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The effects of season of fire on macroinvertebrates in a longleaf pine-wiregrass community

James E. Watkins

To the Graduate Council:

I am submitting herewith a thesis written by James E. Watkins entitled "The effects of season of fire on macroinvertebrates in a longleaf pine-wiregrass community." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

Ralph W. Dimmick, Major Professor

We have read this thesis and recommend its acceptance:

David Buehler, Craig Harper, Charles Pless

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

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Acceptance for the Council:

Vice Provost and Dean of Graduate Studies

THE EFFECTS OF SEASON OF FIRE ON MACROINVERTEBRATES IN A LONGLEAF PINE-WIREGRASS COMMUNITY

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

James E. Watkins
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ABSTRACT

The effects of season of fire on macroinvertebrate abundance and biomass were studied in a relatively undisturbed longleaf pine-wiregrass (*Pinus palustris-Aristida beyrichiana*) community at Fort Stewart, Georgia. The objective was to determine how season of fire affected invertebrate abundance and biomass and to relate these effects to wild turkey (*Meleagris gallopavo*) and northern bobwhite (*Colinus virginianus*) brood habitat management. Invertebrates were collected using a terrestrial vacuum sampler (D-Vac®) during the wild turkey and northern bobwhite brood season (April-September) during 1996-97. Treatment plots were burned in May, July, and December of 1996. Total invertebrate abundance (no. invertebrates/transect) and biomass (g invertebrates/transect) were greater in July and unburned plots during the first year. Abundance in May-burned plots attained or surpassed abundance in unburned plots within 2 months after burning. Invertebrate abundance in July-burned plots recovered to that of unburned plots 1 month after burning, while biomass required 2 months to reach levels of unburned plots. May-burned plots had greater overall abundance and biomass than all other treatments 1 year after burning. Plots burned in December of the previous year had the lowest overall abundance and biomass of all treatments 1 year after burning. Overall abundance and biomass of Orthopterans were greater in May-burned plots than all other treatments 1 year after burning. Overall abundance and biomass of Homopterans were greater in plots burned in May and July and unburned plots 1 year after burning. Overall abundance of Coleopterans was greater in July-burned plots and

unburned plots 1 year after burning. However, no differences were detected for biomass among treatments. Overall Hymenopteran abundance was greater in May-burned plots than in all other treatments in the year burned and also 1 year after burning. Few relationships were detected between invertebrate abundance and biomass and vegetation composition. Treatment had the greatest impact on invertebrate abundance and biomass. Results indicated that growing-season fire had a short-term negative effect on invertebrate abundance and biomass, but recovered to levels of unburned plots within 2 months after burning. In terms of invertebrates, growing-season fire in longleaf pine-wiregrass stands appears to be compatible with wild turkey and northern bobwhite brood habitat when compared to dormant-season burns or no-burn treatments. The potential negative effects of growing-season fire on nesting and poult and chick production, however, must be considered when applying growing-season fire in wild turkey and northern bobwhite brood habitat.

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CHAPTER 1

INTRODUCTION

Prescribed burning is a cost-effective and efficient land management technique used by natural resource managers in southern pine forests. The regular use of prescribed fire maintains the open park-like nature of these forests, especially longleaf pine forests located in the southern Coastal Plain (Stoddard 1963). Longleaf pine forests evolved under a natural fire regime. Wiregrass, the predominant groundcover species in these forests, possesses traits that facilitate the ignition and spread of fire during humid growing seasons (Landers et al. 1995). Historically, most natural fires occurred during the growing season as a result of frequent lightning strikes and are thought to have occurred every 2-8 years (Komarek 1964, Christensen 1981, Frost 1993). Frequent fire results in a 2-layered forest consisting of the grass/herb layer, the tree canopy, and no well-developed midstory (Frost 1993).

Native Americans and European settlers also burned the forests to clear land for crops, to stimulate growth of grasses for cattle forage, and to drive game animals for harvesting. Most of this "prescribed burning" occurred in the fall and winter (Frost 1993). Over the past 70 years, most of the prescribed burning in southern pine forests has occurred during February and March. Much of this burning has been associated with wildlife management (Brennan et al. 1998). The regular use of prescribed fire prevents the establishment of broad-leaved species and hardwoods in the understory and midstory, prepares seedbeds, reduces the risk of catastrophic wildfires by reducing accumulated fuel loads, and maintains the rich floral diversity associated with this community type (Platt et al. 1991, Boyer 1993, Peet and Allard 1993).

Prescribed burning is used to manage habitat for wild turkey and northern bobwhite in the southeastern U.S. (Hurst 1972 and 1981). "Insect catching grounds" (brood habitat) are an important aspect of wild turkey and northern bobwhite management (Stoddard 1963). Burning creates quality brood habitat by reducing accumulated litter, thus allowing poults and chicks to move more freely in search of macroinvertebrates, primarily insects (Hurst 1972). Macroinvertebrates (hereafter invertebrates) are important sources of protein, calcium, and phosphorous for turkey poults and bobwhite chicks during the first few weeks of life (Stoddard 1931, Nestler et al. 1942, Hurst and Stringer 1975). During the first 2 weeks of life, invertebrates can constitute as much as 94% of the diet of bobwhites (Eubanks and Dimmick 1974). The diet of wild turkey poults 1-4 weeks old in West Virginia was 77% invertebrates and 65-95% of pecks taken was to obtain animal matter, primarily insects (Healy 1985). Invertebrates also are important sources of protein, calcium, and phosphorous for female wild turkeys and bobwhites prior to and during the breeding season. Invertebrates supply these much-needed nutrients for egg production (Rosene 1969, Pattee and Beasom 1981). Female wild turkeys and northern bobwhites increase their intake of invertebrates in late winter and early spring (Rosene 1969, Brennan and Hurst 1995). Invertebrates comprise approximately 52% of the total biomass of the diet of turkey hens during mid-spring. This amount, however, contributes approximately 85%

of the respective crude protein, calcium, and phosphorous intake (Pattee and Beasom 1981).

Insect abundance may be closely related to vegetation composition and legumes may attract more insects than non-legumes (Stoddard 1931, Hollifield and Dimmick 1995). "Weedy" fields were found to contain greater invertebrate populations than cultivated patches and burned pine forests in southwestern Georgia (Yates et al. 1995). These "weedy" fields consisted primarily of ragweed (*Ambrosia artemisiifolia*) and partridge pea (*Cassia fasciculata*), plants whose seeds are often consumed by bobwhites. The fields were a result of rotational corn planting and October disking. Seed production in legumes increased on summer-burned plots in the Piedmont of South Carolina (Cushwa 1970). However, Streng et al. (1993) reported season of fire had no effect on groundcover species in a longleaf-wiregrass savanna in northern Florida.

The objective of this study was to determine how season of fire affected invertebrate abundance and biomass in a longleaf pine-wiregrass community and to relate these effects to wild turkey and northern bobwhite brood habitat management.

CHAPTER 2

DESCRIPTION OF STUDY AREA

The study was conducted at Fort Stewart, Georgia (32° 02' 08" N, 81° 41' 00" W), an 111,600-ha (280,000 ac) military reservation located in the Lower Coastal Plain Physiographic Province of Georgia. Fort Stewart is located approximately 360 km (225 miles) southeast of Atlanta, Georgia and 65 km (40 miles) west of Savannah, Georgia (Figure 1). It encompasses areas of Tattnall, Long, Liberty, Evans, and Bryan counties. The topography is relatively flat and ranges in elevation from approximately 58 m (190 feet) on the western property boundary to nearly sea level on the eastern boundary.

