decline. In low-density populations we recommend using the call-playback technique to estimate where bobwhite relative abundance begins to decline. We found the call-playback technique (Coody 1991) increased the number of males heard. Call-playbacks resulted in an increase of 0.9 males/site and 0.4 males/site in 1999 and 2000, respectively (Fig. 1A, B). These results were similar to Coody (1991), who also used the call-playback technique in the ONF. In Oklahoma, Wilson (2000) found the call-playback technique had no significant effect on number of males heard. Although the increase in males heard/site using call playbacks may be considered inconsequential in a high population density area, in a low population density area such as the ONF it resulted in a significant increase in males heard in 1999 and 2000 ($P < 0.001$, $P = 0.020$, respectively). From an efficiency standpoint in low-density populations, we recommend against using winter drive counts to determine where bobwhite abundance begins to decline, or as a population monitoring technique. As bobwhite density decreases the distance between coveys increases as an exponential function (Guthery 2000:140).

The disc of vulnerability can be used to quantify and compare structural characteristics between areas of high and low bobwhite abundance. Where suitable structural habitat is identified but too isolated to support a viable population of bobwhites, additional hectares under pine-grassland management are recommended. As restoration efforts expand across the landscape suitable habitat will increase, envelope and thereby minimize isolated stand conditions.

Because bobwhite relative abundance was highest 3 growing seasons following fire, burn plans should allow for the incorporation of the full range of 1–3 growing seasons postburn within a given landscape. Because ecosystem management principles and specifically management for the RCW allow for timber harvest, at some point in stand rotation total basal area will decline. Research on the transition stage from mature open woodlands to the regeneration phase and its effects on bobwhites and other form of wildlife should be addressed. Likely this transition to regenerate stands would change structure in the advent of reintroduction of large herbivores (Bukenhofer and Hedrick 1997). Research is needed to determine bobwhite response under alternative fire regimes such as increased time between fire and growing-season fire.

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Table 1. Stand overstory and understory response after midstory thinning and growing seasons since burned on the Ouachita National Forest, Arkansas, June–July 1999 and 2000.[a]

| | Treatment[b] | | | | | | | | | | $P > F$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | WSI-NB | | WSI-B1 | | WSI-B2 | | WSI-B3 | | Contrasts[c] | |
| Habitat characteristic | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | C vs. W | NB vs. B |
| Canopy cover (%) | 95.2 | 0.3 A | 79.3 | 1.6 C | 79.5 | 2.1 BC | 83.6 | 1.4 B | 80.9 | 1.9 BC | <0.001 | 0.177 |
| Hardwood basal area ($m^2$/ha) | 6.5 | 0.3 A | 2.2 | 0.2 B | 3.5 | 0.8 B | 3.3 | 0.5 B | 2.6 | 0.6 B | <0.001 | 0.161 |
| Conifer basal area ($m^2$/ha) | 17.2 | 1.0 A | 12.3 | 0.8 B | 15.4 | 0.9 A | 15.5 | 0.8 A | 15.4 | 1.1 A | 0.050 | 0.003 |
| Total basal area ($m^2$/ha) | 23.7 | 1.2 A | 14.6 | 0.7 C | 18.9 | 0.9 B | 18.9 | 0.9 B | 18.0 | 0.8 B | <0.001 | <0.001 |
| Disc of vulnerability ($m^2$) | 244.6 | 39.4 A | 75.8 | 14.8 B | 282.9 | 83.2 A | 60.7 | 8.2 B | 52.0 | 7.7 B | <0.001 | 0.377 |
| Woody stem density (stems/$m^2$) height class | | | | | | | | | | | | |
| 0–1 m | 129.4 | 15.7 B | 126.2 | 15.7 B | 246.6 | 32.0 A | 148.3 | 12.6 B | 161.5 | 21.9 AB | 0.131 | 0.014 |
| 1–3 m | 8.0 | 1.1 | 10.2 | 2.7 | 6.2 | 2.2 | 8.5 | 1.3 | 13.9 | 2.3 | 0.650 | 0.939 |
| >3 m | 6.0 | 1.8 A | 1.5 | 0.5 B | 0.4 | 0.1 C | 0.5 | 0.2 C | 0.7 | 0.3 C | <0.001 | 0.005 |

[a] Row means followed by the same letter or without letters were not significantly different at the 0.05 level (LSD).

[b] Control = unthinned, unburned; WSI-NB = wildlife stand improvement, no burn; WSI-B1 = wildlife stand improvement, first growing season following burn; WSI-B2 = wildlife stand improvement, second growing season following burn; WSI-B3 = wildlife stand improvement, third growing season following burn; $n$ = 8 for each treatment.

[c] Contrasts: Trt = treatment; C = unthinned, unburned control; W = wildlife stand improvement; NB = wildlife stand improvement, no burn; B = wildlife stand improvement and burned.

Table 2. Understory cover (%) response after midstory removal and growing seasons since burned on the Ouachita National Forest, Arkansas, July 1999 and June 2000.[a]

| | Treatment[b] | | | | | | | | | | | P > F | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | WSI-NB | | WSI-B1 | | WSI-B2 | | WSI-B3 | | | Contrasts[c] | |
| Cover (%) | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | Trt | C vs. W | NB vs. B |
| Grass-like | 6.1 | 0.9 B | 12.5 | 1.4 A | 13.8 | 2.7 A | 18.5 | 3.3 A | 14.3 | 1.9 A | 0.001 | <0.001 | 0.329 |
| Forb | 2.7 | 0.3 B | 4.1 | 0.6 B | 12.8 | 2.3 A | 11.3 | 1.8 A | 11.8 | 1.9 A | <0.001 | <0.001 | <0.001 |
| Woody <1 m | 9.3 | 1.2 B | 18.0 | 1.9 A | 15.0 | 2.2 AB | 20.5 | 3.2 A | 22.1 | 3.5 A | 0.002 | <0.001 | 0.882 |
| Woody 1–2 m | 6.7 | 0.8 A | 6.1 | 1.2 A | 0.4 | 0.3 C | 2.6 | 0.7 B | 5.0 | 1.1 AB | <0.001 | <0.001 | 0.001 |
| Cryptogam | 1.7 | 0.4 AB | 2.0 | 0.4 A | 0.2 | 0.1 C | 0.8 | 0.2 B | 0.8 | 0.3 BC | 0.001 | 0.020 | 0.001 |
| Legume | 2.2 | 0.7 B | 2.2 | 0.4 B | 10.1 | 2.4 A | 8.5 | 1.4 A | 9.4 | 1.4 A | <0.001 | <0.001 | <0.001 |
| Vine | 9.2 | 1.9 | 12.5 | 3.0 | 8.4 | 2.4 | 7.0 | 1.6 | 8.8 | 2.6 | 0.701 | 0.810 | 0.174 |
| Rock | 1.4 | 0.7 | 1.8 | 0.8 | 4.4 | 1.3 | 2.1 | 0.6 | 1.9 | 0.8 | 0.073 | 0.078 | 0.158 |
| Soil | 0.2 | 0.0 C | 0.8 | 0.3 BC | 9.5 | 2.2 A | 0.8 | 0.2 B | 0.6 | 0.2 BC | <0.001 | <0.001 | 0.046 |
| Litter | 76.1 | 3.2 A | 56.9 | 5.8 B | 32.8 | 4.7 C | 41.2 | 4.9 C | 44.5 | 7.2 BC | <0.001 | <0.001 | 0.006 |
| Woody stem live | 1.5 | 0.4 | 0.7 | 0.2 | 1.2 | 0.3 | 1.3 | 0.4 | 1.4 | 0.5 | 0.608 | 0.449 | 0.163 |
| Woody stem dead | 3.1 | 0.5 B | 8.7 | 0.6 A | 4.8 | 0.9 B | 4.4 | 1.0 B | 4.0 | 0.6 B | <0.001 | 0.005 | <0.001 |

[a] Row means followed by the same letter or without letters were not significantly different at the 0.05 level (LSD).

[b] Control = unthinned, unburned; WSI-NB = wildlife stand improvement, no burn; WSI-B1 = wildlife stand improvement, first growing season following burn; WSI-B2 = wildlife stand improvement, second growing season following burn; WSI-B3 = wildlife stand improvement, third growing season following burn; $n = 8$ for each treatment.

[c] Contrasts: Trt = treatment; C = unthinned, unburned control; W = wildlife stand improvement; NB = wildlife stand improvement, no burn; B = wildlife stand improvement and burned.

Table 3. Northern bobwhite absolute abundance derived from drive counts (bobwhites/ha) (March 1999), and relative abundance derived from whistle-call counts (mean whistling males/listening point) (May 1999 and 2000), and covey-call counts (mean coveys/listening point) (October 1999 and 2000) on the Ouachita National Forest, Arkansas.[a]

| | Treatment[b] | | | | | | | | | | | $P > F$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | WSI-NB | | WSI-B1 | | WSI-B2 | | WSI-B3 | | | Contrasts[c] | |
| Census method | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | Trt | C vs. W | NB vs. B |
| Drive count[d] | 0.00 | 0.00 | 0.07 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.438 | 0.624 | 0.072 |
| Whistle-call count[e] | 0.08 | 0.05 C | 1.08 | 0.32 AB | 0.44 | 0.18 BC | 0.75 | 0.27 AB | 1.54 | 0.39 A | 0.006 | 0.002 | 0.455 |
| Covey-call count[e] | 0.00 | 0.00 | 0.50 | 0.27 | 0.13 | 0.13 | 0.25 | 0.16 | 0.57 | 0.30 | 0.239 | 0.085 | 0.493 |

[a] Row means followed by the same letter or without letters were not significantly different at the 0.05 level (LSD).

[b] Control = unthinned, unburned; WSI-NB = wildlife stand improvement, no burn; WSI-B1 = wildlife stand improvement, first growing season following burn; WSI-B2 = wildlife stand improvement, second growing season following burn; WSI-B3 = wildlife stand improvement, third growing season following burn.

[c] Contrasts: Trt = treatment; C = unthinned, unburned control; W = wildlife stand improvement; NB = wildlife stand improvement, no burn; B = wildlife stand improvement and burned.

[d] $n = 4$ for each treatment.

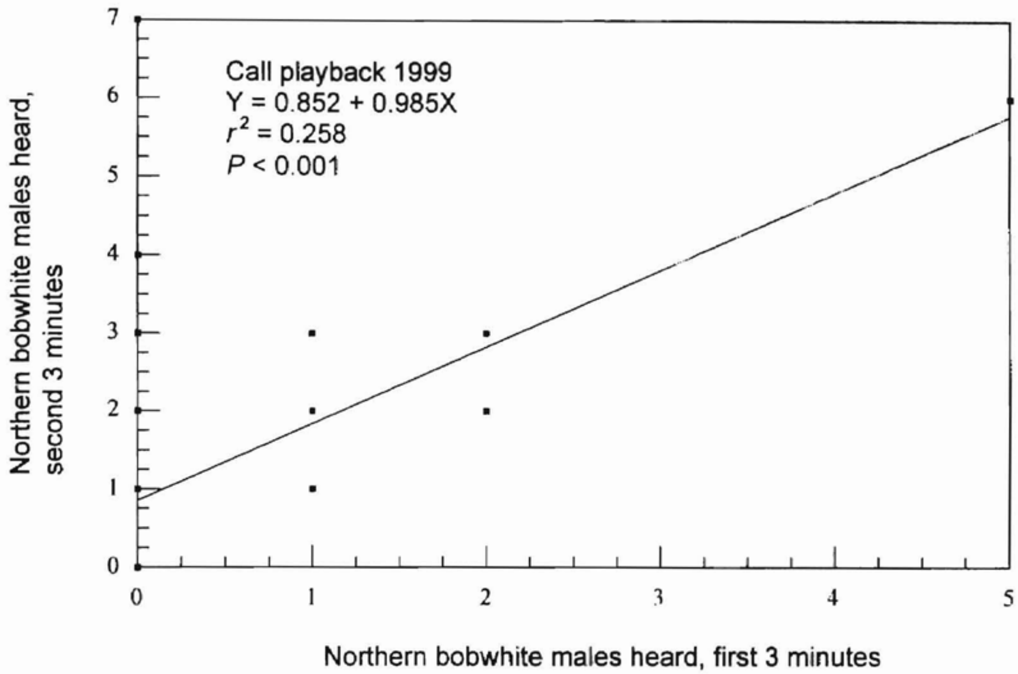
[e] $n = 8$ for each treatment.

Table 4. Northern bobwhite relative abundance (mean whistling males/listening point) correlation with habitat variables ($n$ = 8) following pine-grassland restoration on the Ouachita National Forest, Arkansas, June–July 1999 and 2000.

| | Mean whistling males | |
|---|---|---|
| Habitat variable | $r$ | $P$ |
| Cover (%) | | |
| Grass-like | 0.21 | 0.201 |
| Forb | 0.27 | 0.093 |
| Legume | 0.14 | 0.387 |
| Vine | -0.05 | 0.766 |
| Woody <1 m | 0.25 | 0.127 |
| Woody 1–2 m | 0.21 | 0.198 |
| Litter | -0.26 | 0.117 |
| Rock | -0.11 | 0.493 |
| Bare soil | -0.20 | 0.219 |
| Woody live stem | -0.22 | 0.188 |
| Woody dead stem | 0.21 | 0.202 |
| Woody stem density <1 m (stems/$m^2$) | -0.03 | 0.879 |
| Woody stem density 1–3 m (stems/$m^2$) | 0.41 | 0.010 |
| Woody stem density >3 m (stems/$m^2$) | -0.24 | 0.150 |
| Hardwood basal area ($m^2$/ha) | -0.22 | 0.172 |
| Conifer basal area ($m^2$/ha) | -0.33 | 0.040 |
| Total basal area ($m^2$/ha) | -0.37 | 0.020 |
| Number of times burned | 0.05 | 0.765 |
| Overstory canopy cover (%) | -0.38 | 0.016 |
| Disc of vulnerability ($m^2$) | -0.38 | 0.016 |
| Suitable habitat (ha), 400-m radius | 0.46 | 0.002 |
| Marginal habitat (ha), 400-m radius | -0.46 | 0.002 |
| Suitable habitat (ha), 800-m radius | 0.39 | 0.008 |
| Marginal habitat (ha), 800-m radius | -0.31 | 0.038 |

Figure 1. Northern bobwhite whistling males heard in the first 3 minutes regressed with whistling males heard after call playback (second 3 minutes) on the Ouachita National Forest, Arkansas 1999 (A) and 2000 (B).

