

Influence of Roller Chopping and Prescribed Burning on Insects in Pine Flatwoods

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Abstract: Roller chopping and prescribed burning are treatments frequently applied to many southeastern rangeland systems, including Florida's pine flatwoods. These treatments can improve rangeland condition by reducing the cover of shrubs and promoting the growth of herbaceous species. However, they have the potential to both positively and negatively affect insects, which provide important ecosystem services as pollinators and are a food source for numerous rangeland-associated avian species, some of which are of conservation concern. We compared total insect familial richness and relative abundance, and familial richness and relative abundance within five orders that contain insects important as pollinators and avian prey (i.e., Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, and Orthoptera) at sampling sites randomly located within 50 treated (i.e., dormant season burn, growing season burn, dormant season roller chop, growing season roller chop, or roller chop/burn combination) and untreated (i.e., control) subplots in central and southern Florida during 2007 and 2008. Total relative abundance ($P=0.017$) and Hemiptera familial richness ($P=0.021$) and relative abundance ($P=0.002$) were less in growing season burn compared to control subplots for two years post-treatment. Reductions in total insect familial richness were also observed in growing season burn compared to control subplots but only lasted for one year post-treatment ($P=0.017$). Total insect familial richness ($P\leq 0.001$) and relative abundance ($P=0.001$), as well as familial richness and relative abundance of Diptera, Hemiptera, Hymenoptera, or Orthoptera were also less on dormant season burn than control subplots the first-year post treatment ($P\leq 0.028$). Total insect familial richness ($P=0.017$) and relative abundance ($P=0.032$) were less in dormant season roller chop compared to control subplots for two years post-treatment, as was Hemiptera relative abundance ($P=0.052$). In situations where management of certain insect orders important as pollinators and avian prey is a priority, the use of growing season roller chopping and dormant season burning may be preferred over dormant season roller chopping and growing season burning.

Key words: avian prey, family, insects, pollinators, relative abundance, richness, season

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Frequent fires are considered essential to maintain the structure and diverse herbaceous groundcover of many southeastern rangeland systems (Christensen 1981, Platt et al. 1988, Abrahamson and Hartnett 1990). However, fire exclusion, reductions in fire frequency, and/or a shift in fire season can result in excessive shrub growth and declines in the species diverse herbaceous ground layer of these systems (Wade et al. 1980, Platt et al. 1988, Huffman and Blanchard 1991, Glitzenstein et al. 1995), potentially reducing their value to livestock and certain wildlife species. Depending on season of application, roller chopping and prescribed burning have been shown to improve southeastern rangeland condition by reducing shrub cover and promoting the growth and seeding of herbaceous groundcover species (Tanner et al. 1988, Glitzenstein et al. 1995, Watts and Tanner 2003, Willcox and Giuliano 2012). In Florida, these practices are promoted in a variety of rangeland systems to maintain or enhance wildlife habitat, increase livestock forage quantity and quality, and reduce fuel build up and wildfire risk.

Insects are a critical component of rangeland systems. They are major contributors to biodiversity and play a critical role in eco-

system processes as pollinators, providing benefits to agricultural and livestock producers (Warren et al. 1987, Triplehorn and Johnson 2005). Unfortunately, there is evidence of large-scale declines in populations of important wild pollinators, which include bees, wasps, and some ants (Hymenoptera), butterflies and moths (Lepidoptera), flies (Diptera), and beetles (Coleoptera). Declines are a result of a combination of factors including increasing urbanization, expansion of intensive agriculture, invasive plant species, and the widespread use of pesticides (Campbell et al. 2007, Black et al. 2011). To try to mitigate pollinator declines, the U.S. Department of Agriculture Natural Resources Conservation Services (NRCS) is using a number of Farm Bill programs to provide technical and financial assistance to landowners that implement practices, such as prescribed burning, that promote pollinator habitat on their property (NRCS 2014). Many insects important as pollinators, along with grasshoppers (Orthoptera) and true bugs (Hemiptera), also provide an important food source for some rangeland-associated wildlife. In Florida, this includes numerous avian species of conservation priority such as the Florida grasshopper sparrow (*Am-*