Soils on study sites consist of Pelham, Leefield, Stilson, and Mascotte series. Pelham, Leefield, and Stilson are loamy sand, while Mascotte is fine sand. All occur on 0-2% slopes and are poorly to moderately well-drained. Soils are low in natural fertility and organic matter and are very strongly acidic throughout (Looper 1982). The climate consists of hot, humid summers and cool winters, with occasional brief cold spells. The average daily high temperature is 33°C (91°F) in summer and 19°C (66°F) in winter. The average daily low temperature is 21°C (70°F) in summer and 5°C (41°F) in winter. Average annual rainfall is 122 cm (48 inches), with approximately 60% of this occurring April-September. Thunderstorms are common during this period and occur 70 days of

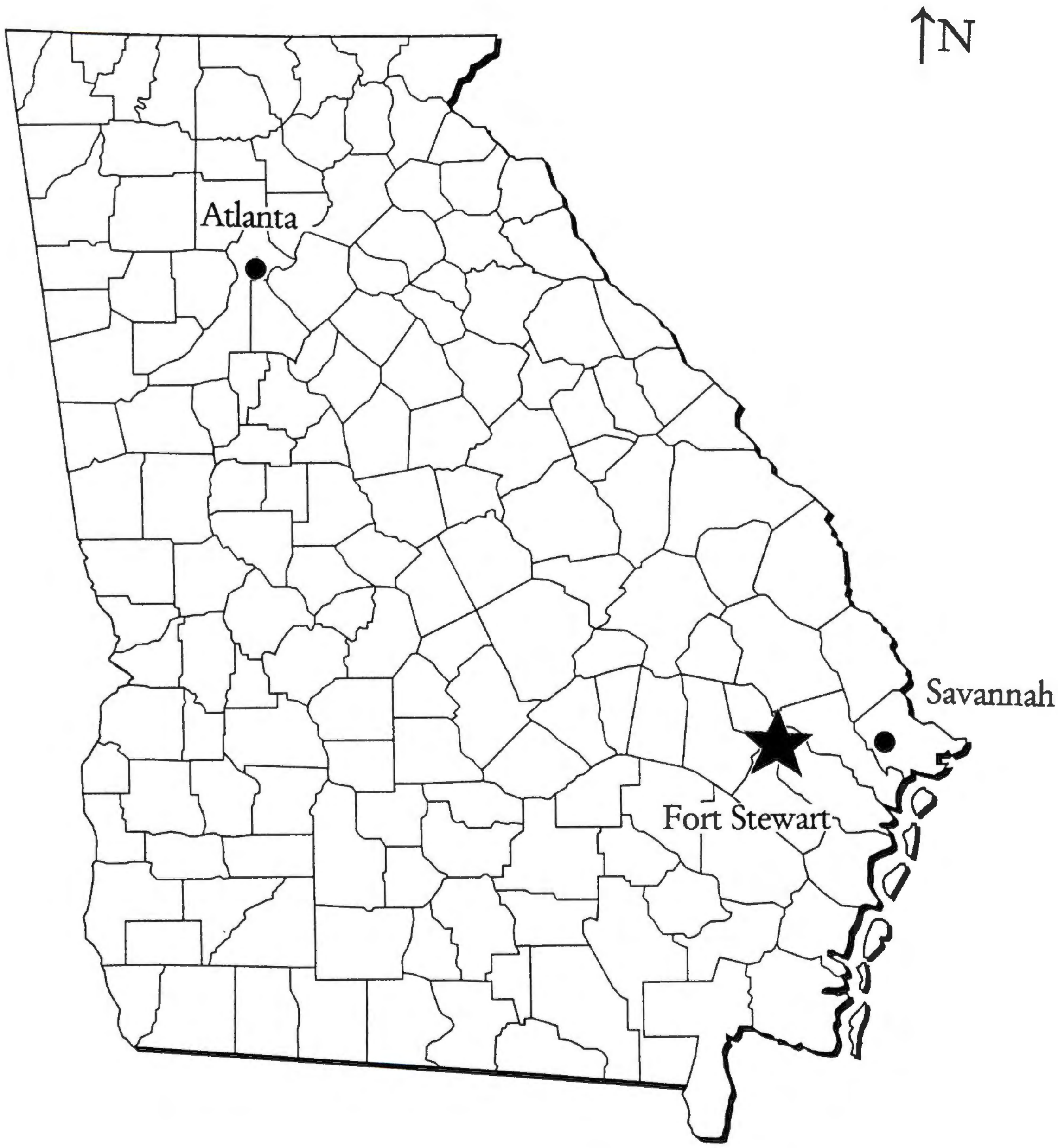

Figure 1. Location of Fort Stewart in Tattnall, Long, Liberty, Evans, and Bryan counties, Georgia.

each year (Looper 1982). Annual rainfall for 1996-97 measured 99 cm (39 inches) and 137 cm (54 inches), respectively.

Fort Stewart is the home of the U.S. Army's Third Infantry Division (Mechanized). Its mission is to provide the support necessary to train, mobilize, and deploy a mechanized infantry division (U.S. Army 1999). In addition to this mission, Fort Stewart's Environmental and Natural Resource Division has the responsibility of managing the Fort's natural and cultural resources. Many threatened and endangered species occur at Fort Stewart, including the eastern indigo snake (*Drymarchon corais*), shortnose sturgeon (*Acipenser brevirostrum*), flatwoods salamander (*Ambystoma cingulatum*), gopher tortoise (*Gopherus polyphemus*), wood stork (*Mycteria americana*), and 1 of the 10 largest known populations of red-cockaded woodpeckers (*Picoides borealis*) in the world (Mitchell et al. 1999). Game species include white-tailed deer (*Odocoileus virginianus*), wild boar (*Sus scrofa*), raccoon (*Procyon lotor*), gray squirrel (*Sciurus carolinensis*), wild turkey, and northern bobwhite. Forest types located at Fort Stewart include upland longleaf pine forests, longleaf-slash-loblolly pine (*P. elliottii*, *P. taeda*) flatwoods, bay swamp-pocosins, and oak-gum-cypress (*Quercus* spp., *Nyssa* spp., *Taxodium* spp.) forests. Approximately 33% of Fort Stewart is classified as wetlands/bottomland hardwoods, 54% upland forest, and 13% permanent openings (i.e., military training/firing ranges, drop zones, landing strips, and housing areas).

On average, Fort Stewart Fish and Wildlife Branch and Forestry Branch personnel prescribe burn 44,000 ha annually. Historically, 40,000 ha were burned during the dormant season (November-March) and 4,000 during the growing season

(April-October) (Fort Stewart Forestry Branch, unpublished data). The majority of prescribed burning in southern pine forests occurred during the dormant season because growing season fire was thought to be detrimental to pine stands (Streng et al. 1993). Currently, management practices in longleaf pine-wiregrass communities have shifted toward growing-season fire. Natural resource managers at Fort Stewart have implemented a growing-season fire regime in existing and potential red-cockaded woodpecker habitat to emulate natural burning (U.S. Fish and Wildlife Service 2000). Growing-season burns at Fort Stewart are conducted on 2-4 year cycles (U.S. Army 2001).

CHAPTER 3

METHODS AND MATERIALS

I. Study Site Selection and Plot Layout

Study sites were selected during March 1996 in relatively undisturbed, mature upland longleaf pine-wiregrass stands using infrared aerial photographs and ground reconnaissance. Sites selected were of similar vegetation composition with natural vegetation intact (Peet and Allard 1993) and had similar burn histories (i.e., not burned 1 or 2 years prior to the study). Within these study sites, 12 0.13-ha (25m x 50m) study plots were established at random. An origin was established in a corner of each site and a random number table was used to select x- and y-coordinates for the starting point of a 50-m base line (Hollifield and Dimmick 1995). The orientation of the base line and the placement of 4 25-m transects along and perpendicular to the base line also were established at random using a random number table. Transects were spaced a minimum of 2 m apart to reduce interference with sampling adjacent transects.

II. Treatments

The 12 study plots involved 4 treatments: May, July, and December burns and unburned plots (Table 1). Individual study plots were in different locations and were

Table 1. Treatment (burn) dates for study plots at Fort Stewart, Georgia, 1996.

Plot #	Date of burn
1	2 May
2	3 May
3	24 May
4	18 July
5	18 July
6	19 July
7	12 December
8	13 December
9	16 December
10	unburned
11	unburned
12	unburned

situated within larger burn units averaging 20 ha (50 ac) in size. Plots were burned to prescription in 1996 using hand-held drip torches and point-source fires. Average flame heights on all plots were approximately 0.6-1.8 m (2-6 ft).

III. Invertebrate Sampling

Invertebrates were collected using a Model 122 D-Vac® insect sampler (D-Vac® Co., Ventura, CA 93002). This sampling method produces results comparable to other sampling methods when collecting relative, rather than absolute, invertebrate abundance and biomass data (Marston et al. 1976, Smith et al. 1976). Each transect was sampled on a time constrained basis by walking at a slow rate (50 m/min), holding the nozzle of the D-Vac® at a 45° angle and approximately 15 cm above the ground (Fuller 1994). This sampling method is deemed to be effective for collecting those invertebrates available to turkey poults and bobwhite chicks (Hurst 1972, Martin and McGinnes 1975). Invertebrates were collected between 0900 and 1700 hours on days with no precipitation and after vegetation had dried to reduce variability. Because of the distance between plots, 2 days were required to sample all plots. Plots were placed into 2 groups based on their proximity to each other and were randomly selected each day for sampling order. Invertebrates were collected 8 times from all plots in 1996 and 6 times in 1997 during the brood rearing season (April-September) (Rosene 1969, Hurst 1972). Sampling was conducted prior to burning, 14 days after burning, 30 days after burning, and subsequently every 30 days until the end of the brood rearing season in September.