A


Call playback 1999
Y = 0.852 + 0.985X
r² = 0.258
P < 0.001
Northern bobwhite males heard, second 3 minutes
Northern bobwhite males heard, first 3 minutes
0
1
2
3
4
5
6
7

B

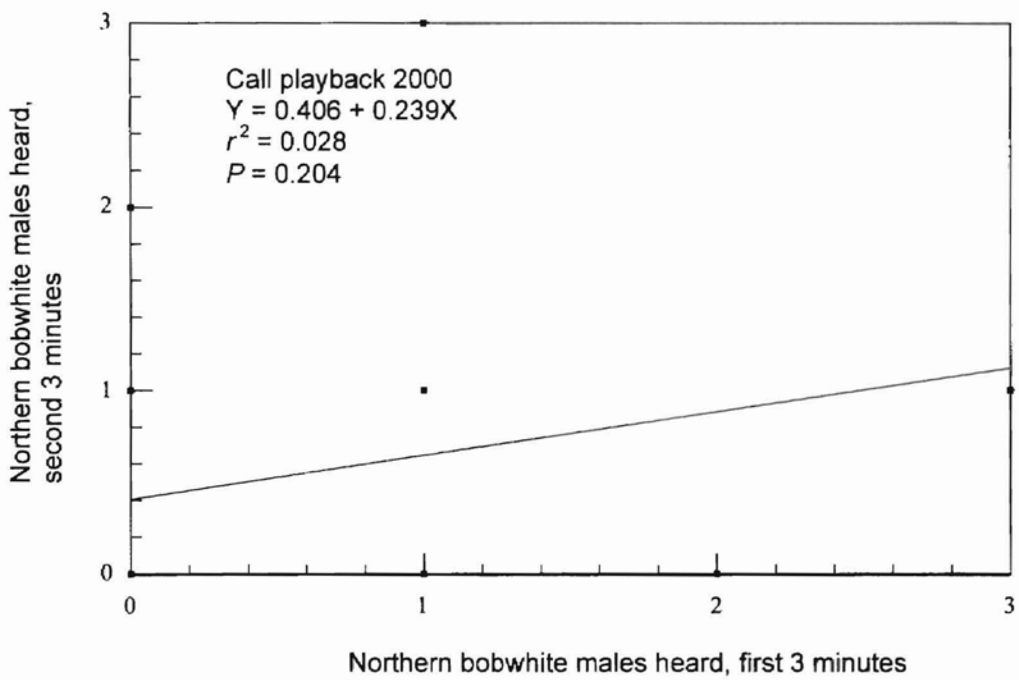

Call playback 2000
Y = 0.406 + 0.239X
r² = 0.028
P = 0.204
Northern bobwhite males heard, second 3 minutes
Northern bobwhite males heard, first 3 minutes
0
1
2
3

Figure 2. Response of northern bobwhite relative abundance (mean whistling males/point) to an increasing disc of vulnerability ($m^2$) on the Ouachita National Forest, Arkansas, 1999–2000.

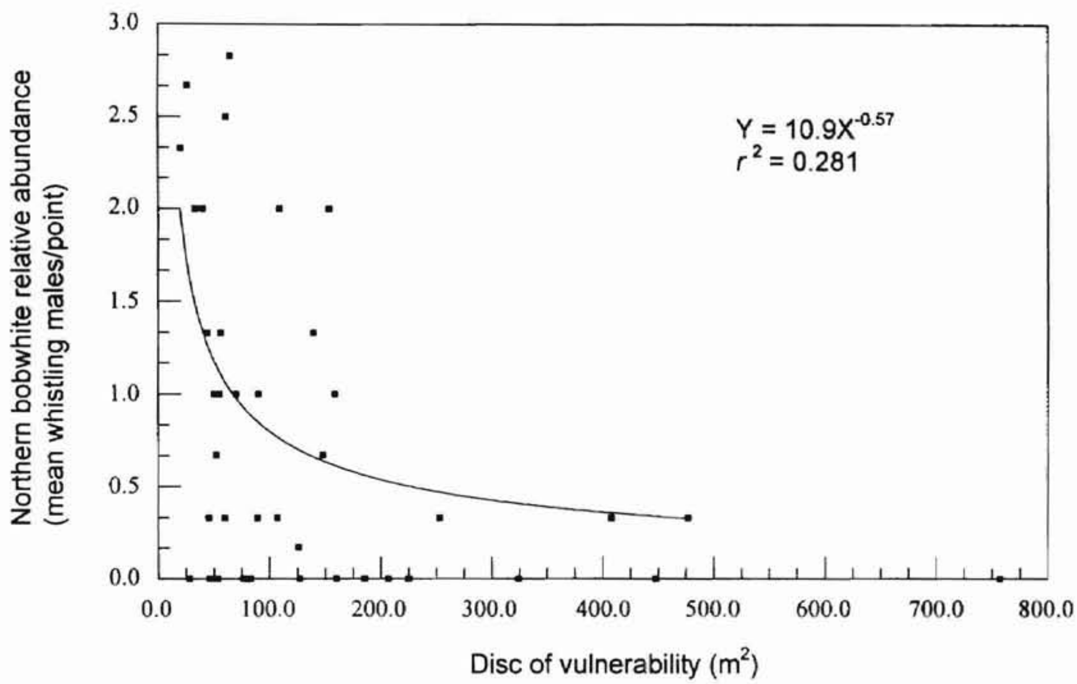
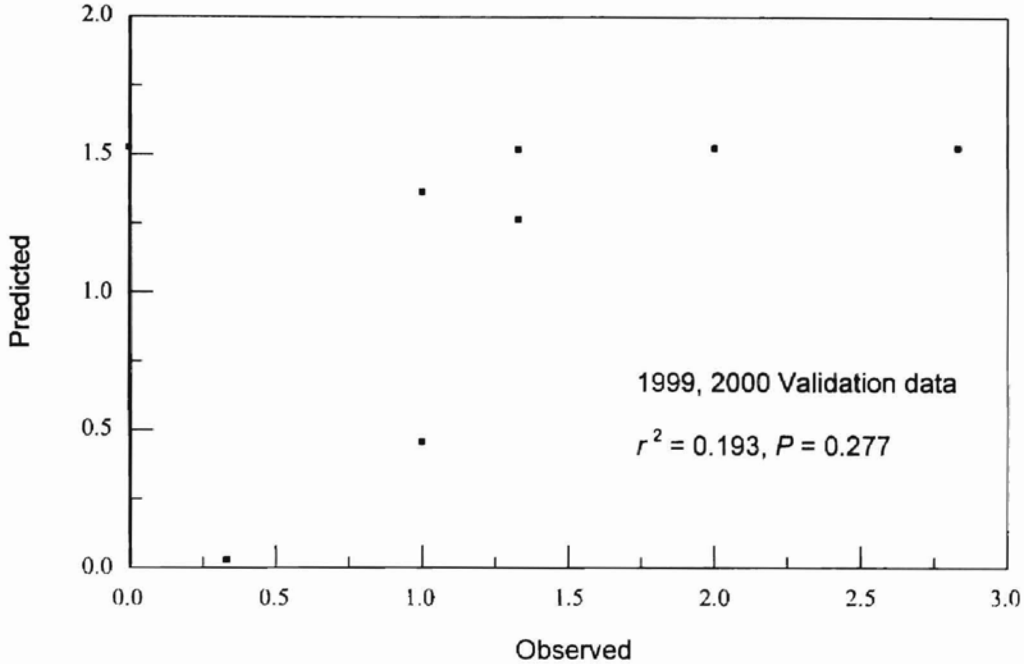

Northern bobwhite relative abundance (mean whistling males/point)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Y = 10.9X^-0.57
r^2 = 0.281
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
Disc of vulnerability (m^2)

Figure 3. Comparison of observed and predicted values (artificial neural network) of northern bobwhite whistling males on the Ouachita National Forest, Arkansas, 1999–2000. The validation data (A) ($n = 8$) show performance of the model on data not used in training model (B) ($n = 32$).

A


Predicted
Observed
1999, 2000 Validation data
$r^2$ = 0.193, $P$ = 0.277

B

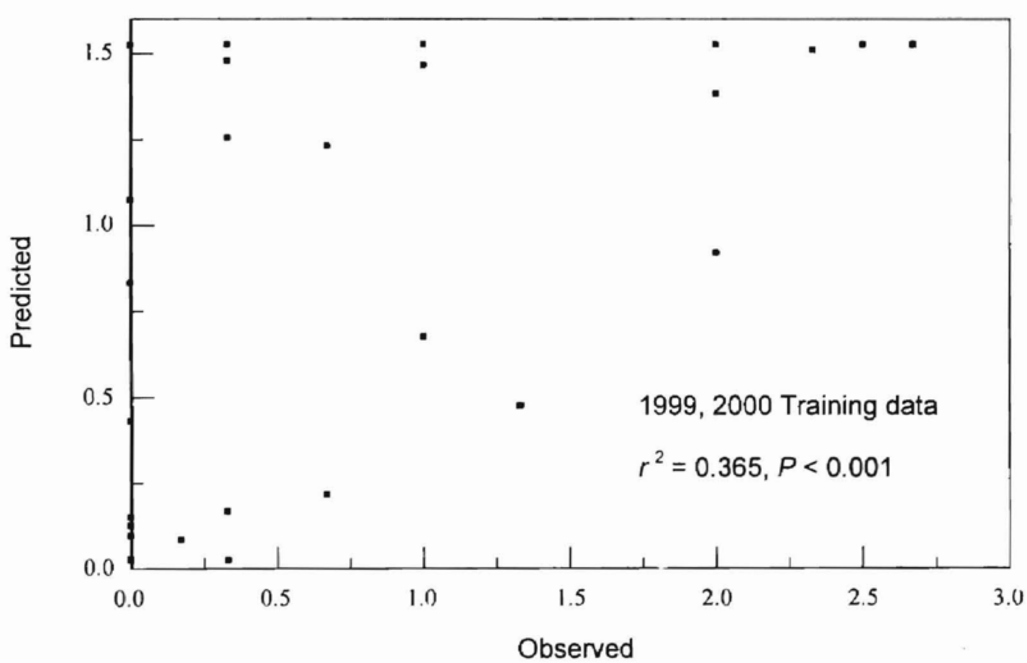

Predicted
Observed
1999, 2000 Training data
$r^2$ = 0.365, $P$ < 0.001

Figure 4. Artificial neural network predictions on the response of northern bobwhite whistling males to conifer and hardwood basal area ($m^2$/ha) (A), and to conifer basal area ($m^2$/ha) and disc of vulnerability ($m^2$) (B) on the Ouachita National Forest, Arkansas 1999–2000.

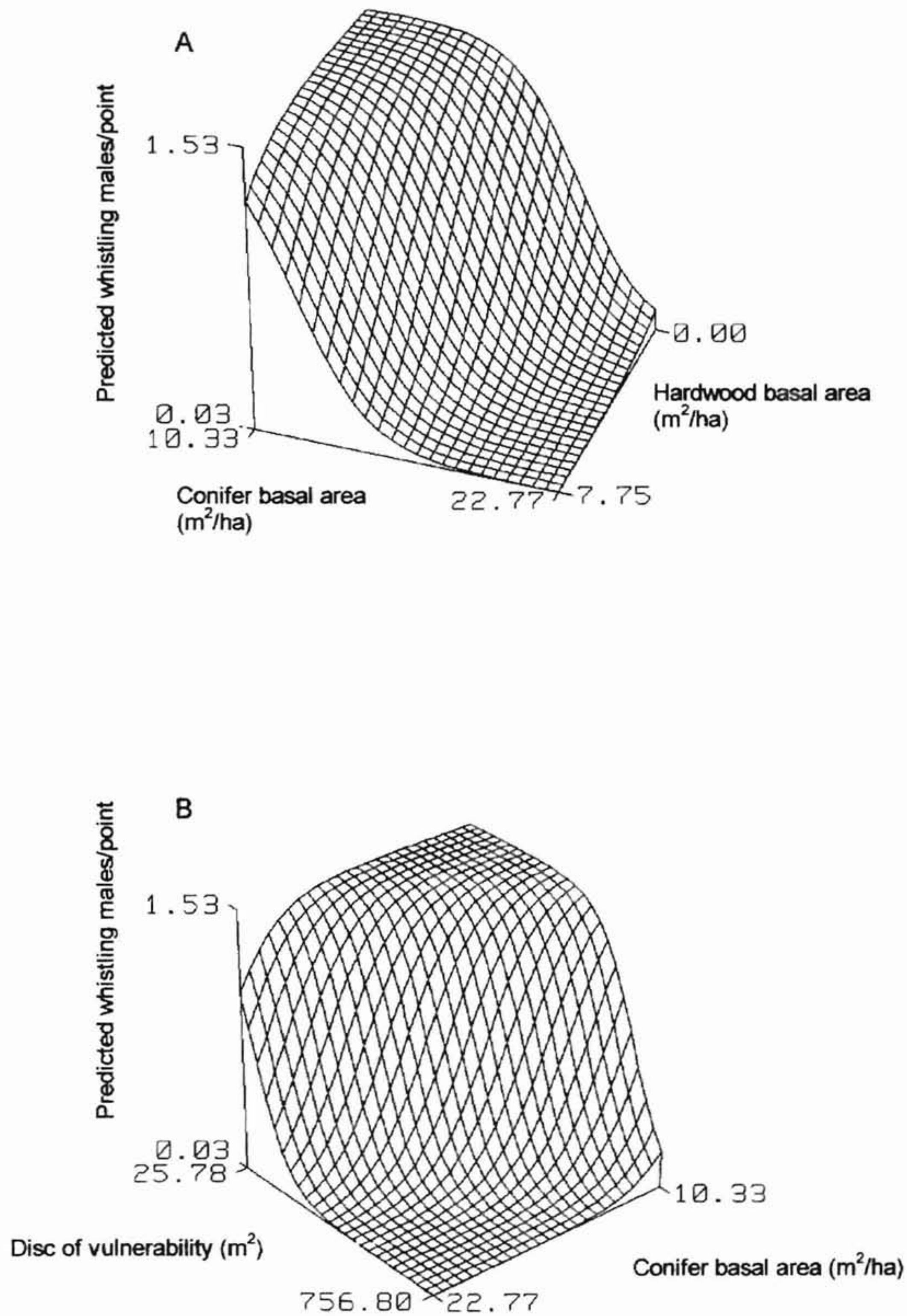
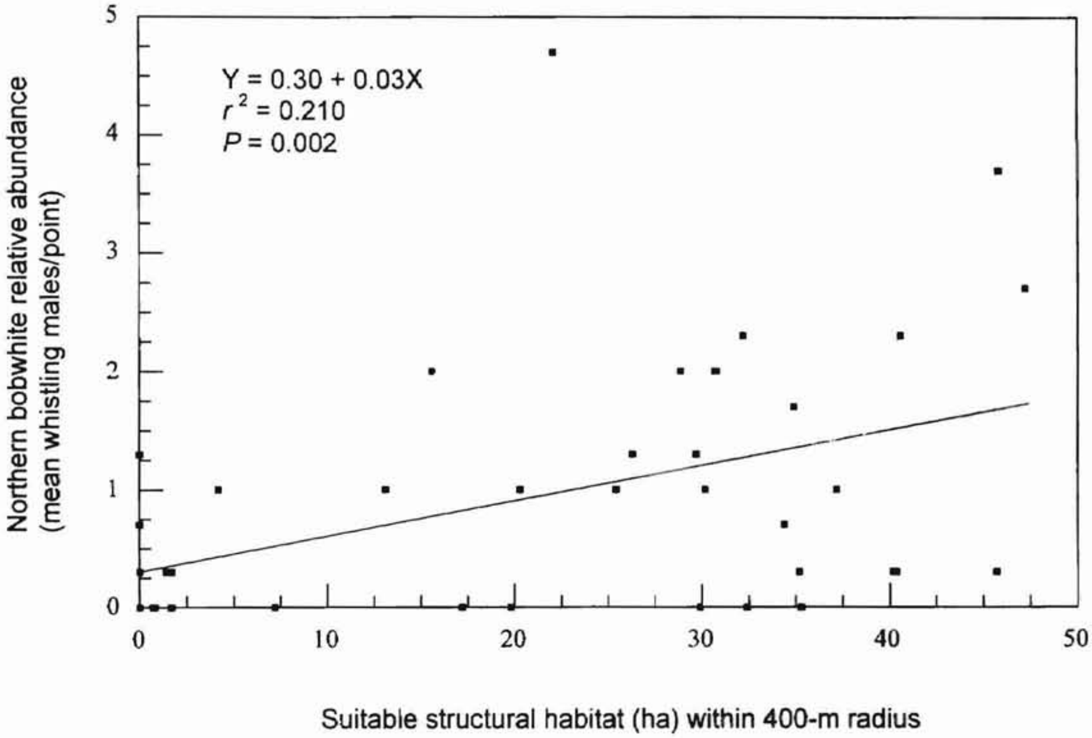