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modramus savannarum floridanus), Bachman's sparrow (*Peucaea aestivalis*), and northern bobwhite (*Colinus virginianus*) (Vickery 1996, Brennan 1999, Dunning 2006). Despite their potential management importance, the effects of prescribed burning and roller chopping on orders containing insects important as pollinators and avian prey have not been extensively studied in Florida's rangelands (Robbins and Myers 1992, Hanula and Wade 2003).

Insect responses to prescribed burning have been shown to be highly variable across orders, families, genera, and species and influenced by a variety of factors including, mobility, life stage at time of burning, burn frequency, degree of flame exposure, and reaction to changes in community composition and habitat (Warren et al. 1987, Siemann et al. 1997, Hanula and Wade 2003, Swengel 2001). Many grassland and savanna insects are fire adapted (Evans 1984, Anderson et al. 1989, Siemann et al. 1997) but the application of prescribed burning and roller chopping in Florida's rangeland systems may cause alterations to associated insect communities via changes in vegetation structure and composition (Herman et al. 1998). A more comprehensive understanding of how Florida rangeland insect abundance and richness respond to prescribed burning and roller chopping can ensure appropriate use of these practices in situations where promotion of insect orders important as pollinators or avian prey is a priority. The objective of our study was to compare familial richness and relative abundance within six orders containing insects important as pollinators and avian prey (i.e., Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, and Orthoptera) on pine flatwoods sites treated with prescribed burning and roller chopping during dormant (November–March) and growing (April–October) seasons.

Study Area

We established 50 pine flatwoods study plots on privately- and publically-owned lands across six counties (Desoto, Highlands, Lee, Manatee, Osceola, and Sarasota) in central and southern Florida. These study plots ranged in size from 8–40 ha. Florida's pine flatwoods are rangelands characterized as having a pure or combined overstory stand of scattered (20–40 ft²/acre basal area; Willcox unpublished data) longleaf (*Pinus palustris*) and slash (*P. elliotti*) pine and, in situations where the shrub layer is relatively open, a diverse herbaceous layer. This herbaceous layer contains a wide variety of grasses (e.g., *Agrostis*, *Andropogon*, *Aristida*, *Eragrostis*, *Panicum*, and *Paspalum* spp.). Common forbs include legumes (e.g., *Cassia*, *Crotalaria*, *Galactia*, *Tephrosia* spp.), milkweeds (*Asclepias* spp.), milkworts (*Polygala* spp.), and a wide variety of composites (e.g., *Aster*, *Chrysopsis*, *Eupatorium*, *Liatis*, and *Solidago* spp.). Understory and shrub species include saw palmetto (*Serenoa repens*), wax myrtle (*Morella cerifera*), gallberry (*Ilex gla-*

bra), fetterbush (*Lyonia lucida*), staggerbush (*Lyonia fruticosa*), dwarf huckleberry (*Gaylussacia dumosa*), dwarf live oak (*Quercus mimima*), and tarflower (*Bejaria racemosa*) (Abrahamson and Hartnett 1990). Flatwoods systems are defined by shallow, sandy soils over limestone caprock (Duever et al. 1986). Precipitation in central and southern Florida follows a pattern of rainy summers and dry winters, with precipitation falling primarily during June–September and averaging 135 cm/year. The annual average high temperature in the region is 32 C and annual average low temperature 11 C (NOAA 2014).