Invertebrates were killed in the field with ethyl acetate (Healy 1985), stored in plastic bags (individual transects separately), and frozen until laboratory analysis was performed.

IV. Laboratory Methods

In the lab, invertebrates were separated from debris by hand with the aid of a lighted magnifying glass and forceps and each specimen was sorted into small (<0.5 cm), medium (0.5-1.0 cm), or large (>1.0 cm) size categories (Hollifield 1992). Samples were then oven-dried for 48 hours at 60°C (Murkin et al. 1994), identified to order according to Borror et al. (1970 and 1989), weighed to the nearest 0.001 g using a digital balance, and recorded.

V. Vegetation Sampling

Vegetation was sampled using a 5-pin frame (20 cm spacing) and the point-intercept method (Higgins et al. 1994, Mitchell and Hughes 1995) along the 25-m transects at 3 equidistant intervals. Pins were lowered to the ground and any vegetation or bare ground struck was considered a hit and recorded. Percent cover by growth form was determined for each plot. Growth forms were classified as graminoid (grasses, rushes, and sedges), forb, fern, or woody plant. Vegetation was sampled 5 times in 1996 as near to the burn date as possible and 3 times in 1997. More sampling was conducted in 1996 than 1997 to assess the rate of re-growth of recently-burned vegetation.

VI. Data Analysis

A completely randomized design with split-plot treatment arrangement was used to study invertebrate abundance and biomass. Invertebrate abundance was defined as the number of invertebrates collected per transect, and biomass was grams of invertebrates collected per transect. Seasons of burn were in the whole-plot and sampling times were in the sub-plot. Analysis of variance (ANOVA) with a significance level of 0.05 was used to determine differences in total invertebrate relative abundance and biomass among treatments and sampling times for small, medium, and large categories using the MIXED procedure (SAS Institute, Inc. 1999). In addition to total abundance and biomass, abundance and biomass for the most commonly consumed taxa of invertebrates by turkey poults and bobwhite chicks were analyzed (Hurst 1972, Eubanks and Dimmick 1974, Healy 1985, Jackson et al. 1987). Interaction among treatments and sampling times also was tested using ANOVA. Invertebrate data were evaluated for normality using the univariate procedure within SAS. Levene's test for homogeneity of variances was used to determine if transformations were needed. In cases where invertebrate abundance and biomass data did not meet the ANOVA requirements of normality and homogeneity of variances, data were natural logarithm transformed. Fisher's Least Significant Difference (LSD) was used to separate means on all significant ANOVA tests (SAS Institute, Inc. 1999).

Relationships between invertebrate abundance and biomass and vegetation composition among treatments and samples for 1997 data were tested using multiple regression and the GLM procedure of SAS (SAS Institute, Inc. 1999). 1997 data were analyzed because plots had recovered from the previous years burn and differences could be attributed to changes in vegetation composition rather than time after burning. Vegetation growth form (i.e., % cover composition in graminoid, forb, fern, and woody plant) was used as the independent variable. Regression models were simplified by eliminating non-significant variables.

CHAPTER 4

RESULTS

I. Total Invertebrate Abundance and Biomass by Year and Season of Burn

Invertebrates from 18 taxa were identified from 668 invertebrate samples collected in longleaf pine-wiregrass stands (Table 2). Common names of invertebrates in each taxa are given in Table 21, Appendix A. A total of 40,114 invertebrates, weighing 22.830 g was collected (Table 3). Insects comprised 82% of the total abundance and 76% of the total biomass. Hymenopterans were most abundant, with 9,058 individuals comprising 23% of the total, while Orthopterans had the greatest biomass, 6.585 g, or 29% of the total collected (Table 2). Medium and large invertebrates were not collected in sufficient numbers to allow meaningful statistical analysis, therefore total abundance and biomass were used for making all comparisons (Table 3).

In 1996, plots burned in July, pre-burn December plots, and unburned plots had greater overall invertebrate abundance ($P<0.001$) and biomass ($P < 0.03$) than May-burned plots, while in 1997, plots burned in May 1996 had greater abundance ($P<0.0001$) and biomass ($P<0.0001$) than any other treatment (Table 4).

Table 2. Total invertebrate abundance, biomass (g), and percentages per taxa at Fort Stewart, Georgia, 1996-97.

Taxa	Total abundance	Percent of total	Total biomass (g)	Percent of total
Non-insects				
Araneae	6295	15.7	3.750	16.4
Opiliones	566	1.4	1.590	7.0
Acari	240	0.6	0.013	0.1
Diplopoda	19	0.1	0.049	0.2
Pseudoscorpiones	2	0.0	0.000	0.0
Insects				
Hymenoptera	9058	22.6	1.832	8.0
Homoptera	7962	19.9	4.402	19.3
Diptera	7559	18.8	2.189	9.6
Hemiptera	2745	6.8	0.919	4.0
Orthoptera	2151	5.4	6.585	28.8
Psocoptera	2089	5.2	0.137	0.6
Coleoptera	919	2.3	0.784	3.4
Lepidoptera[a]	377	0.9	0.498	2.2
Neuroptera	70	0.2	0.050	0.2
Thysanoptera	52	0.1	0.003	0.0
Odonata	7	0.0	0.029	0.1
Isoptera	2	0.0	0.000	0.0
Collembola	1	0.0	0.000	0.0

[a] Includes both adults and larvae.

Table 3. Total abundance and biomass (g) of small, medium, and large category invertebrates collected at Fort Stewart, Georgia, 1996-97.

Year	Small	Medium	Large	Total
1996	20,309	857	60	21,226
	8.164 g	2.882 g	1.271 g	12.317 g
1997	18,134	672	82	18,888
	6.659 g	2.389 g	1.466 g	10.514 g
Total	38,443	1,529	142	40,114
	14.823 g	5.271 g	2.737 g	22.831 g

Table 4. Total mean invertebrate abundance and biomass among plots burned in May, July, and December 1996 and unburned plots at Fort Stewart, Georgia, 1996-97.

	Treatment (no. of transects)	Abundance (SE)	Biomass (g) (SE)
1996			
	May (*n* = 92)	49.0 (3.7) B[a]	0.026 (0.002) B[a]
	July (*n* = 96)	58.8 (6.0) A	0.036 (0.002) A
	December (*n* = 96)	63.3 (6.4) A	0.033 (0.002) A
	Unburned (*n* = 96)	52.1 (2.8) A	0.034 (0.003) A
1997			
	May (*n* = 72)	79.2 (4.5) A	0.048 (0.004) A
	July (*n* = 72)	68.9 (2.7) B	0.038 (0.002) B
	December (*n* = 72)	50.9 (2.7) C	0.023 (0.002) C
	Unburned (*n* = 72)	63.4 (3.4) B	0.037 (0.002) B

[a] Means with the same letter within each year did not differ ($P > 0.05$)

II. Invertebrate Abundance and Biomass by Year, Season of Burn, and Month

i. 1996

May Burn

There were no differences in invertebrate abundance and biomass between pre-burn May plots and unburned plots. Invertebrate abundance ($P<0.0001$) and biomass ($P<0.0001$) was greater in unburned plots 2 weeks and 1 month after burning, while biomass also was greater in unburned plots 2 months after burning (Table 5). No differences were detected in abundance between unburned plots and May-burned plots 2, 4, and 5 months after burning or in biomass 4 and 5 months after burning.

July Burn

No differences were detected in invertebrate abundance in 5 of the 6 pre-burn sampling dates between unburned plots and July-burned plots (Table 6). In July pre-burn plots, mid-April samples had more invertebrates than unburned plots ($P<0.0001$). No differences were detected in abundance 1 and 2 months after burning between July-burned plots and unburned plots, however, biomass in unburned plots was greater 1 month after burning ($P<0.0001$).

Table 5. Mean invertebrate abundance and biomass in samples from plots burned in May 1996 and unburned plots at Fort Stewart, Georgia, 1996.