A
Predicted whistling males/point
1.53
0.03
10.33
Conifer basal area (m²/ha)
22.77
7.75
Hardwood basal area (m²/ha)
0.00
B
Predicted whistling males/point
1.53
0.03
25.78
Disc of vulnerability (m²)
756.80
22.77
Conifer basal area (m²/ha)
10.33

Figure 5. Response of northern bobwhite whistling males (mean whistling males/point) to increasing suitable structural habitat (ha) within a 400-m radius of listening points on the Ouachita National Forest, Arkansas 1999–2000.


Y = 0.30 + 0.03X
r² = 0.210
P = 0.002
Northern bobwhite relative abundance
(mean whistling males/point)
Suitable structural habitat (ha) within 400-m radius
0
1
2
3
4
5
0
10
20
30
40
50

CHAPTER III

**Food availability for northern bobwhites following pine-grassland restoration for red-cockaded woodpeckers**

***Abstract:*** We studied the response of northern bobwhite (*Colinus virginianus*) foods (plants and invertebrates) following thinning and burning for the endangered red-cockaded woodpecker (*Picoides borealis*) on the 60,000-ha pine (*Pinus* spp.)-grassland restoration area in the Ouachita National Forest, Arkansas. Richness, density, and frequency of occurrence of bobwhite food-producing plants increased following thinning and fire. Relative abundance, mass, and frequency of occurrence of bobwhite invertebrates also increased following thinning and fire. Relative invertebrate abundance and mass seemed to increase as a function of time since fire. Important fall and winter food plants, especially from the genera *Desmodium*, and *Lespedeza*, increased in density and frequency of occurrence following thinning and fire. We found food supply following pine-grassland restoration was a function of usable space. Food abundance alone did not characterize bobwhite population response. By comparing stands where usable space and bobwhite abundance was similar, we deduced an increase in food supply had no effect on abundance. Food abundance was not a limiting factor for bobwhites following pine-grassland restoration.

***Wildlife Society Bulletin 00(0): 000–000***

***Key words:*** *Colinus virginianus,* food availability, northern bobwhite, Ouachita Highlands, pine-grassland restoration, prescribed fire

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Management for northern bobwhite (*Colinus virginianus*) habitat often operates on a quality-based premise (Guthery 1997). Quality-based management assumes a higher level of habitat quality (food supply, habitat type interspersion) will support a greater number of bobwhites. Managers often fixate first on addressing the quality and quantity of the food supply. The food-based hypothesis assumes food is limiting in a given area and increasing the food supply, for example with food plots or with supplemental feeding, will increase bobwhite densities. If food is not limiting in a given area, literature reporting on food-increasing management techniques should indicate no effect on bobwhite densities following an increase in food supply (Guthery 1997). Generally, the research literature suggests management techniques aimed at increasing food supplies are ineffective in terms of an increase in fall densities (Burger and Linduska 1967, Ellis et al. 1969, Guthery 1997).

Bobwhite populations have responded positively across the southeastern United States in forest stands managed for the endangered red-cockaded woodpecker (RCW, *Picoides borealis*) (Brennan 1991, Fuller 1994, Wilson et al. 1995, Cram 2001). In Arkansas, bobwhites were found more frequently in thinned and burned stands managed for the RCW than in unthinned and unburned control stands (Wilson et al. 1995, Cram 2001). To manage for the RCW on the Ouachita National Forest (ONF) the United States Forest Service has identified 60,000 ha as the pine (*Pinus* spp.)-grassland ecosystem restoration area. Pine-grassland restoration efforts in the ONF included a program of tree thinning called wildlife stand improvement (WSI) and dormant-season prescribed fire every 3 years. Wildlife stand improvement removes up to 1/3 of the overstory shortleaf pine (*P. echinata*) and 2/3 of the hardwood midstory. Wildlife stand improvement created stand structure with an open, park-like condition and fire maintained the open condition (Cram 2001).

Our objective was to determine how pine-grassland restoration for the RCW affected food supply and availability for bobwhites. We predicted plant and invertebrate food supply would increase through 3 growing seasons following midstory removal and fire. Furthermore, we sought to test the quality-based hypotheses versus the usable-space hypothesis (Guthery 1997) to determine if either or both explained an increase in bobwhite relative abundance. We predicted an increase in the food supply would have nominal effects on bobwhite abundance as compared to an increase in usable space (suitable habitat). To index invertebrate availability during critical brood-rearing months (June–August), we examined the effects WSI and fire had on invertebrate abundance, mass, and frequency of occurrence in untreated pine-hardwood stands as compared to treated stands at varying stages of succession following thinning and burning. To examine potential plant food availability, we estimated density and frequency of occurrence of known bobwhite food-producing plants based on regional food habit studies. Bobwhite relative abundance was indexed using spring whistle counts (Cram 2001).

**Study area**

Study sites were in the west-central Ouachita Mountains on the Poteau Ranger District of the ONF, Scott County, Arkansas. All sites were within the 60,000 ha pine-grassland restoration area and under active management for the endangered RCW. The Ouachita Mountains cover an area approximately 380 km east to west by 100 km north to south in western Arkansas and southeastern Oklahoma. Elevations range from 100 m to 900 m. Masters et al. (1996, 1998) and Sparks et al. (1999) reported the physical and botanical features of these stands.

The forest is composed of mixed pine-hardwood stands with shortleaf pine dominating drier south-facing slopes, and hardwoods (primarily *Quercus* spp. and *Carya* spp.) dominating mesic north-facing slopes (Foti and Glenn 1991). Codominant overstory and midstory species included red maple (*Acer rubrum*), mockernut hickory (*C. tomentosa*), pignut hickory (*C. glabra*), flowering dogwood (*Cornus florida*), black cherry (*Prunus serotina*), Mexican plum (*P. mexicana*), southern red oak (*Q. falcata*), blackjack oak (*Q. marilandica*), northern red oak (*Q. rubra*), post oak (*Q. stellata*), and black oak (*Q. velutina*). Post oak, blackjack oak, red maple, and mockernut hickory sprouts <3 m dominated the understory in WSI stands 3 years post-burn. Woody shrub and vine species included New Jersey tea (*Ceanothus americanus*), blackberry (*Rubus* spp.), Virginia creeper (*Parthenocissus quinquefolia*), winged sumac (*Rhus copallina*), greenbrier (*Smilax bona-nox*), poison ivy (*Toxicodendron radicans*), low-bush huckleberry (*Vaccinium pallidum*), and muscadine (*Vitis rotundifolia*) (Sparks 1996).

## Methods

### Experimental design

We used a completely randomized design over 2 years (1999, 2000), with 4 replications of 5 treatments in 20 stands in 1999, and 4 replications of 5 treatments in 20 stands in 2000 for a total of 40 stands ($n = 40$). Each year 20 stands $\geq$16 ha were randomly selected from a list of all suitable stands in the restoration area. Treatment stands in 1999 and 2000 were stratified based on the number of 3-year burning cycles completed (1–7). Treatments ($n = 8$ for each treatment) were as follows:

1. Control, unthinned and unburned;
2. WSI-no burn (WSI-NB);
3. WSI-burn, first growing season after dormant-season burn (WSI-B1);
4. WSI-burn, second growing season after dormant-season burn (WSI-B2);
5. WSI-burn, third growing season after dormant-season burn (WSI-B3).

**Invertebrate sampling**

We collected invertebrates using a standard canvas sweepnet (48-cm handle, 38-cm net hoop diameter, and 76-cm net depth) to estimate relative abundance, mass and percent frequency of occurrence. Invertebrate sweepnet samples were collected in each stand along 6 randomly located transects 25 m in length on 2 randomly spaced parallel lines, perpendicular to the contour. We used 20 sweepnet strokes/transect line. Transect lines bisected bobwhite whistle-call sampling points (Cram 2001). Invertebrates were collected in July 1999 and 2000 during the middle of brood-rearing period (Rosene 1969:59), between 1000 and 1500 hours when cloud cover was <50% and temperatures were <35C. Contents of sweepnets were transferred to labeled plastic bags, sealed, and frozen for storage. Invertebrates were sorted to order, and in some cases to family (Borror et al. 1989), dried at 40C for 72 hours, and weighed to the nearest 0.001 g. Mean relative invertebrate abundance and mass were calculated from the 6 transect samples, and reported as mean individuals/sample and mean mg/sample. Percent frequency of occurrence was calculated for the 6 transects.

**Vegetation sampling**

To characterize and index bobwhite food-producing plants in each stand, we sampled 30 1-m$^2$ plots at 30-m intervals on 2–4 randomly spaced parallel lines, perpendicular to the contour over a 2-week period in July 1999 and late-June 2000. We recorded density for each herbaceous species within plots. We recorded density for woody vegetation within 30 fixed-radius plots (radius 3.59 m). We divided woody understory, shrub, and midstory species into 3 height classes: 0–1, >1–3, and >3 m. We identified bobwhite herbaceous and woody plant foods based on a food habits study by Baumgartner et al. (1952), and summarized by Masters et al. (1995), and Bidwell et al. (1998). We estimated conifer and hardwood basal area and canopy cover using a 10-factor prism (Avery 1967) and a spherical densiometer (Lemmon 1957) (Cram 2001). To avoid bias from surrounding stands, no sampling was conducted within 50 m of stand edge (Mueller-Dombois and Ellenberg 1974:123).

To characterize invertebrate habitat structure, we estimated canopy cover (%) using the following categories: grass-like, forb, vine, legume, woody (0–1 m, and >1–2 m), litter, rock, soil, woody live stem, and woody dead stem. Cover was estimated in 30 1-m$^2$ plots located at 5 meter intervals along 6 sweepnet transect lines. A cover-value scale modified after Daubenmire (1959) was used to estimate cover (Cram 2001).

**Data analysis**

Kruskal-Wallis nonparametric tests were used to test for differences among treatment means (Steel et al. 1997:177). All variables were tested for homogeneity of variance between treatments using Levene's test (Snedecor and Cochran 1980). We further differentiated the effects of WSI and fire by using orthogonal contrasts to compare control versus thinned stands, and thinned unburned stands versus thinned burned stands (Masters et al. 1998, Sparks et al. 1998). Stand (year × treatment) type III mean square was the error term (SAS Institute 1985:651). We used multiple comparisons between mean ranks with the Least Significant Difference (LSD) test ($P < 0.05$) (Steel et al. 1997:178). We calculated species richness of bobwhite food-producing herbaceous and woody vegetation at the stand level. We summarized herbaceous and woody species by mean density and percent frequency of occurrence for each treatment. Pearson product-moment correlation analysis (SAS Institute 1985) was used to examine relationships between invertebrate abundance and habitat cover variables. Because of the inherent variability in invertebrate data sets, we reported correlation coefficients at $P < 0.10$. Regression analysis was used to examine relationships among total plant food abundance and invertebrate abundance and mass with whistle-count results (Cram 2001).

We modeled bobwhite relative abundance to habitat variables using artificial neural network (ANN) models. Neural Connection software (SPSS Inc., Chicago, Illinois, USA) was used to conduct modeling. Neural models are used in many areas of research including physics, chemistry, and ecology (Lek and Guegan 1999). We used ANN models to detect relationships between mean whistling-male abundance and habitat structure and composition following treatment. Habitat variables were selected based on significant $r$ values ($P < 0.05$) from correlation analysis and specific variables of interest such as forb cover and Orthopteran mass. Our model used 6 input nodes (independent variables), 1 hidden node, and 1 output node (dependent variable). The input nodes were year and stand means for forb cover, Orthopteran mass, hardwood basal area, conifer basal area, and disc of vulnerability (Cram 2001). The output node was predicted whistling males/point. The ANN model was trained using a randomly drawn data set comprising 80% of the data ($n = 32$); validation was conducted on the remaining 20% of the data ($n = 8$).

## Results

### Invertebrate response

Relative invertebrate abundance (mean invertebrates/sample) and mass (mean mg/sample) increased over control stands following WSI and fire treatment (Table 1, 2). Thinned stands in the third growing season following fire had the greatest total invertebrate abundance and mass as compared to other treatments (Table 1, 2). Abundance was over 2-fold >controls and mass was over 3-fold >controls in these stands (Table 1, 2).

Invertebrates frequently consumed by bobwhite adults and chicks included Coleoptera, Hemiptera, Homoptera, Lepidoptera larvae, and Orthoptera (Handley 1931, Hurst 1972, Jackson et al. 1987). Orthoptera mass was the greatest relative to other orders and families in WSI treated stands (Table 2). Coleoptera, Hemiptera, Homoptera, Lepidoptera larvae, and Orthoptera abundance and mass were greater following WSI treatment compared to control stands (Table 1, 2). Percent frequency of occurrence of important invertebrate orders increased following thinning and fire (Table 3). Araneae and Orthoptera had 100% frequency of occurrence in WSI-B3 stands.

We found Coleoptera, Hemiptera, Homoptera, and Orthoptera abundance were positively related to grass-like, and forb cover, and negatively associated with litter cover (Table 4). The above-mentioned invertebrate orders, with the exception of Hemiptera, were also positively related to legume cover (Table 4). Araneae, Coleoptera, Homoptera, Lepidoptera larvae, and Orthoptera abundance were all positively related to number of times a stand had been burned (Table 4).

**Herbaceous and woody response**

Of 286 different herbaceous and woody species identified using stem counts on the ONF, 52 (18%) herbaceous and 14 (5%) woody species were known to be bobwhite food-producing plants, and subsequently used in data analysis. Orthogonal contrasts indicated 23 herbaceous and 5 woody species increased in density following thinning and burning ($P < 0.10$) as compared to controls (Table 5). Herbaceous species richness of bobwhite foods was greatest in thinned and burned stands 1, 2 and 3 growing seasons following fire (Table 5). Total herbaceous stems (stems/$m^2$) were greatest following fire and decreased 2 and 3 growing seasons following fire (Table 5).

Total panicum species (*Panicum* spp.), preferred bobwhite food in pine-oak forests (Baumgartner et al. 1952), increased following thinning and maintained higher densities than controls following fire (Table 5). Percent frequency of occurrence of wooly panicum (*P. acuminatum*), Bosc panicum (*P. boscii*), forked panicum (*P. dichotomun*), open-flower panicum (*P. laxiflorum*), and slimleaf panicum (*P. linearifolium*) all increased following thinning and again following burning (Table 6).

We identified 25 different species of legumes, including 10 species of *Desmodium* and 7 species of *Lespedeza* (Table 5). Hog peanut (*Amphicarpaea bracteata*), partridge pea (*Cassia fasciculate*), and downy-milk pea (*Galactia regularis*), preferred legumes by bobwhites (Baumgartner et al. 1952), increased in density in WSI treated stands as compared to control stands (Table 5). We found 13 legume species increased significantly ($P < 0.10$) in percent frequency of occurrence in response to fire alone.

*Desmodium* spp., *Lepedeza* spp., bicolor lespedeza (*L. bicolor*), reclining lespedeza (*L. repens*), and trailing wild bean (*Strophostyles umbellata*) were positively related to number of times burned ($r$ = 0.389, 0.496, 0.368, 0.333, and 0.366 respectively).

Total forb stems (stems/$m^2$) increased after thinning and again following fire (Table 5). Preferred forbs common ragweed (*Ambrosia artemisiifolia*) and rough-leaf sunflower (*Helianthus hirsutus*) increased in density following WSI treatment (Table 5). Three-seeded mercury (*Acalypha gracilens*), plains tickseed (*Coreopsis tinctoria*), rough-leaf sunflower, and black-eyed susan (*Rudbeckia hirta*) increased in percent frequency of occurrence following fire treatment (Table 6).

Total woody stems (stems/$m^2$) were greatest following fire and decreased 2 and 3 growing seasons following fire (Table 5). Winged sumac (*Rhus copallina*), smooth sumac (*R. glabra*), and farkleberry (*Vaccinium arboreum*) increased in density in response to thinning and again in response to fire (Table 5). Winged sumac, smooth sumac and blackberry (*Rubus* spp.) increased in percent frequency of occurrence following WSI (Table 6).

**Bobwhite response to food abundance**

We observed an increase in abundance and mass of frequently consumed invertebrates explained 20% and 31% of the variation in bobwhite relative abundance (Fig. 1A, B). No strong relationships were detected between total stems of grass, panicum, legume, or forb with bobwhite relative abundance. Linear regression indicated an increase in total herbaceous stems explained 15% of the variation in bobwhite relative abundance (Fig. 2). The ANN model explained 37% of the variation in the training data and 19% of the variation in the validation data. We found a collapse of predicted whistling males as a function of habitat structure. Bobwhite relative abundance appeared to be more sensitive to a decrease in disc of vulnerability as compared to increases in forb cover or Orthopteran mass (Fig. 3A, B).

**Discussion and conclusions**

Bobwhite plant and invertebrate food supply and availability increased following pine-grassland restoration on the ONF. Wildlife stand improvement opened up the canopy and midstory allowing light to reach the forest floor. Increased light and nutrient availability (Masters et al. 1993) combined with the disturbance from thinning activity lead to an increase in species richness and density of herbaceous food-producing plants. Herbaceous species richness and stem density further increased in the first growing season following fire, as did total invertebrate abundance and mass. A relationship seemed to exist between invertebrates and herbaceous stems as invertebrate abundance and mass increased following WSI. Invertebrate abundance and mass continued to increase as a function of time since burned in the second and third growing seasons following fire while herbaceous stem richness and density seemed to reach a plateau 2 and 3 growing-seasons following fire.

Hurst (1972) found as succulent vegetation increased following fire invertebrate abundance and availability increased. Furthermore, fire-tolerant legumes are believed to attract more invertebrates than non-leguminous plants (Stoddard 1931:129, Hurst 1972, Jackson et al. 1987). Stoddard (1935) originally called attention to the importance of legumes to bobwhites and recommended controlled burning to promote legumes in pine forests. The hard seed coat of legumes protects them from rapid break down and makes them valuable to bobwhites in winter months when energy demands to maintain core body temperatures are increased. We found WSI and dormant season fire provided an increased legume food base, especially in the preferred genera of *Desmodium* and *Lespedeza*.

An increase in bobwhite food supply does not automatically translate to an increase in availability. However, the increase in frequency of occurrence in herbaceous species and preferred bobwhite invertebrates following thinning and fire suggests an increase in bobwhite food availability. Frequency of occurrence provides an indication of uniformity in distribution (Mueller-Dombois and Ellenberg 1974).

The importance of invertebrates to bobwhite chicks and hens (Stoddard 1931, Nestler et al. 1942, Hurst 1972, Brennan and Hurst 1995) as well as invertebrate response to management practices (Hurst 1972, Dunaway 1977, Burger et al. 1993, Manley et al. 1994) is well documented. Furthermore, bobwhite food habits (Davison 1942, Baumgartner et al. 1952, Robel 1969, Eubanks and Dimmick 1974) and bobwhite habitat response following fire (Stoddard 1935, Speake 1966, Dimmick 1972, Landers 1981, Cram 2001) have also been well documented. The eminent question in bobwhite habitat management remains managing for quality or usable space.

Currently, bobwhite habitat managers have 2 competing hypothesis from which to choose from when considering management practices. The usable space hypothesis as formalized by Guthery (1997) contends as suitable habitat (habitat compatible with the physical, physiological, and behavioral adaptations of bobwhites) increases on an area of fixed size, mean bobwhite density will increase. The second competing hypothesis predicts bobwhite density as a function of habitat quality. This hypothesis contends habitat quality exists along a continuum ranging from 0 (unsuitable habitat) to 1 (optimal habitat). Bobwhite management practices such as food plots and food supplementation, as well as some habitat suitability models (e.g., Schroeder 1985, Bidwell et al. 1991), operate under the quality hypothesis.

The effects of increased food supply and availability (invertebrate abundance and mass, and herbaceous food stems) following thinning and fire on bobwhite relative abundance were ambiguous in terms of supporting either the usable space hypothesis or the quality hypothesis. Because bobwhite abundance increased as a function of usable space (Cram 2001) and bobwhite abundance increased somewhat as a function of food supply (Fig. 2), food supply and usable space are confounded; food supply may be a function of usable space. Food, however, is not a condition of the usable space hypothesis and therefore food abundance cannot create usable space per se. Deductions can be made to separate the correlated effects of usable space and food supply. For example, WSI-NB and WSI-B3 stands both had similar amounts of usable space (as measured by the disc of vulnerability and woody stem density) and measures of bobwhite relative abundance (Cram 2001), but significantly different food supplies as measured in preferred invertebrate abundance, mass, and herbaceous food stems (Table 1, 2, 5).

The quality hypothesis contends an increase in food supply should result in an increase in bobwhite abundance, while the usable space hypothesis contends a threshold in the food supply has been met and no further increase in food supply will result in an increase in bobwhite abundance. Based on this observation, we deduced bobwhites respond to an increase in usable space rather than an increase in food supply, or conversely, food was not limiting following thinning and burning. Artificial neural network model predictions were consistent with this deduction. A threshold region appeared to exist beyond which the addition of increased food resources had a null effect on bobwhite abundance (Fig. 3A, B). Guthery (1999) offered a hypothesis explaining the general circumstance: food supplies as evaluated through energy-based carrying capacity routinely exceed the needs of bobwhite populations. Furthermore, the literature on the effects of food plots and food supplementation has failed to provide unchallengeable evidence an increase in food supply results in positive bobwhite population response (Guthery 1997). Higher winter survival rates were reported on supplemented sites in Oklahoma (Townsend et al. 1999), but increased winter survival does not necessarily translate to an increase in bobwhite abundance in the fall.

Increased food availability and creation of suitable habitat for bobwhites are 2 outcomes following pine-grassland restoration on the ONF. We recommend management efforts in similar mixed shortleaf pine-oak forests aimed at increasing bobwhite densities include thinning to reduce midstory cover and frequent fire to maintain park-like conditions. Planting food plots or providing supplemental feed on similar sites following thinning and fire are unnecessary.

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Table 1. Invertebrate relative abundance (mean invertebrates/sample) response to wildlife stand improvement and fire on the Ouachita National Forest, Arkansas, July 1999 and 2000.[a]

| Invertebrate order and family | Treatment[b] Control $\bar{x}$ | Control SE | WSI-NB $\bar{x}$ | WSI-NB SE | WSI-B1 $\bar{x}$ | WSI-B1 SE | WSI-B2 $\bar{x}$ | WSI-B2 SE | WSI-B3 $\bar{x}$ | WSI-B3 SE | $P > F$ Contrasts[c] C vs. W | NB vs. B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Araneae | 3.75 | 0.77 | 3.60 | 0.58 | 3.71 | 0.70 | 4.50 | 0.72 | 6.69 | 1.00 | 0.223 | 0.137 |
| Coleoptera | 0.77 | 0.23 B | 1.33 | 0.26 AB | 2.37 | 0.73 A | 2.27 | 0.35 A | 1.98 | 0.28 A | 0.003 | 0.050 |
| Diptera | 2.71 | 0.50 | 2.10 | 0.52 | 3.40 | 0.60 | 2.21 | 0.44 | 3.26 | 0.66 | 0.925 | 0.163 |
| Hemiptera | 0.02 | 0.02 B | 1.83 | 0.43 A | 1.28 | 0.18 A | 1.50 | 0.31 A | 1.99 | 0.49 A | <0.001 | 0.726 |
| Homoptera | 0.33 | 0.14 B | 1.63 | 0.49 A | 1.82 | 0.64 A | 2.13 | 0.43 A | 3.18 | 1.15 A | 0.002 | 0.595 |
| Hymenoptera | 1.63 | 0.57 | 0.69 | 0.19 | 0.97 | 0.21 | 1.19 | 0.36 | 0.93 | 0.29 | 0.317 | 0.295 |
| Lepidoptera | 0.35 | 0.17 | 0.23 | 0.14 | 0.04 | 0.03 | 0.33 | 0.16 | 0.25 | 0.09 | 0.836 | 0.970 |
| Lepidoptera larvae | 0.27 | 0.09 C | 0.42 | 0.07 BC | 0.69 | 0.21 AB | 0.94 | 0.32 AB | 1.00 | 0.14 A | 0.003 | 0.012 |
| Mantodea | 0.00 | 0.00 B | 0.17 | 0.03 A | 0.10 | 0.06 AB | 0.15 | 0.08 A | 0.24 | 0.11 A | 0.002 | 0.147 |
| Miscellaneous[d] | 0.03 | 0.02 | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.744 | 0.374 |
| Orthoptera | 0.89 | 0.23 C | 2.25 | 0.33 B | 2.85 | 0.69 B | 5.21 | 0.50 A | 5.94 | 0.87 A | <0.001 | 0.001 |
| Phasmatidea | 0.25 | 0.07 B | 0.29 | 0.25 B | 0.25 | 0.07 B | 0.77 | 0.14 A | 0.70 | 0.16 A | 0.060 | 0.049 |
| Total abundance | 11.09 | 1.89 C | 14.55 | 1.64 C | 17.51 | 3.11 BC | 21.20 | 2.38 AB | 26.17 | 3.57 A | 0.003 | 0.029 |

[a] Row means followed by the same letter or without letters were not significantly different at the 0.05 level (LSD); differences are based on treatment effect rather than specific contrasts.

[b] Control = unthinned, unburned; WSI-NB = wildlife stand improvement, no burn; WSI-B1 = wildlife stand improvement, first growing season following burn; WSI-B2 = wildlife stand improvement, second growing season following burn; WSI-B3 = wildlife stand improvement, third growing season following burn; $n$ = 8 for each treatment.

[c] Specific orthogonal contrasts; C = control; W = wildlife stand improvement; NB = wildlife stand improvement, no burn; B = wildlife stand improvement and burned.

[d] Miscellaneous invertebrates include Acari, Neuroptera, Odonata, Opiliones, Phasmatodea, and unknowns.