Sample Date	Treatment (no. of transects)	Abundance (SE)	Biomass (g) (SE)
early-April	Pre-burn (*n* = 12)	39.7 (3.1) A[a]	0.013 (0.002) A
	Unburned (*n* = 12)	29.7 (3.3) A	0.010 (0.001) A
mid-April	Pre-burn (*n* = 12)	69.6 (12.8) A	0.025 (0.003) A
	Unburned (*n* = 12)	47.7 (8.5) A	0.021 (0.004) A
late-April	Pre-burn (*n* = 12)	53.3 (8.5) A	0.024 (0.003) A
	Unburned (*n* = 12)	51.1 (8.7) A	0.027 (0.005) A
mid-May	Burned (*n* = 8)	13.9 (2.0) B	0.006 (0.002) B
	Unburned (*n* = 12)	75.4 (11.2) A	0.050 (0.008) A
late-May	Burned (*n* = 12)	22.8 (5.0) B	0.016 (0.003) B
	Unburned (*n* = 12)	60.9 (6.1) A	0.043 (0.005) A
June	Burned (*n* = 12)	43.2 (6.3) A	0.021 (0.003) B
	Unburned (*n* = 12)	64.1 (5.4) A	0.042 (0.006) A
August	Burned (*n* = 12)	67.7 (5.5) A	0.052 (0.011) A
	Unburned (*n* = 12)	45.0 (4.6) A	0.044 (0.010) A
September	Burned (*n* = 12)	73.4 (14.5) A	0.047 (0.009) A
	Unburned (*n* = 12)	42.7 (7.0) A	0.032 (0.005) A

[a] Means with the same letter within a sample date did not differ ($P>0.05$).

Table 6. Mean invertebrate abundance and biomass in samples from plots burned in July 1996 and unburned plots at Fort Stewart, Georgia, 1996.

Sample Date	Treatment (no. of transects)	Abundance (SE)	Biomass (g) (SE)
early-April	Pre-burn (*n* = 12)	49.8 (6.8) A[a]	0.021 (0.003) A
	Unburned (*n* = 12)	29.7 (3.3) A	0.010 (0.001) A
mid-April	Pre-burn (*n* = 12)	72.3 (5.6) A	0.031 (0.003) A
	Unburned (*n* = 12)	47.7 (8.5) B	0.021 (0.004) A
late-April	Pre-burn (*n* = 12)	54.3 (5.5) A	0.031 (0.004) A
	Unburned (*n* = 12)	51.1 (8.7) A	0.027 (0.005) A
mid-May	Pre-burn (*n* = 12)	66.3 (5.8) A	0.051 (0.004) A
	Unburned (*n* = 12)	75.4 (11.2) A	0.050 (0.008) A
late-May	Pre-burn (*n* = 12)	72.0 (8.8) A	0.051 (0.005) A
	Unburned (*n* = 12)	60.9 (6.1) A	0.043 (0.005) A
June	Pre-burn (*n* = 12)	66.8 (9.5) A	0.060 (0.013) A
	Unburned (*n* = 12)	64.1 (5.4) A	0.042 (0.006) A
August	Burned (*n* = 12)	37.2 (4.5) A	0.015 (0.003) B
	Unburned (*n* = 12)	45.0 (4.6) A	0.044 (0.010) A
September	Burned (*n* = 12)	51.5 (4.4) A	0.031 (0.004) A
	Unburned (*n* = 12)	42.7 (7.0) A	0.032 (0.005) A

[a] Means with the same letter within a sample date did not differ ($P>0.05$).

Scheduled December Burn

Because no treatment was applied to December plots during the invertebrate sampling season in 1996, these plots essentially served as additional control plots. Comparisons of the pre-burn December plots and unburned plots were made to evaluate the homogeneity of the invertebrate populations at these sites. There were no differences in invertebrate abundance and biomass between pre-burn December plots and unburned plots on any sampling date in 1996 (Table 7).

ii. 1997

May Burn

Invertebrates were more numerous in plots burned in May 1996 than in unburned plots only during late-August ($P<0.0002$) (Table 8). Invertebrate biomass did not differ between plots burned in May 1996 and unburned plots for any sampling dates in 1997 ($P>0.98$).

July Burn

Invertebrates were more abundant in plots burned in July 1996 than in unburned plots only during late-August ($P<0.0002$) (Table 9). Invertebrate biomass did not differ between plots burned in July 1996 and unburned plots for any sampling dates in 1997 ($P>0.98$).

Table 7. Mean invertebrate abundance and biomass in samples from December pre-burn plots and unburned plots at Fort Stewart, Georgia, 1996.

Sample Date	Treatment (no. of transects)	Abundance (SE)	Biomass (g) (SE)
early-April	Pre-burn (n = 12)	39.9 (5.0) A[a]	0.019 (0.003) A
	Unburned (n = 12)	29.7 (3.3) A	0.010 (0.001) A
mid-April	Pre-burn (n = 12)	71.1 (17.0) A	0.024 (0.005) A
	Unburned (n = 12)	47.7 (8.5) A	0.021 (0.004) A
late-April	Pre-burn (n = 12)	115.8 (40.6) A	0.031 (0.007) A
	Unburned (n = 12)	51.1 (8.7) A	0.027 (0.005) A
mid-May	Pre-burn (n = 12)	85.4 (15.5) A	0.041 (0.007) A
	Unburned (n = 12)	75.4 (11.2) A	0.050 (0.008) A
late-May	Pre-burn (n = 12)	64.9 (7.5) A	0.040 (0.006) A
	Unburned (n = 12)	60.9 (6.1) A	0.043 (0.005) A
June	Pre-burn (n = 12)	53.3 (5.5) A	0.045 (0.007) A
	Unburned (n = 12)	64.1 (5.4) A	0.042 (0.006) A
August	Pre-burn (n = 12)	36.8 (7.6) A	0.038 (0.006) A
	Unburned (n = 12)	45.0 (4.6) A	0.044 (0.010) A
September	Pre-burn (n = 12)	39.3 (5.0) A	0.029 (0.008) A
	Unburned (n = 12)	42.7 (7.0) A	0.032 (0.005) A

[a] Means with the same letter within a sample date did not differ ($P > 0.05$).

Table 8. Mean invertebrate abundance and biomass in samples from plots burned in May 1996 and unburned plots at Fort Stewart, Georgia, 1997.

Sample Date	Treatment (no. of transects)	Abundance (SE)	Biomass (g) (SE)
April	Burned (n = 12)	98.9 (12.4) A[a]	0.045 (0.006) A[a]
	Unburned (n = 12)	72.3 (5.5) A	0.032 (0.006) A
May	Burned (n = 12)	101.3 (10.1) A	0.047 (0.006) A
	Unburned (n = 12)	89.8 (4.9) A	0.042 (0.002) A
June	Burned (n = 12)	83.6 (9.1) A	0.059 (0.008) A
	Unburned (n = 12)	85.7 (8.4) A	0.046 (0.004) A
early-August	Burned (n = 12)	72.6 (10.3) A	0.049 (0.015) A
	Unburned (n = 12)	55.3 (7.2) A	0.040 (0.008) A
late-August	Burned (n = 12)	74.3 (9.1) A	0.049 (0.012) A
	Unburned (n = 12)	38.7 (3.8) B	0.038 (0.008) A
October	Burned (n = 12)	44.5 (7.5) A	0.037 (0.010) A
	Unburned (n = 12)	38.4 (4.3) A	0.026 (0.003) A

[a] Means with the same letter within a sample date are not different ($P > 0.05$).

Table 9. Mean invertebrate abundance and biomass in samples from plots burned in July 1996 and unburned plots at Fort Stewart, Georgia, 1997.

Sample Date	Treatment (no. of transects)	Abundance (SE)	Biomass (g) (SE)
April	Burned (n = 12)	56.6 (6.1) A[a]	0.031 (0.005) A[a]
	Unburned (n = 12)	72.3 (5.5) A	0.032 (0.006) A
May	Burned (n = 12)	90.5 (6.6) A	0.045 (0.004) A
	Unburned (n = 12)	89.8 (4.9) A	0.042 (0.002) A
June	Burned (n = 12)	85.1 (7.3) A	0.045 (0.004) A
	Unburned (n = 12)	85.7 (8.4) A	0.046 (0.004) A
early-August	Burned (n = 12)	65.3 (4.0) A	0.034 (0.003) A
	Unburned (n = 12)	55.3 (7.2) A	0.040 (0.008) A
late-August	Burned (n = 12)	62.4 (4.7) A	0.035 (0.004) A
	Unburned (n = 12)	38.7 (3.8) B	0.038 (0.008) A
October	Burned (n = 12)	53.5 (3.2) A	0.037 (0.006) A
	Unburned (n = 12)	38.4 (4.3) A	0.026 (0.003) A

[a] Means with the same letter within a sample date are not different ($P>0.05$).

December Burn

In April 1997, invertebrates were more abundant in unburned plots than in plots burned the previous December ($P<0.0002$) (Table 10). Invertebrate biomass did not differ between plots burned December 1996 and unburned plots for any sampling date in 1997 ($P>0.98$).

III. Abundance and Biomass of Selected Invertebrate Taxa Commonly Consumed by Wild Turkeys and Northern Bobwhites

i. Orthoptera

Orthopterans ranked sixth in overall abundance during this study (Table 2). In 1996, no differences were detected in overall Orthopteran abundance ($P > 0.18$) and biomass ($P >0.37$) among treatments, while in 1997, plots burned in May 1996 had greater Orthopteran abundance ($P<0.0001$) and biomass ($P<0.0009$) than all other treatments (Table 11).

In 1996, Orthopteran abundance was greater in unburned plots ($\bar{x}=8.8$/transect) than in May-burned plots ($\bar{x}=2.5$/transect) in mid-May, 2 weeks post-burning ($P<0.0001$). Biomass also was greater in unburned plots ($\bar{x}= 0.019$ g/transect) than May-burned plots ($\bar{x}=0.001$ g/transect) 2 weeks after burning ($P<0.005$). Orthopterans were more abundant in unburned plots ($\bar{x}=5.5$/transect) than in May-burned plots ($\bar{x}=2.1$/transect) in late-May, 1 month after burning. Biomass did not differ 1 month

Table 10. Mean invertebrate abundance and biomass in samples from plots burned in December 1996 and unburned plots at Fort Stewart, Georgia, 1997.

Sample Date	Treatment (no. of transects)	Abundance (SE)	Biomass (g) (SE)
April	Burned (n = 12)	42.9 (7.6) B[a]	0.023 (0.005) A[a]
	Unburned (n = 12)	72.3 (5.5) A	0.032 (0.006) A
May	Burned (n = 12)	73.4 (5.8) A	0.032 (0.003) A
	Unburned (n = 12)	89.8 (4.9) A	0.042 (0.002) A
June	Burned (n = 12)	64.9 (5.8) A	0.029 (0.004) A
	Unburned (n = 12)	85.7 (8.4) A	0.046 (0.004) A
early-August	Burned (n = 12)	40.3 (2.6) A	0.024 (0.004) A
	Unburned (n = 12)	55.3 (7.2) A	0.040 (0.008) A
late-August	Burned (n = 12)	50.8 (4.7) A	0.020 (0.002) A
	Unburned (n = 12)	38.7 (3.8) A	0.038 (0.008) A
October	Burned (n = 12)	32.9 (4.1) A	0.013 (0.002) A
	Unburned (n = 12)	38.4 (4.3) A	0.026 (0.003) A

[a] Means with the same letter within a sample date are not different ($P>0.05$).

Table 11. Mean abundance and biomass of Orthoptera among plots burned in May, July and December 1996 and unburned plots at Fort Stewart, Georgia, 1996-97.

	Treatment (no. of transects)	Abundance (SE)	Biomass (g) (SE)
1996			
	May (n = 92)	2.3 (0.2) A	0.009 (0.002) A
	July (n = 96)	3.9 (0.5) A	0.014 (0.002) A
	December (n = 96)	2.8 (0.3) A	0.013 (0.002) A
	Unburned (n = 96)	3.7 (0.4) A	0.012 (0.002) A
1997			
	May (n = 72)	4.8 (0.5) A	0.020 (0.003) A
	July (n = 72)	2.5 (0.2) B	0.010 (0.001) B
	December (n = 72)	2.3 (0.3) B	0.008 (0.001) B
	Unburned (n = 72)	3.3 (0.3) B	0.012 (0.002) B

[a] Means with the same letter within each year are not different ($P>0.05$).

after burning. No differences were detected in abundance and biomass 2, 4, or 5 months after burning between May-burned plots and unburned plots. Orthopterans were more abundant in unburned plots ($\bar{x}$=2.2/transect) than in July-burned plots ($\bar{x}$=0.6/transect) in August, 1 month after burning ($P<0.0001$). Biomass also differed between unburned plots ($\bar{x}$=0.021 g/transect) and July-burned plots ($\bar{x}$=0.001 g/transect) 1 month after burning.

In 1997, Orthopteran abundance ($P>0.23$) and biomass ($P>0.97$) did not differ on any sampling date among plots burned in May, July, or December 1996 and unburned plots.

ii. Homoptera

Homopteran abundance did not differ among treatments in 1996 ($P>0.18$), however, biomass was greater in July and December plots ($P<0.02$). In 1997, plots burned in May 1996 contained more Homopterans than plots burned in December 1996 ($P<0.04$) (Table 12). Homopteran biomass in plots burned in December was lower than all other treatments in 1997 ($P<0.02$).

In early-May, 2 weeks after burning, Homopterans were more abundant in unburned plots ($\bar{x}$=17.7/transect) than in burned plots ($\bar{x}$=1.0/transect) ($P<0.0001$). Biomass also was greater in unburned plots ($\bar{x}$=0.009 g/transect) than in May-burned plots ($\bar{x}$=0.002 g/transect) 2 weeks after burning ($P<0.0001$). Unburned plots ($\bar{x}$=11.8/transect) had greater abundance than May-burned plots ($\bar{x}$=4.3/transect) in

Table 12. Mean abundance and biomass of Homoptera among plots burned in May, July and December 1996 and unburned plots at Fort Stewart, Georgia, 1996-97.

	Treatment (no. of transects)	Abundance (SE)	Biomass (g) (SE)
1996			
	May (n = 92)	11.0 (1.1) A	0.005 (0.001) B
	July (n = 96)	12.0 (1.0) A	0.007 (0.001) A
	December (n = 96)	11.1 (0.9) A	0.007 (0.001) A
	Unburned (n = 96)	11.0 (0.8) A	0.006 (0.001) AB
1997			
	May (n = 72)	16.0 (1.6) A	0.009 (0.001) A
	July (n = 72)	12.0 (0.7) AB	0.008 (0.001) A
	December (n = 72)	11.0 (0.9) B	0.006 (0.000) B
	Unburned (n = 72)	13.2 (1.2) AB	0.008 (0.001) A

[a] Means with the same letter within each year are not different (P>0.05).

late-May, 1 month after burning. Biomass was greater in unburned plots ($\bar{x}=0.007$ g/transect) than in May-burned plots ($\bar{x}=0.002$ g/transect) 2 months after burning.

No differences in Homopteran abundance and biomass were found for any sample dates between plots burned in July and unburned plots in 1996. Also, Homopteran abundance and biomass did not differ on any sampling dates in 1996 between pre-burn December plots and unburned plots.

In 1997, abundance of Homopterans differed between plots burned in May 1996 and unburned plots on only 1 of the 6 sampling dates. In late-August, Homopterans were more abundant in plots burned in May 1996 ($\bar{x}=17.6$/transect) than in unburned plots ($\bar{x}=6.2$/transect) ($P<0.0003$). No differences in Homopteran biomass were found on any sampling date between unburned plots and plots burned in May, July, or December 1996 ($P>0.23$) in 1997.

Homopterans differed between plots burned in July 1996 and unburned plots on 2 of the 6 sampling dates in 1997. Homopterans were more abundant in unburned plots ($\bar{x}=19.5$/transect) than in July-burned plots ($\bar{x}=10.5$/transect) in April, and more abundant in July-burned plots ($\bar{x}=12.2$/transect) than unburned plots ($\bar{x}=6.2$/transect) in late-August ($P<0.0003$).

In 1997, Homopterans were more abundant in April in unburned plots ($\bar{x}=19.5$/transect) than in plots burned in December 1996 ($\bar{x}=12.6$/transect) ($P<0.0003$).

iii. Coleoptera

Coleopterans, which ranked eight in overall abundance, were not collected in great numbers during this study (Table 2). Overall abundance ($P>0.30$) and biomass ($P>0.50$) of Coleoptera did not differ among treatments in 1996. In 1997, Coleopterans were more abundant in plots burned in July 1996 and unburned plots ($P<0.006$), while biomass did not differ among treatments ($P>0.37$) (Table 13).

In 1996, Coleopterans were more abundant in unburned plots ($\bar{x}=3.8$/transect) than in May plots ($\bar{x}=0.6$/transect) 2 weeks after burning ($P<0.01$). Unburned plots ($\bar{x}=2.2$/transect) also had more Coleopterans than May-burned plots ($\bar{x}=0.5$/transect) 1 month after burning. No differences in Coleopteran abundance were detected for any samples between July-burned plots and unburned plots in 1996. Differences were detected on only 1 of 8 sampling dates between pre-burn December plots and unburned plots in 1996. Pre-burn December plots ($\bar{x}=1.7$/transect) had more Coleopterans than unburned plots ($\bar{x}=0.4$/transect) in mid-April ($P<0.01$). Coleopteran biomass did not differ on any sampling date between unburned plots and May, July, or December plots on any sampling date in 1996 ($P>0.54$).

In 1997, no differences were detected in Coleopteran abundance ($P>0.21$) and biomass ($P>0.93$) between unburned plots and plots burned in May, July, or December 1996.