Table 2. Relative invertebrate mass (mean mg/sample) response to wildlife stand improvement and fire on the Ouachita National Forest, Arkansas, July 1999 and 2000.[a]

| Invertebrate order and family | Treatment[b] | | | | | | | | | | $P > F$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | WSI-NB | | WSI-B1 | | WSI-B2 | | WSI-B3 | | | Contrasts[c] | |
| | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | Trt. | C vs. W | NB vs. B |
| Araneae | 10.8 | 3.1 BC | 11.6 | 3.2 BC | 7.8 | 1.4 C | 15.0 | 2.0 AB | 22.8 | 3.4 A | 0.004 | 0.138 | 0.167 |
| Coleoptera | 2.9 | 1.3 C | 4.3 | 1.3 BC | 8.6 | 2.6 AB | 8.7 | 1.0 A | 7.5 | 2.1 AB | 0.014 | 0.006 | 0.034 |
| Diptera | 1.9 | 0.3 | 2.5 | 1.0 | 2.3 | 0.5 | 2.5 | 0.8 | 2.8 | 0.5 | 0.774 | 0.605 | 0.539 |
| Hemiptera | 0.0 | 0.0 B | 8.6 | 2.4 A | 14.6 | 3.4 A | 12.1 | 4.5 A | 13.2 | 2.5 A | <0.001 | <0.001 | 0.322 |
| Homoptera | 0.5 | 0.3 B | 6.7 | 2.8 A | 4.9 | 2.0 A | 6.0 | 2.3 A | 9.5 | 3.5 A | 0.012 | 0.001 | 0.977 |
| Hymenoptera | 1.1 | 0.3 | 0.8 | 0.3 | 1.1 | 0.3 | 1.4 | 0.4 | 0.7 | 0.2 | 0.591 | 0.928 | 0.320 |
| Lepidoptera | 1.6 | 0.6 | 0.6 | 0.4 | 0.3 | 0.2 | 1.1 | 0.5 | 1.4 | 0.7 | 0.361 | 0.693 | 0.661 |
| Lepidoptera larvae | 2.1 | 0.9 C | 5.1 | 1.3 BC | 7.1 | 4.7 BC | 9.4 | 2.5 AB | 13.4 | 3.3 A | 0.004 | 0.003 | 0.344 |
| Mantodea | 0.0 | 0.0 B | 1.4 | 0.4 A | 1.3 | 0.8 AB | 1.2 | 0.8 AB | 2.8 | 1.2 A | 0.011 | 0.002 | 0.215 |
| Miscellaneous[d] | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.764 | 0.651 | 0.421 |
| Orthoptera | 13.3 | 7.2 D | 35.9 | 13.4 BC | 33.9 | 16.2 CD | 68.1 | 17.7 AB | 83.5 | 22.0 A | 0.001 | 0.001 | 0.142 |
| Phasmatidea | 20.8 | 20.3 B | 2.2 | 0.7 AB | 2.2 | 1.3 B | 6.9 | 2.9 A | 8.4 | 2.6 A | 0.026 | 0.034 | 0.307 |
| Total biomass | 55.3 | 19.2 C | 79.8 | 15.6 BC | 84.1 | 21.4 BC | 132.4 | 21.6 AB | 166.0 | 28.9 A | 0.004 | 0.004 | 0.096 |

[a] Row means followed by the same letter or without letters were not significantly different at the 0.05 level (LSD).

[b] Control = unthinned, unburned; WSI-NB = wildlife stand improvement, no burn; WSI-B1 = wildlife stand improvement, first growing season following burn; WSI-B2 = wildlife stand improvement, second growing-season following burn; WSI-B3 = wildlife stand improvement, third growing season following burn; $n$ = 8 for each treatment.

[c] Specific orthogonal contrasts; C = control; W = wildlife stand improvement; NB = wildlife stand improvement, no burn; B = wildlife stand improvement and burned.

[d] Miscellaneous invertebrates include Acari, Neuroptera, Odonata, Opiliones, Phasmatodea, and unknowns.

Table 3. Invertebrate percent frequency of occurrence response to wildlife stand improvement and fire on the Ouachita National Forest, Arkansas, July 1999 and 2000.[a]

| Invertebrate order and family | Treatment[b] | | | | | | | | | | | $P < F$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | WSI-NB | | WSI-B1 | | WSI-B2 | | WSI-B3 | | | Contrasts[c] | |
| | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | Trt | C vs. W | NB vs. B |
| Araneae | 87.5 | 6.9 | 91.7 | 3.2 | 89.6 | 5.4 | 97.9 | 2.1 | 100.0 | 0.0 | 0.206 | 0.338 | 0.141 |
| Coleoptera | 43.8 | 9.9 B | 54.2 | 7.6 B | 77.1 | 8.9 A | 81.3 | 5.8 A | 85.7 | 7.7 A | 0.003 | 0.003 | 0.003 |
| Diptera | 79.2 | 7.6 | 72.9 | 9.9 | 91.7 | 6.3 | 72.9 | 5.4 | 78.6 | 7.9 | 0.231 | 0.973 | 0.507 |
| Hemiptera | 2.1 | 2.1 B | 56.3 | 8.3 A | 62.5 | 8.8 A | 62.5 | 5.2 A | 76.2 | 8.8 A | <0.001 | <0.001 | 0.278 |
| Homoptera | 18.8 | 6.6 B | 56.3 | 10.9 A | 60.4 | 10.4 A | 66.7 | 13.7 A | 76.2 | 13.5 A | 0.012 | 0.001 | 0.354 |
| Hymenoptera | 54.2 | 9.8 | 33.3 | 8.9 | 58.3 | 8.9 | 47.9 | 8.6 | 54.8 | 10.1 | 0.412 | 0.703 | 0.075 |
| Lepidoptera | 20.8 | 9.3 | 16.7 | 7.7 | 4.2 | 2.7 | 22.9 | 8.9 | 26.2 | 7.1 | 0.194 | 0.944 | 0.949 |
| Lepidoptera larvae | 16.7 | 5.5 D | 35.4 | 5.8 CD | 39.6 | 8.9 BC | 60.4 | 9.4 AB | 64.3 | 5.7 A | <0.001 | <0.001 | 0.024 |
| Mantodea | 0.0 | 0.0 C | 14.6 | 2.1 A | 10.4 | 6.3 AB | 12.5 | 6.1 A | 26.2 | 11.4 A | 0.010 | 0.002 | 0.247 |
| Miscellaneous[d] | 8.3 | 4.5 | 4.2 | 2.7 | 12.5 | 4.2 | 8.3 | 4.5 | 7.1 | 5.0 | 0.659 | 0.991 | 0.326 |
| Orthoptera | 56.3 | 8.3 C | 83.3 | 6.3 B | 87.5 | 6.9 AB | 97.9 | 2.1 A | 100.0 | 0.0 A | <0.001 | <0.001 | 0.012 |
| Phasmatidea | 18.8 | 3.8 B | 22.9 | 6.3 B | 25.0 | 7.7 B | 45.8 | 6.1 A | 61.9 | 13.5 A | 0.006 | 0.032 | 0.027 |

[a] Row means followed by the same letter or without letters were not significantly different at the 0.05 level (LSD).

[b] Control = unthinned, unburned; WSI-NB = wildlife stand improvement, no burn; WSI-B1 = wildlife stand improvement, first growing season following burn; WSI-B2 = wildlife stand improvement, second growing season following burn; WSI-B3 = wildlife stand improvement, third growing season following burn; $n$ = 8 for each treatment.

[c] Specific orthogonal contrasts; C = control; W = wildlife stand improvement; NB = wildlife stand improvement, no burn; B = wildlife stand improvement and burned.

[d] Miscellaneous invertebrates include Acari, Neuroptera, Odonata, Opiliones, Phasmatodea, and unknowns.

Table 4. Preferred northern bobwhite invertebrate correlation with habitat variables following pine-grassland restoration on the Ouachita National Forest, Arkansas, July 1999 and 2000.[a]

| | Araneae | | Coleoptera | | Hemiptera | | Homoptera | | Lepidoptera larvae | | Orthoptera | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Habitat variable | *r* | *P* | *r* | *P* | *r* | *P* | *r* | *P* | *r* | *P* | *r* | *P* |
| Cover (%) | | | | | | | | | | | | |
| Grass-like | | | 0.332 | 0.039 | 0.488 | 0.002 | 0.348 | 0.032 | | | 0.532 | 0.001 |
| Forb | | | 0.468 | 0.003 | 0.303 | 0.061 | 0.307 | 0.058 | 0.507 | 0.001 | 0.365 | 0.022 |
| Vine | -0.297 | 0.066 | -0.282 | 0.082 | | | | | | | | |
| Woody <1 m | 0.400 | 0.012 | | | 0.453 | 0.004 | | | 0.341 | 0.034 | | |
| Woody 1–2 m | | | | | | | 0.397 | 0.012 | | | | |
| Litter | | | -0.520 | 0.001 | -0.503 | 0.001 | -0.358 | 0.025 | -0.364 | 0.023 | -0.457 | 0.004 |
| Bare soil | -0.297 | 0.066 | | | | | | | | | | |
| Woody live stem | | | 0.318 | 0.049 | 0.428 | 0.007 | | | 0.380 | 0.017 | | |
| Woody dead stem | -0.441 | 0.005 | | | | | | | | | | |
| Legume | | | 0.388 | 0.015 | | | 0.404 | 0.011 | 0.419 | 0.008 | 0.567 | <0.001 |
| Times burned | 0.323 | 0.045 | 0.444 | 0.005 | | | 0.487 | 0.002 | 0.629 | <0.001 | 0.524 | 0.001 |

[a] Only correlations coefficients $P < 0.10$ listed.

Table 5. Herbaceous (stems/m$^2$) and woody (stems/ha) northern bobwhite food-producing species ( $\bar{x} \pm$ SE) reponse to midstory thinning and dormant-season prescribed fire on the Ouachita National Forest, Arkansas, July 1999 and June 2000.[a]

| | Treatment[b] | | | | | | | | | | P > F | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | WSI-NB | | WSI-B1 | | WSI-B2 | | WSI-B3 | | Contrasts[c] | |
| Category<br>Species | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | C vs. W | NB vs. B |
| Grasses | | | | | | | | | | | | |
| *Chasmanthium latifolium* | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.492 | 0.402 |
| *Sporobolus asper* | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.627 | 0.531 |
| *Sporobolus* spp. | 0.3 | 0.2 | 0.2 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.122 | 0.049 |
| Total grass stems[d] | 0.3 | 0.2 | 0.2 | 0.2 | 0.6 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.636 | 0.165 |
| Other grasses | | | | | | | | | | | | |
| *Panicum aciculare* | 0.7 | 0.3 | 2.1 | 1.1 | 1.9 | 0.9 | 2.2 | 0.4 | 1.3 | 0.5 | 0.076 | 0.553 |
| *Panicum acuminatum* | 0.3 | 0.1 B | 2.4 | 1.6 A | 2.9 | 0.9 A | 2.5 | 0.5 A | 1.8 | 0.5 A | 0.001 | 0.172 |
| *Panicum anceps* | 0.0 | 0.0 | 0.4 | 0.4 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.225 | 0.825 |
| *Panicum boscii* | 0.2 | 0.1 B | 2.2 | 0.7 A | 2.5 | 0.8 A | 2.1 | 0.9 A | 2.6 | 0.8 A | 0.003 | 0.962 |
| *Panicum dichotomum* | 0.3 | 0.2 C | 2.5 | 0.8 B | 3.8 | 0.8 AB | 4.0 | 0.9 AB | 4.6 | 0.6 A | <0.001 | 0.012 |
| *Panicum laxiflorum* | 0.3 | 0.2 B | 5.8 | 2.4 A | 7.9 | 3.3 A | 5.2 | 2.1 A | 7.4 | 3.7 A | <0.001 | 0.985 |
| *Panicum linearifolium* | 0.7 | 0.2 C | 2.5 | 0.9 B | 5.0 | 1.2 AB | 8.7 | 2.4 A | 6.9 | 2.1 A | <0.001 | 0.007 |
| *Panicum ravenellii* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 | 0.574 | 0.470 |
| *Panicum sphaerocarpon* | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.2 | 0.5 | 0.3 | 0.1 | 0.1 | 0.181 | 0.088 |
| *Panicum* spp. | 0.0 | 0.0 | 0.3 | 0.2 | 0.4 | 0.3 | 0.5 | 0.4 | 0.1 | 0.1 | 0.048 | 0.887 |
| *Panicum virgatum* | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 1.0 | 1.0 | 0.0 | 0.0 | 0.933 | 0.960 |
| Total panicum stems[d] | 2.5 | 0.6 C | 18.5 | 4.2 A | 24.9 | 3.2 AB | 26.6 | 3.1 A | 24.9 | 5.7 AB | <0.001 | 0.058 |
| Sedges | | | | | | | | | | | | |
| *Scleria* spp. | 0.4 | 0.2 B | 0.3 | 0.2 B | 1.2 | 0.3 A | 1.3 | 0.8 AB | 0.5 | 0.2 AB | 0.143 | 0.023 |
| *Scleria triglomerata* | 1.8 | 0.2 B | 7.9 | 1.3 A | 6.6 | 3.0 A | 7.8 | 2.2 A | 7.7 | 3.1 A | 0.001 | 0.187 |
| Total sedge stems[d] | 2.2 | 0.3 B | 8.2 | 1.4 A | 7.8 | 2.9 A | 9.0 | 2.1 A | 8.2 | 3.0 A | <0.001 | 0.431 |

Table 5. Continued.

| Category Species | Control $\bar{x}$ | Control SE | WSI-NB $\bar{x}$ | WSI-NB SE | WSI-B1 $\bar{x}$ | WSI-B1 SE | WSI-B2 $\bar{x}$ | WSI-B2 SE | WSI-B3 $\bar{x}$ | WSI-B3 SE | $P > F$ Contrasts[c] C vs. W | $P > F$ Contrasts[c] NB vs. B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Treatment[b] | | | | | | | | | | | |
| Legumes | | | | | | | | | | | | |
| *Amphicarpa bracteata* | 0.0 | 0.0 C | 0.2 | 0.1 BC | 1.6 | 0.6 A | 1.0 | 0.4 A | 1.5 | 1.2 AB | 0.001 | 0.017 |
| *Cassia fasciculate* | 0.0 | 0.0 C | 0.2 | 0.1 B | 2.5 | 1.4 A | 0.8 | 0.3 A | 0.3 | 0.1 AB | <0.001 | 0.003 |
| *Clitoria mariana* | 0.8 | 0.2 | 0.6 | 0.1 | 1.1 | 0.3 | 1.3 | 0.3 | 1.0 | 0.2 | 0.449 | 0.063 |
| *Desmodium canadense* | 0.0 | 0.0 B | 0.0 | 0.0 B | 1.0 | 0.8 A | 0.0 | 0.0 B | 0.0 | 0.0 B | 0.322 | 0.204 |
| *Desmodium canescens* | 0.2 | 0.2 | 0.0 | 0.0 | 0.3 | 0.2 | 0.1 | 0.0 | 0.1 | 0.1 | 0.720 | 0.504 |
| *Desmodium ciliare* | 0.1 | 0.1 | 0.9 | 0.4 | 2.1 | 0.8 | 1.3 | 0.6 | 1.1 | 0.3 | 0.015 | 0.514 |
| *Desmodium illinoense* | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.627 | 0.531 |
| *Desmodium laevigatum* | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.2 | 0.1 | 0.1 | 0.3 | 0.1 | 0.025 | 0.055 |
| *Desmodium marilandicum* | 0.1 | 0.1 | 0.6 | 0.4 | 2.3 | 1.1 | 2.2 | 0.7 | 1.5 | 0.7 | 0.014 | 0.093 |
| *Desmodium paniculatum* | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.3 | 0.2 | 0.1 | 0.1 | 0.094 | 0.167 |
| *Desmodium* spp. | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.2 | 0.1 | 0.2 | 0.1 | 0.509 | 0.754 |
| *Desmodium strictum* | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.627 | 0.066 |
| *Desmodium viridiflorum* | 0.3 | 0.1 | 0.4 | 0.1 | 0.8 | 0.5 | 1.2 | 0.5 | 0.6 | 0.2 | 0.246 | 0.583 |
| *Galactia regularis* | 0.1 | 0.0 B | 0.2 | 0.0 A | 0.3 | 0.1 A | 0.3 | 0.1 A | 0.3 | 0.1 A | 0.001 | 0.142 |
| *Lespedeza bicolor* | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 0.3 | 0.3 | 0.0 | 0.0 | 0.492 | 0.378 |
| *Lespedeza hirta* | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.223 | 0.677 |
| *Lespedeza intermedia* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.330 | 0.212 |
| *Lespedeza procumbens* | 0.4 | 0.2 B | 0.4 | 0.3 B | 2.5 | 1.3 A | 4.0 | 1.4 A | 4.5 | 1.5 A | 0.002 | 0.001 |
| *Lespedeza repens* | 1.3 | 0.4 | 0.8 | 0.3 | 4.0 | 1.2 | 5.4 | 1.7 | 5.9 | 1.7 | 0.067 | <0.001 |
| *Lespedeza striata* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 0.6 | 0.0 | 0.0 | 0.220 | 0.117 |
| *Lespedeza violacea* | 0.0 | 0.0 B | 0.0 | 0.0 B | 0.7 | 0.6 A | 0.1 | 0.1 AB | 0.1 | 0.0 AB | 0.037 | 0.008 |
| *Lespedeza virginica* | 0.1 | 0.1 | 0.1 | 0.0 | 1.3 | 1.0 | 0.2 | 0.1 | 0.2 | 0.0 | 0.762 | 0.111 |
| *Strophostyles umbellata* | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | 0.090 | 0.051 |