Table 13. Mean abundance and biomass of Coleoptera among plots burned in May, July, and December 1996 and unburned plots at Fort Stewart, Georgia, 1996-97.

	Treatment (no. of transects)	Abundance (SE)	Biomass (g) (SE)
1996			
	May (*n* = 92)	1.0 (0.1) A	0.001 (0.000) A
	July (*n* = 96)	1.3 (0.1) A	0.002 (0.000) A
	December (*n* = 96)	1.2 (0.1) A	0.002 (0.000) A
	Unburned (*n* = 96)	1.3 (0.2) A	0.002 (0.000) A
1997			
	May (*n* = 72)	1.3 (0.2) AB	0.003 (0.000) A
	July (*n* = 72)	1.8 (0.2) A	0.002 (0.000) A
	December (*n* = 72)	1.1 (0.2) B	0.002 (0.000) A
	Unburned (*n* = 72)	2.2 (0.3) A	0.002 (0.000) A

[a] Means with the same letter within each year are not different (P>0.05).

iv. Hymenoptera

Overall abundance of Hymenoptera was greater in July plots (P <0.0001) than all other treatments in 1996, while biomass was greater in May, July, and unburned plots (P<0.0008) (Table 20). In 1997, Hymenopterans also had greater abundance (P<0.03) and biomass (P<0.0002) in plots burned in July 1996 (Table 14).

In 1996, Hymenopterans were more abundant in unburned plots ($\bar{x}$=13.0/transect) than in plots burned in May ($\bar{x}$=0.8/transect) 2 weeks after burning (P<0.0001), while no differences were detected on any other post-burn sampling date. Biomass also was greater in unburned plots ($\bar{x}$=0.005 g/transect) than in May-burned plots ($\bar{x}$=0.000 g/transect) 2 weeks after burning (P<0.007). No differences in Hymenopteran abundance were detected between unburned plots and plots burned in July 1996, however, plots burned in July ($\bar{x}$=0.004 g/transect) had greater biomass than unburned plots ($\bar{x}$=0.001 g/transect) in September, 2 months after burning. Hymenopteran abundance also did not differ on any sampling date in 1996 between unburned plots and pre-burn December plots.

In 1997, Hymenopterans were more abundant in plots burned in May 1996 ($\bar{x}$=13.5/transect) than in unburned plots ($\bar{x}$=8.0/transect) in late-August (P <0.0007). In October, July-burned plots ($\bar{x}$=13.8/transect) had more Hymenopterans than unburned plots ($\bar{x}$=8.7/transect). Unburned plots ($\bar{x}$=14.5/transect) had more Hymenopterans than did plots burned in December 1996 ($\bar{x}$=7.4/transect) in April,

Table 14. Mean abundance and biomass of Hymenoptera among plots burned in May, July, and December 1996 and unburned plots at Fort Stewart, Georgia, 1996-97.

	Treatment (no. of transects)	Abundance (SE)	Biomass (g) (SE)
1996			
	May (n = 92)	10.7 (0.9) B	0.003 (0.000) A
	July (n = 96)	16.1 (1.0) A	0.003 (0.000) A
	December (n = 96)	8.8 (0.7) B	0.002 (0.000) B
	Unburned (n = 96)	11.2 (0.8) B	0.003 (0.000) A
1997			
	May (n = 72)	15.8 (1.0) AB	0.003 (0.000) B
	July (n = 72)	18.9 (1.5) A	0.004 (0.001) A
	December (n = 72)	15.0 (1.0) B	0.002 (0.000) B
	Unburned (n = 72)	15.0 (1.1) B	0.003 (0.000) B

[a] Means with the same letter within each year are not different (P>0.05).

although by late-August, December-burned plots ($\bar{x} = 16.0$/transect) had more Hymenopterans than unburned plots ($\bar{x} = 8.0$/transect) ($P<0.0007$). In 1997, no differences were detected for any sample dates between unburned plots and plots burned in May, July, and December 1996 ($P>0.40$).

IV. Invertebrate Abundance and Biomass and Vegetation Composition

Few relationships were detected between vegetation composition and total invertebrate abundance ($R^2 = 0.83$, $P<0.001$) (Table 15) and biomass ($R^2 = 0.66$, $P<0.10$) (Table 16) in 1997. Treatment, plot within treatment, and sample were important in explaining the variation in invertebrate abundance and biomass in 1997. Woody plants ($P<0.004$) also explained some of the variation in invertebrate abundance in the model, but when all non-significant variables were removed, woody plants ($P>0.11$) were not helpful in explaining abundance. Woody plants, as a percent of the total groundcover composition, did not differ among treatments in 1997 ($P>0.81$). The percent cover of forbs ($P<0.05$) was greatest in plots burned in July. The percent cover of graminoids ($P<0.002$) was greatest in plots burned in May (Table 17) and July 1996 (Table 18) and unburned plots (Table 19). The percent cover of graminoids ($P<0.002$) was lowest in plots burned in December 1996 (Table 20).

Table 15. Variables used in multiple regression to test for relationships between invertebrate abundance and vegetation composition (growth form) at Fort Stewart, Georgia, 1997.

Source	df	F	Pr > F
Treatment	3	10.94	< 0.0001[a]
Plot (Treatment)	8	4.84	0.0001
Transect (Treatment*Plot)	36	1.12	0.3475
Sample	2	70.61	<0.0001
Treatment*Sample	6	0.97	0.4551
Fern	1	1.44	0.2349
Fern*Fern	1	0.00	0.9588
Fern*Treatment	3	1.00	0.3998
Fern*Sample	2	0.71	0.4937
Shrub	1	9.08	0.0038
Shrub*Shrub	1	1.52	0.2217
Shrub*Treatment	3	0.64	0.5904
Shrub*Sample	2	1.91	0.1566
Forb	1	0.07	0.7979
Forb*Forb	1	0.50	0.4812
Forb*Treatment	3	0.20	0.8983
Forb*Sample	2	0.99	0.3766
Graminoid	1	1.30	0.2590
Graminoid*Graminoid	1	0.13	0.7233
Graminoid*Treatment	3	0.23	0.8784
Graminoid*Sample	2	2.11	0.1295

[a] Significance level of alpha=0.05 was used.

Table 16. Variables used in multiple regression to test for relationships between invertebrate biomass and vegetation composition (growth form) at Fort Stewart, Georgia, 1997.

Source	df	F	Pr > F
Treatment	3	6.19	0.0010[a]
Plot (Treatment)	8	4.78	0.0001
Transect (Treatment*Plot)	36	0.59	0.9530
Sample	2	4.63	0.0135
Treatment*Sample	6	0.50	0.8083
Fern	1	0.09	0.7641
Fern*Fern	1	1.63	0.2070
Fern*Treatment	3	1.22	0.3118
Fern*Sample	2	0.20	0.8224
Shrub	1	2.50	0.1190
Shrub*Shrub	1	0.71	0.4019
Shrub*Treatment	3	0.56	0.6456
Shrub*Sample	2	0.99	0.3769
Forb	1	0.14	0.7097
Forb*Forb	1	0.21	0.6463
Forb*Treatment	3	0.49	0.6927
Forb*Sample	2	0.40	0.6725
Graminoid	1	0.14	0.7105
Graminoid*Graminoid	1	0.08	0.7807
Graminoid*Treatment	3	2.26	0.0908
Graminoid*Sample	2	0.67	0.5171

[a] Significance level of alpha=0.05 was used.

Table 17. Mean vegetative cover (%) by growth form in plots burned in May 1996 at Fort Stewart, Georgia, 1996-97.

Sample Date	$\bar{x}$ Total Vegetative Cover (%)	Percentage (%) of Vegetative Cover by Growth Form			
		Graminoid	Forb	Fern	Woody Plants
1996					
mid-April[a]	91	74	5	1	11
early-May[a]	90	67	4	0	19
June	75	56	3	1	15
August	97	74	10	1	12
September	92	69	12	0	11
1997					
May	84	57	4	2	21
July	93	55	11	0	27
October	93	53	9	0	31

[a] pre-burn sample

Table 18. Mean vegetative cover (%) by growth form in plots burned in July 1996 at Fort Stewart, Georgia, 1996-97.

Sample Date	$\bar{x}$ Total Vegetative Cover (%)	Percentage (%) of Vegetative Cover by Growth Form			
		Graminoid	Forb	Fern	Woody Plants
1996					
mid-April[a]	92	78	2	0	12
mid-May[a]	99	75	4	1	19
June[a]	93	66	5	1	21
August	88	72	8	1	7
September	92	73	9	1	9
1997					
May	92	55	8	1	28
July	91	54	14	0	23
October	96	64	11	1	20

[a] pre-burn sample

Table 19. Mean vegetative cover (%) by growth form in unburned plots at Fort Stewart, Georgia, 1996-97.

Sample Date	$\bar{x}$ Total Vegetative Cover (%)	Percentage (%) of Vegetative Cover by Growth Form			
		Graminoid	Forb	Fern	Woody Plants
1996					
mid-April	85	71	1	0	13
mid-May	93	65	8	3	17
June	93	65	5	4	19
August	89	63	6	1	19
September	93	71	6	0	16
1997					
May	85	43	11	5	26
July	91	50	10	2	29
October	92	64	4	0	24

Table 20. Mean vegetative cover (%) by growth form in plots burned in December 1996 at Fort Stewart, Georgia, 1996-97.

Sample Date	$\bar{x}$ Total Vegetative Cover (%)	Percentage (%) of Vegetative Cover by Growth Form			
		Graminoid	Forb	Fern	Woody Plants
1996					
mid-April[a]	77	48	1	3	25
mid-May[a]	87	56	2	1	28
June[a]	92	50	2	2	38
August[a]	94	59	2	0	33
September[a]	91	61	5	0	25
1997					
May	74	42	4	4	24
July	78	35	9	1	33
October	83	41	6	0	28

[a] pre-burn sample

CHAPTER 5

DISCUSSION

I. Total Invertebrate Abundance and Biomass

Prescribed burning has been used to manage brood habitat for wild turkeys and northern bobwhites in southern Coastal Plain pine forests for many years (Stoddard 1963, Hurst 1972). Traditionally, burning has been conducted in February and March, but in recent years natural resource managers have been using fire during the growing season (Hermann et al. 1998). In 1996, there was no difference in total invertebrate abundance or biomass among plots burned in July or unburned plots at Fort Stewart. When analyzed monthly, however, invertebrate abundance in May-burned plots was equal to or exceeded that of unburned plots in June, August, and September, while biomass was equal to that of unburned plots in August and September (Table 21). These months coincide with peak hatch dates for wild turkeys and bobwhites in southern Georgia (Hurst 1981, Landers and Mueller 1992, Peoples et al. 1996, Brennan et al. 2000).

Early successional vegetation has been considered good turkey and bobwhite brood habitat. Management techniques such as prescribed burning and strip disking are preferred ways to maintain early successional habitat (Stoddard 1931, Rosene 1969, Hurst 1981, Landers and Mueller 1992, Peoples et al. 1996). These methods, especially

Table 21. Summary of significant[a] ANOVA P-values for total invertebrate abundance and biomass comparing samples from unburned plots to plots burned in May, July, and December 1996, Fort Stewart, Georgia, 1996.

	early-April	mid-April	late-April	mid-May	late-May	June	August	September
May				<[b]A[c] <B[d]	<A <B	<B		
July		>A					<B	
December								

[a]Significance level of alpha=0.05.
[b]< = treatment plot is less than unburned plot, > = treatment plot is greater than unburned plot
[c]Abundance
[d]Biomass

burning, produce fresh succulent vegetation that offers more palatable forage for many invertebrates (Schowalter 1985, Robbins and Myers 1992, Manley 1994). Invertebrate abundance and biomass in plots burned in May and July recovered quickly and may be attributed to the rapid re-growth of vegetation after growing-season burns. Recovery time for July-burned plots was quicker than that of May-burned plots and is probably the result of increased vegetation growth due to warmer temperatures and longer day length (Robbins and Myers 1992).

Studies conducted in old-field habitat in southern Georgia have shown no differences in invertebrate abundance or biomass between spring burning (April-May) and traditional winter burning (Sisson and Speake 1994, Brennan et al. 2000). Both studies reported no differences in abundance or biomass 7 weeks after burning in spring compared to winter burning. Invertebrate abundance and biomass in this study produced similar results. Abundance in May-burned plots was equal to unburned plots in June, 6 weeks after burning, however, no comparison could be made to December plots because they had not been burned yet. It appears that longleaf pine-wiregrass habitat responds similarly to old-field pine habitats.

Pavon (1995) reported invertebrate abundance and biomass in plots burned in June in longleaf pine-wiregrass stands recovered to or were greater than pre-burn levels by September. The results were attributed to recolonization from surrounding unburned areas. Recolonization from surrounding unburned areas also was reported by Cancelado and Yonke (1970) as the reason for increased numbers of Homoptera and Hemiptera for several weeks following spring burns in Missouri prairies. Recolonization from unburned areas is a probable explanation for the rapid recovery of invertebrates in this study. Although relatively large areas were burned, with sites averaging 20 ha (50 ac), the proximity of unburned hardwood drains, cypress ponds, roads, and small unburned patches may have facilitated the rapid influx of invertebrates into the recently burned areas.

The ability of invertebrates to escape fire by flight, ascending trees, or burrowing depends on its particular life stage and may influence population response after a fire. Hall and Schweitzer (1992) reported invertebrates in southeastern savannas and flatwoods might survive and/or recolonize best after a growing-season fire because most insects have a mobile phase at that time of year. Although the method of escape was not tested in this study, numerous invertebrates were noticed flying away and climbing trees to escape fire. Komarek (1969) noted that insects fleeing fires attract certain predatory insects and birds that hunt in the cooling burn and smoke.

In 1997, May-burned plots had greater overall invertebrate abundance and biomass than all other treatments. When analyzed monthly, abundance differed from unburned plots on only 1 sample date, while biomass did not differ on any sample date (Table 22). Abundance and biomass in plots burned in July responded similarly. Greater abundance in May- and July-burned plots in 1997 may be attributed to greater abundance at the end of the 1996 sampling season. It is common for invertebrates to succumb to extremely cold temperatures (Uvarov 1931, Borror et al. 1989), but mild winter weather probably contributed little to over-winter mortality in this study. Overall abundance and biomass in December plots was relatively low at the end of the 1996 sampling season, which may

Table 22. Summary of significant[a] ANOVA P-values for total invertebrate abundance and biomass comparing samples from unburned plots to plots burned in May, July, and December 1996, Fort Stewart, Georgia, 1997.

	April	May	June	early-August	late-August	October
May					>[b]A[c]	
July					>A	
December	<A					

[a]Significance level of alpha=0.05.
[b]< = treatment plot is less than unburned plot, > = treatment plot is greater than unburned plot
[c]Abundance

explain low abundance and biomass in 1997. Burning during the dormant-season also may have contributed to lower invertebrate numbers in 1997, because vegetation grows more slowly after a dormant-season burn (Robbins and Myers 1992), resulting in less forage. These results suggest that in terms of invertebrate abundance and biomass, dormant-season burns may require more recovery time than growing-season burns.

Weather plays an important role in invertebrate populations (Uvarov 1931, Borror et al. 1989). During this study, average temperatures at Fort Stewart fell within the normal range, however, annual rainfall was lower in 1996 than in 1997, 99 cm (39 inches) and 137 cm (54 inches), respectively (Fort Stewart Forestry Branch, unpublished data). Three weather stations located near the study plots received approximately equal amounts of rainfall, therefore, the effects of rainfall on each plot was probably the same. The increase in annual rainfall in 1997 probably had a positive effect on vegetation response and overall invertebrate populations. The increase in rainfall may explain the slightly greater invertebrate abundance and biomass among treatments in 1997.

II. Abundance and Biomass of Selected Invertebrate Taxa Commonly Consumed by Wild Turkeys and Northern Bobwhites

Orthoptera, Homoptera, Coleoptera, and Hymenoptera responded to season of fire similar to all invertebrates combined. Abundance and biomass were reduced immediately following burning but recovered to that of unburned plots relatively quickly. Abundance and biomass of Orthoptera in May-burned plots were greater than all other treatments 1 year after burning. Orthoptera responded to May- and June-burns better than February burns 1 year after burning in southern Georgia (Brennan et al. 2000). Hurst (1972) found more Orthoptera in 3-year-old "roughs" than in plots burned annually in February. The difference was attributed to the lack of litter in annually-burned plots and suggested a 1-year "rough" in longleaf pine forests would provide adequate litter for an increase in Orthoptera. The greater abundance and biomass of Orthoptera in plots burned in May 1996 in this study may be the result of increased recovery time, since they were burned first. This may have allowed the "rough" to build up to a level preferred by Orthopterans.

Abundance and biomass of Homoptera also were greater in May-burned plots than in December-burned plots 1 year after burning. Brennan et al. (2000) also found this in old-field habitat, while Pavon (1995) reported abundance of Homoptera did not differ with season of fire. Pavon also found the alpha-diversity of invertebrate families did not differ between dormant- versus growing-season burns in longleaf pine forests.