Table 5. Continued.

| Category Species | Treatment[b] | | | | | | | | | | P > F | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | WSI-NB | | WSI-B1 | | WSI-B2 | | WSI-B3 | | Contrasts[c] | |
| | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | C vs. W | NB vs. B |
| *Stylosanthes biflora* | 0.6 | 0.2 | 0.7 | 0.3 | 3.3 | 2.0 | 2.2 | 0.9 | 1.1 | 0.5 | 0.169 | 0.098 |
| *Tephrosia virginiana* | 0.3 | 0.2 | 0.0 | 0.0 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.0 | 0.421 | 0.063 |
| Total legume stems[d] | 4.3 | 1.0 B | 5.3 | 0.9 B | 25.3 | 6.1 A | 22.3 | 4.3 A | 19.0 | 2.2 A | 0.001 | <0.001 |
| Forbs | | | | | | | | | | | | |
| *Acalypha gracilens* | 0.0 | 0.0 C | 0.0 | 0.0 C | 4.2 | 3.6 A | 0.1 | 0.0 AB | 0.0 | 0.0 BC | 0.008 | 0.009 |
| *Acalypha virginica* | 0.0 | 0.0 D | 0.2 | 0.1 BC | 1.1 | 0.8 A | 0.2 | 0.0 AB | 0.0 | 0.0 CD | 0.001 | 0.329 |
| *Ambrosia artemisiifolia* | 0.0 | 0.0 | 0.1 | 0.1 | 0.6 | 0.4 | 0.1 | 0.1 | 0.0 | 0.0 | 0.111 | 0.914 |
| *Coreopsis tinctoria* | 0.0 | 0.0 B | 0.2 | 0.2 B | 0.7 | 0.3 A | 0.5 | 0.3 A | 0.5 | 0.2 A | <0.001 | 0.002 |
| *Elephantopus carolinianus* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.459 | 0.341 |
| *Euphorbia corollata* | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.616 | 0.881 |
| *Helianthus hirsutus* | 0.3 | 0.1 C | 1.6 | 0.4 B | 6.4 | 2.6 A | 6.3 | 1.3 A | 6.6 | 1.5 A | <0.001 | 0.001 |
| *Oxalis violacea* | 0.0 | 0.0 B | 0.0 | 0.0 B | 0.1 | 0.0 A | 0.0 | 0.0 B | 0.0 | 0.0 B | 0.180 | 0.087 |
| *Physalis virginiana* | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.133 | 0.670 |
| *Phytolacca americana* | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.459 | 0.341 |
| *Rudbeckia hirta* | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.0 | 0.330 | 0.061 |
| Total forb stems[d] | 0.4 | 0.2 C | 2.2 | 0.5 B | 13.5 | 4.0 A | 7.6 | 1.3 A | 7.4 | 1.4 A | <0.001 | <0.001 |
| Total herbaceous stems[d] | 9.7 | 1.7 C | 34.5 | 5.2 B | 72.1 | 8.8 A | 65.5 | 6.1 A | 59.5 | 8.5 A | <0.001 | <0.001 |
| Herbaceous species richness[d] | 16.5 | 1.5 C | 23.1 | 1.0 B | 29.9 | 1.6 A | 28.4 | 1.4 A | 27.6 | 0.9 A | <0.001 | <0.001 |
| Woody | | | | | | | | | | | | |
| *Callicarpa americana* | 41 | 31 B | 104 | 36 A | 12 | 12 B | 6 | 4 B | 76 | 54 B | 0.635 | 0.001 |
| *Parthenocissus quinquefolia* | 1,203 | 560 | 1,139 | 399 | 4,419 | 1,178 | 791 | 296 | 1,254 | 421 | 0.480 | 0.620 |
| *Rhus aromatica* | 129 | 97 | 57 | 32 | 73 | 53 | 21 | 15 | 17 | 16 | 0.917 | 0.360 |

Table 5. Continued.

| Category Species | Treatment[b] | | | | | | | | | | P > F | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | WSI-NB | | WSI-B1 | | WSI-B2 | | WSI-B3 | | Contrasts[c] | |
| | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | C vs. W | NB vs. B |
| *Rhus copallina* | 22 | 5 C | 173 | 70 C | 2,047 | 452 A | 583 | 138 B | 678 | 195 B | <0.001 | <0.001 |
| *Rhus glabra* | 0 | 0 D | 6 | 4 CD | 357 | 274 A | 19 | 7 BC | 75 | 28 AB | <0.001 | 0.001 |
| *Rubus* spp. | 261 | 60 B | 2,003 | 703 A | 2,308 | 452 A | 1,733 | 503 A | 2,457 | 547 A | <0.001 | 0.468 |
| *Smilax bona-nox* | 697 | 119 | 651 | 76 | 1,214 | 352 | 630 | 242 | 721 | 182 | 0.751 | 0.761 |
| *Smilax glauca* | 155 | 69 | 133 | 87 | 117 | 20 | 50 | 25 | 80 | 18 | 0.531 | 0.486 |
| *Smilax rotundifolia* | 216 | 80 | 123 | 45 | 102 | 37 | 42 | 18 | 60 | 28 | 0.387 | 0.178 |
| *Toxicodendron radicans* | 17,837 | 2,881 | 13,689 | 3,381 | 21,172 | 7,103 | 11,040 | 3,270 | 9,433 | 2,354 | 0.166 | 0.854 |
| *Vaccinium arboreum* | 162 | 37 B | 381 | 125 B | 3,346 | 1,629 A | 1,192 | 175 A | 913 | 228 A | <0.001 | 0.002 |
| *Vitis aestivalis* | 62 | 26 | 50 | 14 | 168 | 60 | 121 | 57 | 82 | 30 | 0.453 | 0.318 |
| *Vitis palmate* | 5 | 3 | 85 | 46 | 83 | 37 | 62 | 33 | 100 | 65 | 0.057 | 0.679 |
| *Vitis rotundifolia* | 2,278 | 1,193 | 2,120 | 509 | 1,139 | 307 | 696 | 164 | 788 | 211 | 0.851 | 0.024 |
| Total woody stems[d] | 23,068 | 3,822 | 20,714 | 3,446 | 36,556 | 7,670 | 16,987 | 3,659 | 16,733 | 3,428 | 0.638 | 0.953 |
| Woody species richness[d] | 10.3 | 0.3 | 11.9 | 0.6 | 11.6 | 0.8 | 10.6 | 0.8 | 11.9 | 0.6 | 0.013 | 0.682 |

[a] Column means within rows followed by the same letter or without letters were not significantly different at the 0.05 level (LSD); differences are based on treatment effect rather than specific contrasts.

[b] Treatments are: Control = unthinned, unburned; WSI-NB = wildlife stand improvement, no burning; WSI-B1 = wildlife stand improvement, first growing season following burn; WSI-B2 = wildlife stand improvement, second growing season following burn; WSI-B3 = wildlife stand improvement, third growing season following burn; $n = 8$ for each treatment.

[c] Specific orthogonal contrasts; C = control; W = wildlife stand improvement; NB = wildlife stand improvement, no burn; B = wildlife stand improvement and burned.

[d] Food-producing stems only.

Table 6. Herbaceous and woody northern bobwhite food-producing species percent frequency of occurrence response to midstory thinning and dormant-season prescribed fire on the Ouachita National Forest, Arkansas, July 1999 and June 2000.[a]

| | Treatment[b] | | | | | | | | | | $P > F$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | WSI-NB | | WSI-B1 | | WSI-B2 | | WSI-B3 | | Contrasts[c] | |
| Category Species | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | C vs. W | NB vs. B |
| Grasses | | | | | | | | | | | | |
| *Chasmanthium latifolium* | 0.0 | 0.0 | 0.4 | 0.4 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.492 | 0.377 |
| *Setaria geniculata* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.627 | 0.531 |
| *Sporobolus asper* | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.627 | 0.531 |
| *Sporobolus* spp. | 5.0 | 3.5 | 0.8 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.094 | 0.061 |
| Other grasses | | | | | | | | | | | | |
| *Panicum aciculare* | 5.8 | 2.3 | 9.2 | 3.1 | 10.0 | 3.6 | 17.9 | 4.5 | 14.8 | 3.1 | 0.047 | 0.177 |
| *Panicum acuminatum* | 6.7 | 1.3 C | 17.5 | 4.8 BC | 26.3 | 6.3 AB | 35.0 | 4.0 A | 31.0 | 4.1 A | <0.001 | 0.013 |
| *Panicum anceps* | 0.0 | 0.0 | 0.8 | 0.8 | 1.3 | 0.6 | 0.0 | 0.0 | 0.5 | 0.5 | 0.226 | 0.823 |
| *Panicum boscii* | 5.0 | 1.4 B | 13.8 | 2.9 AB | 25.0 | 7.7 A | 17.5 | 4.6 A | 25.7 | 5.0 A | 0.002 | 0.224 |
| *Panicum dichotomum* | 6.3 | 1.8 C | 20.0 | 2.1 B | 40.4 | 4.8 A | 49.6 | 4.2 A | 48.1 | 4.2 A | <0.001 | <0.001 |
| *Panicum laxiflorum* | 3.8 | 1.0 C | 16.7 | 2.8 B | 33.8 | 6.4 A | 22.5 | 3.4 AB | 19.1 | 3.9 B | <0.001 | 0.038 |
| *Panicum linearifolium* | 5.8 | 1.5 B | 11.3 | 2.7 B | 24.2 | 4.7 A | 25.4 | 3.2 A | 33.8 | 5.1 A | <0.001 | <0.001 |
| *Panicum ravenellii* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.9 | 1.9 | 0.574 | 0.470 |
| *Panicum rigidulum* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.5 | 0.574 | 0.470 |
| *Panicum sphaerocarpon* | 0.0 | 0.0 | 0.0 | 0.0 | 2.5 | 1.8 | 2.9 | 1.7 | 0.5 | 0.5 | 0.181 | 0.088 |
| *Panicum* spp. | 0.0 | 0.0 | 2.5 | 1.6 | 1.3 | 0.6 | 2.1 | 0.9 | 1.4 | 1.0 | 0.046 | 0.964 |
| *Panicum virgatum* | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.5 | 0.975 | 0.968 |
| Sedges | | | | | | | | | | | | |
| *Scleria* spp. | 4.6 | 1.8 | 3.3 | 1.4 | 12.9 | 4.2 | 10.8 | 5.6 | 7.6 | 2.0 | 0.274 | 0.039 |
| *Scleria triglomerata* | 24.2 | 4.6 | 42.9 | 4.7 | 32.9 | 9.3 | 35.8 | 4.7 | 33.8 | 5.2 | 0.085 | 0.133 |
| Legume | | | | | | | | | | | | |
| *Amphicarpa bracteata* | 0.4 | 0.4 B | 3.3 | 1.7 B | 19.2 | 6.1 A | 18.8 | 6.6 A | 14.3 | 3.8 A | 0.001 | 0.004 |
| *Cassia fasciculata* | 0.0 | 0.0 B | 3.8 | 1.8 B | 25.4 | 8.6 A | 21.3 | 6.2 A | 12.4 | 4.9 A | <0.001 | 0.001 |

Table 6. Continued.