Coleopterans were more abundant in May- and July-burned plots and unburned plots 1 year after burning, while no difference was detected the year of the burn. Pavon (1995) reported Coleopterans were more abundant in plots burned in June than February 1 year after burning. Few Coleoptera were collected during this study, which may have prevented the detection of differences among treatments. The use of other sampling methods, or a combination of other methods, such as pitfall traps or the use of a terrestrial vacuum and a bottomless frame box (Harper and Guynn 1998) may have collected more Coleopterans. Because the nozzle of the D-vac® was held approximately

15 cm above the ground (Fuller 1994), primarily invertebrates from the vegetation were collected, not from the ground where many Coleopterans occur.

Hymenopterans recovered from burning very rapidly in 1996. Abundance and biomass in May- and July-burned plots required only 1 month to reach levels of unburned plots. Pavon (1995) reported abundance of Hymenoptera was greatest in plots burned in February, with ants constituting the majority of the order. Most Hymenoptera in this study were small parasitic wasps, with relatively few ants collected. Small wasps were important food items for wild turkey poults in Mississippi (Hurst and Stringer 1975, Hurst 1978).

III. Invertebrate Abundance and Biomass and Vegetation Composition

Invertebrate abundance may be closely related to vegetation composition and forbs, especially legumes, may attract more invertebrates than non-legumes (Stoddard 1931, Hollifield and Dimmick 1995). This study found few relationships between invertebrate abundance and biomass and vegetation composition. Treatment had the greatest effect on invertebrate abundance and biomass, not vegetation composition. Although the percent composition of growth forms varied among treatments, it did not have a significant effect on invertebrate abundance and biomass. In southwestern Georgia, more invertebrates were found in weedy fields containing primarily ragweed and partridge pea than in cultivated patches or burned pine forests (Yates et al. 1995). In southeastern Georgia, more invertebrates were found in forest openings characterized by abundant herbaceous vegetation, such as ragweed, blackberry (*Rubusargutus*), trumpet creeper (*Campsis radicans*) and panic grasses, than in planted pine stands or annually burned pine forests (Peoples et al. 1996). Harper et al. (2001) reported more invertebrates within forest stands than openings in the mountains of western North Carolina, however, the density of invertebrates preferred by turkey poults was equal to or greater in openings than in forested habitats. The openings sampled in these studies were primarily forb-dominated habitats, which differed from the wiregrass-dominated plots at Fort Stewart where forbs represented only a small portion of the total groundcover. Also, these studies compared different habitat types (i.e., forest openings, hardwoods, planted pines, unburned roughs, and annually burned pine woods), while only longleaf pine-wiregrass stands were sampled at Fort Stewart. Similarity of habitats made it more difficult to detect relationships between vegetation composition and invertebrate abundance and biomass.

Legume seed production increased the year after burning in July and August in South Carolina, however, legume density did not differ among plots burned in spring, summer, or unburned plots (Cushwa 1970). Season of fire had little effect on groundcover species composition in a 10-year study conducted in longleaf-wiregrass savannas in northern Florida (Streng et al. 1993). However, they did find many of the dominant grasses and forbs flowered more abundantly following growing-season fire versus dormant-season fire. Streng et al. (1993) concluded the short-term (<10 years) application of growing-season fire in areas with a history of dormant-season fire did not result in major shifts in the herbaceous community, but some change may occur after repeated growing-season fires. This may have been the case at Fort Stewart, and might have precluded the detection of any short-term differences in invertebrate abundance or biomass based on vegetation composition.

Although invertebrates are an important component of wild turkey and northern bobwhite brood habitat, the importance of cover, for both nesting and brooding, also is important. In addition to abundant invertebrates, proper brood habitat should provide the vegetative structure that allows hens to detect predators and to protect poults and chicks while foraging (Harper et al. 2001). Cover left unburned after March has been shown to be desirable nesting habitat for wild turkeys (Sisson and Speake 1994). The loss of nests and the potential loss of poult and chick production must be considered when implementing a growing-season burn regime. Although renesting occurs in both species, it is more common in northern bobwhites than in wild turkeys (Stoddard 1931, Rosene 1969, Davis et al. 1995). Natural resource managers must decide whether or not the trade-off between the short-term loss of nesting and brooding cover and the loss of poult and chick production is worth the potential benefit of improved habitat over the long term. This issue is still being debated and studied (Robbins and Myers 1992, Sisson and Speake 1994, Brennan et al. 1998, Hermann et al. 1998).

CHAPTER 6

MANAGEMENT IMPLICATIONS

Natural resource managers at Fort Stewart are using growing season fire to improve existing and potential red-cockaded woodpecker habitat in longleaf pine-wiregrass stands. The effects of growing season fire for this purpose have been positive (Lawrence Carlile, personal communication). Some sportsmen and biologists, however, are concerned about the potentially detrimental effects growing season fire has on ground-nesting birds, especially wild turkeys and northern bobwhites. While this study did not address the nesting issue, I found little or no evidence suggesting that burning during the growing season had any detrimental effects on invertebrates, an important aspect of wild turkey and northern bobwhite brood habitat quality.

While burning is an important tool in managing brood habitat for wild turkeys and northern bobwhites, its use is critical for managing the longleaf pine-wiregrass ecosystem. Today, only about 3 percent, or 3 million acres remain of what was one of the most extensive forest ecosystems in North America (Frost 1993). This ecosystem evolved with naturally-occurring fires resulting from lightning strikes during spring and summer (Komarek 1964). Ecologists have encouraged natural resource managers to use growing-season fire in longleaf pine forests to mimic these natural processes (Robbins and Myers 1992). While there may be negative short-term responses to growing-season fire (i.e., reduced invertebrate abundance and biomass and loss of nesting and brooding cover), as with any disturbance, the long-term health of the ecosystem may benefit from growing-season fire (Hermann et al. 1998).

A mixture of growing-and dormant-season fires should be used on a 2- to 3-year burn rotation in longleaf pine-wiregrass stands. Growing-season fire should be used in areas where hardwood encroachment has occurred. In areas where the fuel load is too high to tolerate growing-season fires, dormant-season fires should be used. Burns should be scattered across the landscape so recently burned areas are not adjacent to one another and varied over time (i.e., not burned in the same month burn after burn). Burn size should be dictated by the size of the installation or forest in which the burn is being conducted. On a 2- to 3-year rotation, approximately one third of the area should be burned each year. If possible, burns should be conducted as late in the turkey- and bobwhite-nesting season as possible to minimize nest loss. This may not be possible at an installation as large as Fort Stewart because burning on such a schedule would condense the burning season, and not allow time for all growing-season burns to be conducted. In all likelihood, some areas will not get burned during the time-frame prescribed because of factors beyond control (e.g., rain, high winds, improper wind for smoke sensitive areas, access to areas, etc.). In this event, areas not burned on schedule should be burned during the dormant season. This mixture of growing- and dormant-season burning should provide adequate nesting, loafing, and escape cover for wild turkeys and northern bobwhites. Because red-cockaded woodpeckers and bobwhites share similar habitats (i.e., open-canopied, park-like pine woods, Fuller 1994) this burning regime also should satisfy the burning requirements for red-cockaded woodpecker management and that of wild turkey and northern bobwhite brood habitat management.

Because prescribed burning is an integral part of the management of the red-cockaded woodpecker and the longleaf pine-wiregrass ecosystem, research should focus on long-term studies designed to determine the effects of growing-season fire on ground-nesting bird populations, including wild turkeys and bobwhites. Attention should be focused on wild turkey and northern bobwhite brood ecology, with an emphasis on poult and chick production and survival. Additional research on invertebrate response to growing-season fire also should be continued. A collection technique similar to that described by Harper and Guynn (1998) should be used to obtain density estimates so different habitats can be compared. This may be of particular importance in areas that have both old-field habitat and areas with undisturbed native groundcover. Continued long-term studies on the effects of growing-season fire on groundcover composition also should be continued.

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APPENDIX A

Table 23. Common names of invertebrates per taxa at Fort Stewart, Georgia, 1996-97.

Order	Common names
Acari	mites and ticks
Araneae	spiders
Coleoptera	beetles
Collembola	springtails
Diplopoda	millipedes
Diptera	flies
Hemiptera	true bugs
Homoptera	aphids, leafhoppers, spittlebugs, and treehoppers
Hymenoptera	ants, bees, and wasps
Isoptera	termites
Lepidoptera	butterflies and moths
Neuroptera	lacewings and dobsonflies
Odonata	damselflies and dragonflies
Opiliones	harvestmen
Orthoptera	crickets, grasshoppers, roaches, mantids, and walking sticks
Pseudoscorpiones	pseudoscorpions
Psocoptera	barklice
Thysanoptera	thrips

VITA

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