| | Treatment[b] | | | | | | | | | | P > F | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | WSI-NB | | WSI-B1 | | WSI-B2 | | WSI-B3 | | Contrasts[c] | |
| Category<br>Species | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | C vs. W | NB vs. B |
| Legumes (continued) | | | | | | | | | | | | |
| *Clitoria mariana* | 27.1 | 6.7 | 18.3 | 3.6 | 28.8 | 6.9 | 39.6 | 6.9 | 34.8 | 4.5 | 0.358 | 0.011 |
| *Desmodium canadense* | 0.0 | 0.0 B | 0.0 | 0.0 B | 2.1 | 1.3 A | 0.0 | 0.0 B | 0.0 | 0.0 B | 0.322 | 0.204 |
| *Desmodium canescens* | 3.3 | 2.9 | 1.3 | 0.9 | 1.7 | 0.9 | 1.3 | 0.6 | 1.4 | 1.0 | 0.827 | 0.716 |
| *Desmodium ciliare* | 3.3 | 1.5 B | 9.2 | 2.8 AB | 12.5 | 4.5 AB | 7.5 | 3.4 B | 16.7 | 2.7 A | 0.013 | 0.579 |
| *Desmodium illinoense* | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.627 | 0.531 |
| *Desmodium laevigatum* | 0.4 | 0.4 | 1.7 | 1.3 | 2.9 | 1.3 | 3.8 | 1.6 | 7.1 | 2.7 | 0.031 | 0.069 |
| *Desmodium marilandicum* | 3.3 | 1.7 | 5.4 | 2.3 | 12.5 | 3.3 | 13.8 | 4.4 | 8.1 | 2.5 | 0.041 | 0.098 |
| *Desmodium paniculatum* | 0.0 | 0.0 | 0.8 | 0.8 | 1.7 | 0.9 | 2.9 | 2.0 | 1.4 | 1.0 | 0.097 | 0.256 |
| *Desmodium rotundifolium* | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.627 | 0.531 |
| *Desmodium* spp. | 2.1 | 0.9 | 4.2 | 1.6 | 2.1 | 1.3 | 6.7 | 2.3 | 2.4 | 0.6 | 0.471 | 0.666 |
| *Desmodium strictum* | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.627 | 0.066 |
| *Desmodium viridiflorum* | 4.6 | 1.3 | 7.9 | 2.1 | 11.3 | 4.8 | 20.0 | 5.9 | 10.5 | 2.5 | 0.080 | 0.452 |
| *Galactia regularis* | 4.2 | 1.8 B | 12.1 | 1.8 A | 16.3 | 2.9 A | 16.7 | 2.8 A | 18.1 | 3.6 A | <0.001 | 0.146 |
| *Lespedeza bicolor* | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 1.3 | 1.7 | 1.7 | 0.0 | 0.0 | 0.492 | 0.378 |
| *Lespedeza capitata* | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.627 | 0.066 |
| *Lespedeza hirta* | 0.0 | 0.0 | 0.4 | 0.4 | 2.1 | 1.1 | 0.0 | 0.0 | 0.5 | 0.5 | 0.221 | 0.678 |
| *Lespedeza intermedia* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 1.3 | 1.0 | 0.6 | 0.330 | 0.212 |
| *Lespedeza procumbens* | 4.2 | 1.6 C | 6.7 | 2.2 BC | 13.3 | 3.3 AB | 23.3 | 6.2 A | 25.2 | 5.0 A | 0.002 | 0.002 |
| *Lespedeza repens* | 17.5 | 4.4 B | 16.7 | 2.8 B | 27.5 | 2.9 AB | 35.4 | 6.0 A | 41.4 | 7.4 A | 0.028 | 0.002 |
| *Lespedeza* spp. | 0.4 | 0.4 | 0.8 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 1.4 | 1.4 | 0.856 | 0.139 |
| *Lespedeza striata* | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 0.9 | 1.7 | 0.9 | 0.0 | 0.0 | 0.222 | 0.118 |
| *Lespedeza violacea* | 0.0 | 0.0 B | 0.0 | 0.0 B | 5.8 | 2.5 A | 2.1 | 1.3 AB | 1.9 | 1.0 AB | 0.033 | 0.007 |
| *Lespedeza virginica* | 4.2 | 1.8 | 2.1 | 0.9 | 7.1 | 3.0 | 6.7 | 2.7 | 5.7 | 1.6 | 0.694 | 0.082 |
| *Rhynchosia latifolia* | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.627 | 0.531 |
| *Strophostyles umbellata* | 2.9 | 1.9 | 2.1 | 0.9 | 12.1 | 1.8 | 8.8 | 3.1 | 4.3 | 1.7 | 0.152 | 0.104 |
| *Stylosanthes biflora* | 7.5 | 1.5 | 8.8 | 1.7 | 24.2 | 6.6 | 22.5 | 5.7 | 16.2 | 6.5 | 0.087 | 0.078 |
| *Tephrosia virginiana* | 2.9 | 1.7 | 0.0 | 0.0 | 1.3 | 0.9 | 1.7 | 0.6 | 1.4 | 0.7 | 0.437 | 0.059 |

Table 6. Continued.

| Category Species | Treatment[b] | | | | | | | | | | $P > F$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | WSI-NB | | WSI-B1 | | WSI-B2 | | WSI-B3 | | Contrasts[c] | |
| | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | C vs. W | NB vs. B |
| Forbs | | | | | | | | | | | | |
| *Acalypha gracilens* | 0.8 | 0.6 C | 1.7 | 0.6 C | 22.5 | 10.8 A | 6.3 | 1.8 AB | 2.4 | 1.0 BC | 0.004 | 0.012 |
| *Acalypha virginica* | 0.4 | 0.4 D | 9.2 | 4.3 BC | 22.9 | 4.3 A | 10.4 | 2.3 AB | 2.9 | 1.8 CD | <0.001 | 0.299 |
| *Ambrosia artemisiifolia* | 0.0 | 0.0 | 0.8 | 0.6 | 1.2 | 2.2 | 0.8 | 0.6 | 0.0 | 0.0 | 0.108 | 0.914 |
| *Cocculus carolinus* | 0.4 | 0.4 | 1.7 | 0.9 | 0.4 | 0.4 | 1.7 | 1.3 | 0.5 | 0.5 | 0.529 | 0.243 |
| *Coreopsis tinctoria* | 0.4 | 0.4 B | 2.1 | 1.1 B | 11.7 | 3.9 A | 10.8 | 3.5 A | 10.0 | 2.7 A | <0.001 | <0.001 |
| *Diodia teres* | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.5 | 0.5 | 0.460 | 0.342 |
| *Elephantopus carolinianus* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 0.9 | 0.0 | 0.0 | 0.459 | 0.341 |
| *Euphorbia commutata* | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.627 | 0.531 |
| *Euphorbia corollata* | 1.3 | 1.3 | 1.7 | 1.3 | 1.3 | 0.6 | 0.0 | 0.0 | 2.4 | 1.6 | 0.616 | 0.823 |
| *Euphorbia cyathophora* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.627 | 0.531 |
| *Helianthus hirsutus* | 12.1 | 4.0 D | 19.2 | 4.5 CD | 33.8 | 10.2 BC | 49.2 | 7.9 AB | 57.6 | 6.4 A | <0.001 | 0.002 |
| *Oxalis violacea* | 0.0 | 0.0 B | 0.0 | 0.0 B | 2.5 | 1.1 A | 0.4 | 0.4 B | 0.0 | 0.0 B | 0.183 | 0.089 |
| *Physalis virginiana* | 0.4 | 0.4 | 2.5 | 1.4 | 7.5 | 3.7 | 2.1 | 1.7 | 2.9 | 1.5 | 0.133 | 0.781 |
| *Phytolacca americana* | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.459 | 0.341 |
| *Polygonum* spp. | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.627 | 0.531 |
| *Rudbeckia hirta* | 1.3 | 0.6 | 1.3 | 1.3 | 3.8 | 1.6 | 9.6 | 3.7 | 8.1 | 3.1 | 0.336 | 0.038 |
| Woody | | | | | | | | | | | | |
| *Callicarpa americana* | 6.3 | 4.5 B | 7.8 | 1.4 A | 0.8 | 0.8 B | 0.9 | 0.6 B | 10.0 | 7.9 B | 0.818 | <0.001 |
| *Parthenocissus quinquefolia* | 39.6 | 8.6 | 47.6 | 6.0 | 47.7 | 11.0 | 33.4 | 6.9 | 53.8 | 7.5 | 0.506 | 0.854 |
| *Rhus aromatica* | 1.3 | 0.9 | 2.1 | 0.9 | 3.0 | 1.7 | 1.3 | 0.9 | 1.0 | 0.6 | 0.629 | 0.444 |
| *Rhus copallina* | 5.4 | 1.7 C | 19.2 | 6.4 C | 59.0 | 5.2 A | 42.1 | 6.1 B | 58.1 | 6.3 AB | <0.001 | <0.001 |
| *Rhus glabra* | 0.0 | 0.0 C | 1.7 | 0.9 BC | 15.2 | 6.2 A | 4.8 | 1.6 B | 14.8 | 4.8 A | <0.001 | 0.001 |
| *Rubus* spp. | 20.0 | 2.3 C | 49.6 | 7.0 B | 54.0 | 7.5 AB | 46.2 | 9.7 B | 69.1 | 7.8 A | <0.001 | 0.445 |

Table 6. Continued.

| Category<br>Species | Treatment[b] | | | | | | | | | | *P* > F | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | WSI-NB | | WSI-B1 | | WSI-B2 | | WSI-B3 | | Contrasts[c] | |
| | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | C vs. W | NB vs. B |
| Woody (continued) | | | | | | | | | | | | |
| *Smilax bona-nox* | 60.8 | 3.1 | 54.1 | 2.8 | 65.5 | 8.7 | 45.8 | 6.7 | 59.1 | 8.0 | 0.466 | 0.282 |
| *Smilax glauca* | 19.2 | 6.8 | 9.2 | 3.1 | 16.4 | 3.0 | 7.0 | 2.6 | 18.1 | 3.6 | 0.682 | 0.290 |
| *Smilax rotundifolia* | 15.8 | 5.1 | 18.0 | 3.6 | 10.1 | 3.7 | 6.0 | 1.6 | 10.0 | 3.0 | 0.587 | 0.025 |
| *Toxicodendron radicans* | 84.2 | 7.7 | 78.8 | 4.8 | 62.5 | 11.3 | 61.9 | 9.2 | 70.5 | 7.7 | 0.072 | 0.233 |
| *Vaccinium arboreum* | 23.3 | 3.5 | 25.3 | 5.1 | 31.3 | 8.8 | 34.0 | 2.6 | 36.7 | 6.9 | 0.165 | 0.225 |
| *Vitis aestivalis* | 7.1 | 2.1 | 8.2 | 2.8 | 15.6 | 3.1 | 13.0 | 5.5 | 16.7 | 5.4 | 0.249 | 0.211 |
| *Vitis palmate* | 2.1 | 1.3 | 8.1 | 4.1 | 6.3 | 1.8 | 6.5 | 2.8 | 8.6 | 4.8 | 0.122 | 0.859 |
| *Vitis rotundifolia* | 0.8 | 11.9 | 66.2 | 8.3 | 38.2 | 8.9 | 29.5 | 6.3 | 43.3 | 9.4 | 0.568 | 0.026 |

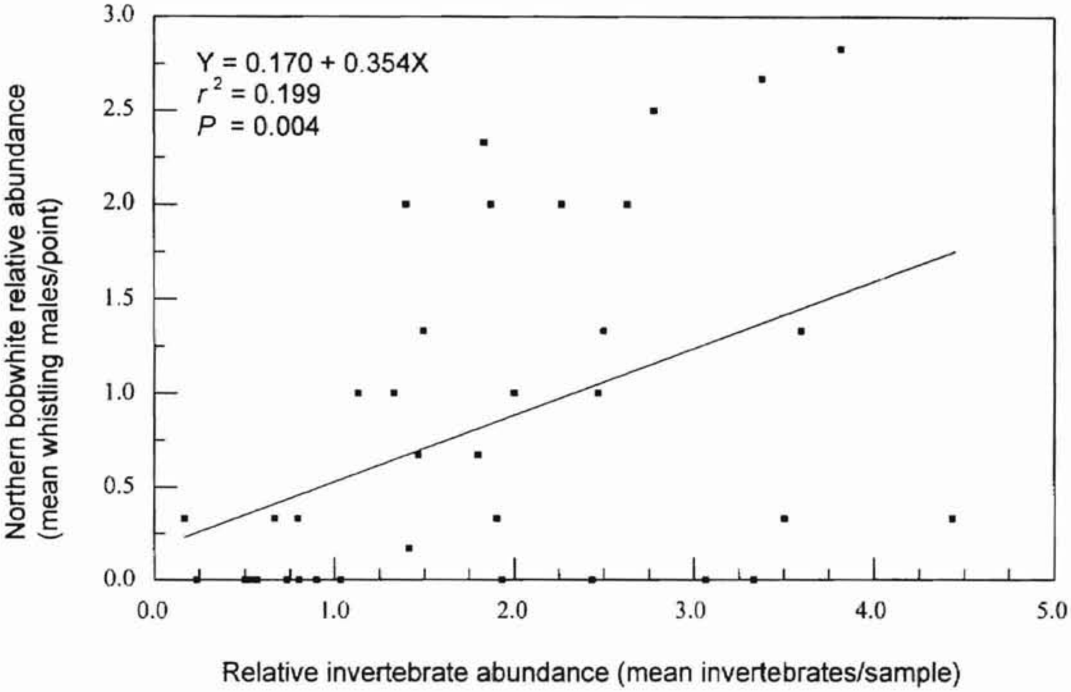
[a] Column means within rows followed by the same letter or without letters were not significantly different at the 0.05 level (LSD); differences are based on treatment effect rather than specific contrasts.

[b] Treatments are: Control = unthinned, unburned; WSI-NB = wildlife stand improvement, no burning; WSI-B1 = wildlife stand improvement, first growing season following burn; WSI-B2 = wildlife stand improvement, second growing season following burn; WSI-B3 = wildlife stand improvement, third growing season following burn; $n$ = 8 for each treatment.

[c] Specific orthogonal contrasts; C = control: W = wildlife stand improvement: NB = wildlife stand improvement, no burn; B = wildlife stand improvement and burned.

Figure 1. Response of northern bobwhite whistling males (mean whistling males/point) to increasing relative invertebrate abundance (mean invertebrates/sample) ($n$ = 40) of Coleoptera, Hemiptera, Homoptera, Lepidoptera larvae, and Orthoptera (A), and to increasing relative invertebrate mass (mean mg/sample) ($n$ = 40) of Coleoptera, Hemiptera, Homoptera, Lepidoptera larvae, and Orthoptera (B) on the Ouachita National Forest, Arkansas, July 1999 and 2000.

A


Y = 0.170 + 0.354X
$r^2$ = 0.199
P = 0.004
Northern bobwhite relative abundance (mean whistling males/point)
Relative invertebrate abundance (mean invertebrates/sample)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
1.0
2.0
3.0
4.0
5.0

B

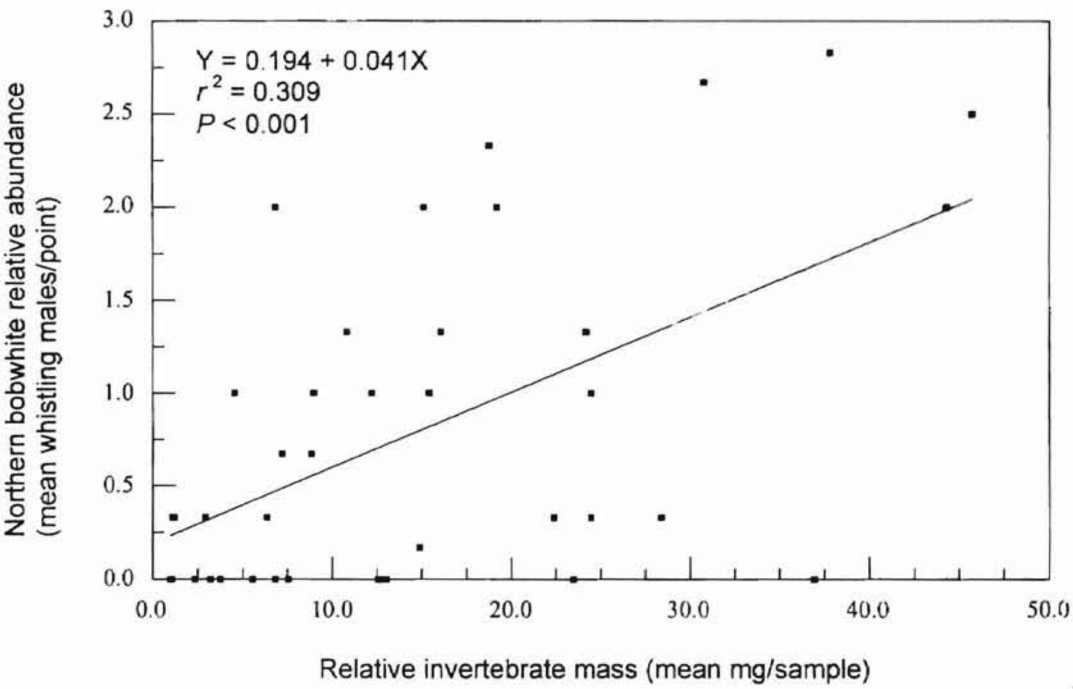
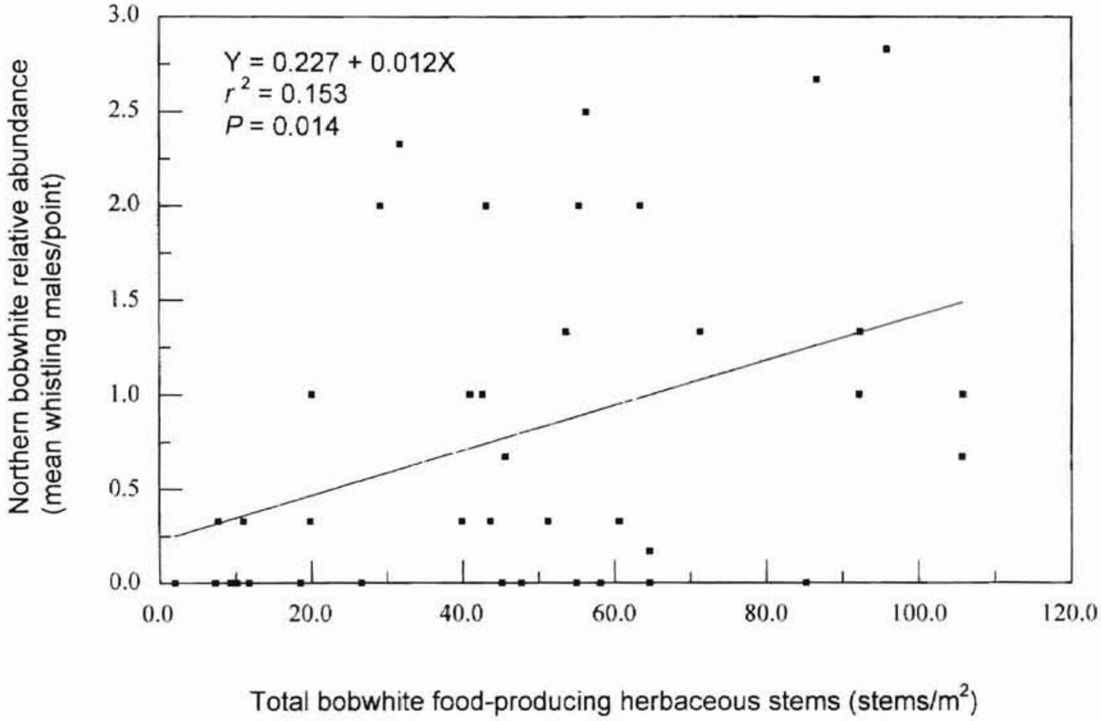
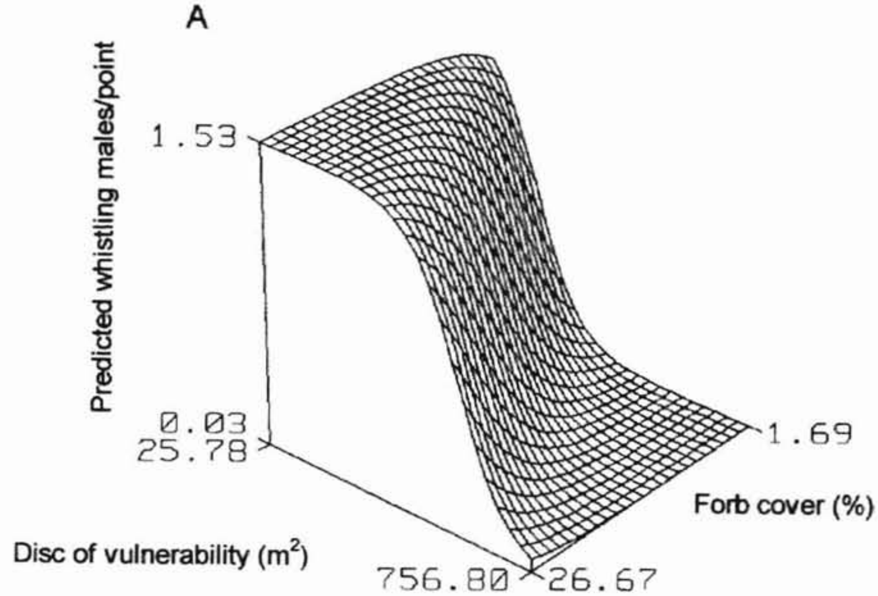

Y = 0.194 + 0.041X
$r^2$ = 0.309
P < 0.001
Northern bobwhite relative abundance (mean whistling males/point)
Relative invertebrate mass (mean mg/sample)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
10.0
20.0
30.0
40.0
50.0

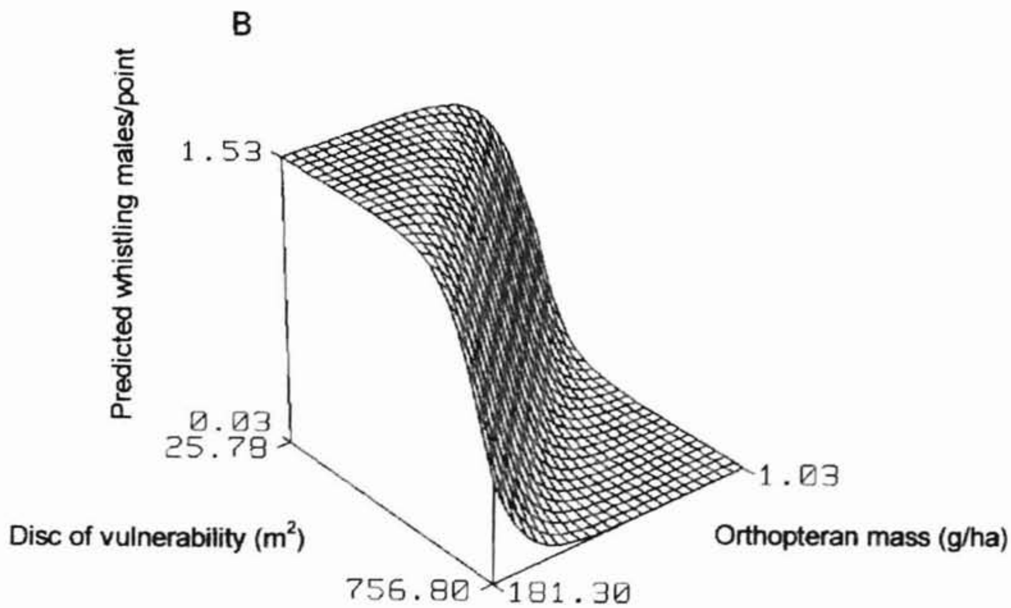
Figure 2. Response of northern bobwhite whistling males (mean whistling males/point) to increasing total bobwhite food-producing herbaceous stems (stems/$m^2$) ($n = 40$) on the Ouachita National Forest, Arkansas, July 1999 and 2000.



Y = 0.227 + 0.012X
r² = 0.153
P = 0.014
Northern bobwhite relative abundance (mean whistling males/point)
Total bobwhite food-producing herbaceous stems (stems/m²)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
20.0
40.0
60.0
80.0
100.0
120.0

Figure 3. Artificial neural network predictions on the response of northern bobwhite whistling males to percent forb cover (%) and disc of vulnerability ($m^2$) (A), and to Orthopteran mass (g/ha) and disc of vulnerability ($m^2$) (B) on the Ouachita National Forest, Arkansas, 1999–2000.


A
Predicted whistling males/point
1.53
0.03
25.78
Disc of vulnerability (m²)
756.80
26.67
Forb cover (%)
1.69


B
Predicted whistling males/point
1.53
0.03
25.78
Disc of vulnerability (m²)
756.80
181.30
Orthopteran mass (g/ha)
1.03

APPENDIX

Appendix A. Stand locations and management history on Ouachita National Forest, Arkansas, 1999–2000.

| Year | Compartment | Stand(s) | Treatment[a] | Size (ha) | WSI | Times burned |
|---|---|---|---|---|---|---|
| 1999 | 1215 | 8 | Control | 24.7 | NA | 0 |
| 1999 | 1276 | 1 | Control | 16.1 | NA | 0 |
| 1999 | 1277 | 13 | Control | 20.2 | NA | 0 |
| 1999 | 1294 | 2 | Control | 18.2 | NA | 0 |
| 1999 | 1235 | 33, 34 | WSI-NB | 20.6 | 1997 | 0 |
| 1999 | 1243 | 18 | WSI-NB | 28.3 | 1997 | 0 |
| 1999 | 1256 N | 2 | WSI-NB | 56.7 | 1997 | 0 |
| 1999 | 1256 S | 8 | WSI-NB | 42.9 | 1997 | 0 |
| 1999 | 1272 | 7 | WSI-B1 | 64.8 | 1986 | 5 |
| 1999 | 1282 | 22, 38 | WSI-B1 | 21.9 | 1989 | 3 |
| 1999 | 1253 E | 5, 8 | WSI-B1 | 41.2 | 1980 | 6 |
| 1999 | 1253 W | 16 | WSI-B1 | 34.0 | 1994 | 2 |
| 1999 | 1251 | 6, 38, 39 | WSI-B2 | 48.6 | 1995 | 1 |
| 1999 | 1274 N | 12, 19 | WSI-B2 | 24.3 | 1989 | 3 |
| 1999 | 1274 E | 20 | WSI-B2 | 17.8 | 1989 | 7 |
| 1999 | 1274 S | 14, 21 | WSI-B2 | 17.4 | 1980 | 6 |
| 1999 | 1215 S | 8 | WSI-B3 | 29.6 | 1991 | 2 |
| 1999 | 1259 N | 7, 11, 14 | WSI-B3 | 61.1 | 1990 | 5 |
| 1999 | 1259 S | 8, 22, 28 | WSI-B3 | 42.5 | 1995 | 1 |
| 1999 | 1281 | 18 | WSI-B3 | 19.4 | 1984 | 4 |

Appendix A. (continued)

| Year | Compartment | Stand(s) | Treatment[a] | Size (ha) | WSI | Times burned |
|---|---|---|---|---|---|---|
| 2000 | 1276 | 1 | Control | 16.1 | NA | 0 |
| 2000 | 1277 N | 2 | Control | 39.3 | NA | 0 |
| 2000 | 1277 S | 13 | Control | 20.2 | NA | 0 |
| 2000 | 1294 | 2 | Control | 18.2 | NA | 0 |
| 2000 | 1242 | 7, 8, 9 | WSI-NB | 100.4 | 1997 | 0 |
| 2000 | 1271 E | 7 | WSI-NB | 48.6 | 1999 | 0 |
| 2000 | 1271 W | 1, 13 | WSI-NB | 64.8 | 1999 | 0 |
| 2000 | 1275 | 7, 18, 20 | WSI-NB | 30.4 | 1997 | 0 |
| 2000 | 1235 | 33, 34 | WSI-B1 | 20.6 | 1997 | 1 |
| 2000 | 1244 | 20, 32 | WSI-B1 | 32.4 | 1995 | 1 |
| 2000 | 1256 | 8 | WSI-B1 | 42.9 | 1997 | 1 |
| 2000 | 1259 | 7, 11, 14 | WSI-B1 | 61.1 | 1990 | 6 |
| 2000 | 1243 | 10, 15 | WSI-B2 | 23.5 | 1997 | 1 |
| 2000 | 1253 N | 5, 8 | WSI-B2 | 41.2 | 1980 | 6 |
| 2000 | 1253 S | 4, 24 | WSI-B2 | 36.8 | 1995 | 2 |
| 2000 | 1282 | 22, 38 | WSI-B2 | 21.9 | 1989 | 3 |
| 2000 | 1251 | 6, 38, 39 | WSI-B3 | 48.6 | 1995 | 1 |
| 2000 | 1274 E | 14, 21 | WSI-B3 | 17.4 | 1980 | 6 |
| 2000 | 1274 W | 2 | WSI-B3 | 46.1 | 1989 | 4 |
| 2000 | 1305 | 13 | WSI-B3 | 36.4 | 1995 | 1 |

Appendix A. (continued)

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[a] Control = unthinned, unburned; WSI-NB = wildlife stand improvement, no burn; WSI-B1 = wildlife stand improvement, first growing season following burn; WSI-B2 = wildlife stand improvement, second growing season following burn; WSI-B3 = wildlife stand improvement, third growing season following burn.

# VITA

Douglas Scott Cram

Candidate for Degree of

Master of Science

Thesis: NORTHERN BOBWHITE POPULATION AND HABITAT RESPONSE TO PINE-GRASSLAND RESTORATION

Major Field: Forest Resources

Biographical:

Personal Data: Born in Los Alamos, New Mexico, May 24, 1973, the son of Scott and Betty Cram. Enjoy outdoor activities especially backpacking, hiking, and skiing.

Education: Graduated from Los Alamos High School, Los Alamos, New Mexico in May 1992; received a Bachelor of Science degree in Wildlife Science from New Mexico State University, Las Cruces, New Mexico in May 1996; completed requirements for Master of Science degree in Forest Resources at Oklahoma State University, Stillwater, Oklahoma in August 2001.

Experience: Seasonal Backcountry Staff, Philmont Scout Ranch, Cimarron, New Mexico, 1992-1998. Graduate Research Assistant, Ecology Group, Los Alamos National Laboratory, Los Alamos, New Mexico, Fall 1996 to Spring 1997. Graduate Research Assistant, Department of Forestry, Oklahoma State University, Stillwater, Oklahoma, Spring 1998 to Spring 2001.

Professional Organizations: The Wildlife Society, Honor Society of Xi Sigma Pi.