Methods

Experimental Design and Treatments

We used a paired sampling approach to assess the effects of treatment type on familial richness and relative abundance within six insect orders of interest. We compared richness and relative abundance between sampling points randomly located in paired treated and untreated flatwoods subplots. Approximately one-half of each of our 50 pine flatwoods study plots received treatment, while the other half remained untreated for comparison. Adjacent untreated control subplots were identical in terms of current and past management and environmental conditions (e.g., grazing regime, burn regime, plant community, and soil conditions), with the only difference being our treatment. We subjected treated subplots to one of five treatment types, which included 1) dormant season (November–March) roller chop, 2) growing season (April–October) roller chop, 3) dormant season burn, 4) growing season burn, or 5) dormant season roller chop followed by a burn within six months (hereafter referred to as roller chop/burn). Treatments were applied to subplots during the growing season of 2006 through growing season 2007. This resulted in 9–11 replicates of each treatment type.

Insect Sampling

Within each treated and paired control subplot, we established one randomly selected sampling point. If insects were clustered in subplots, one sampling point per subplot may not provide a truly representative estimate of insect richness and relative abundance. To minimize edge effects, we rejected and randomly relocated sampling points that fell within 50 m of the edge of a treatment or control site. We collected insects at sampling points once during winter (February–March), spring (April–May), and summer (July–August), during each of two years (2007–2008) following treatment. We subsampled insects occupying vegetation less than 30 cm above the ground from within four 1-m² quadrats, delineated using a plastic sampling frame, randomly located in each quadrant of a 0.03-ha nested circular plot centered on the sampling

point (Dueser and Shugart 1978, Higgins et al. 2005). We sampled insects using a suction sampler (Wright and Stewart 1992, Ausden 1996). Within each 1-m² quadrat, we turned the suction sampler on and systematically moved around the quadrat area, no more than 30 cm above the ground, for a three-minute period collecting insects. Suction sampling was conducted on days when vegetation was dry and had not been flattened by wind, rain, or trampling (Ausden 1996). We separated insects collected in each suction sample from coarse vegetation and combined them in a vial containing 75% ethanol and 25% distilled water (Schauff 1986).

We collected samples of mobile insects and insects occupying vegetation more than 30 cm above the ground along two perpendicular 20-m sweep net transects centered on the sampling point (Dueser and Shugart 1978, Ausden 1996, Higgins et al. 2005). We made 50 sweeps (one sweep comprising a forward and backward stroke of the sweep net) along each of the 20-m transects, ensuring the sweep net did not pass within 30 cm of the ground (Schauff 1986). Sampling quadrats and transects did not overlap and during insect collection the field crew made every effort to ensure they did not disturb areas still to be sampled. We combined and preserved insects collected in each sweep net sample as described for those collected using suction sampling. In the laboratory, we identified insects contained in each suction and sweep net sample to order and family level using a microscope and appropriate identification keys (Triplehorn and Johnson 2005)

Analyses

Relatively few insects were captured during sweep net sampling; therefore, prior to analyses, we combined data collected from suction and sweep-net samples for each subplot. We used a split-plot experimental design to examine fire and roller chopping treatments and their temporal effects on insects, including 1) within treatment effects—how insects responded to each treatment type seasonally and for two years post-treatment and 2) among treatment effects—how insect response varied among treatments seasonally and for two years post-treatment. We analyzed differences in total insect familial richness and relative abundance (all families combined) and familial richness and relative abundance within five of our six orders of interest. Insufficient Lepidoptera were captured to permit statistical analyses. We examined differences both within and among treatment types using repeated measures mixed model regressions. Repeated measures were season and time since treatment (time). Study site pair (i.e., paired treatment and control subplot) was included as a blocking factor to remove the effects of current and past management and environmental conditions (e.g., grazing regime, burn regime, plant community, and soil conditions). We used Fisher’s Protected LSD tests to make post hoc

comparisons and only present results for which a significant difference was found, based on these tests. We rank transformed all data prior to analyses to meet normality and homogeneity of variance assumptions (Conover 1998, Zar 1999, SYSTAT 2007). We concluded statistical significance for all tests at $P \leq 0.05$ (Zar 1999). All statistical tests were performed using SYSTAT (2007) statistical software.

Results

We collected 9442 insects from 13 orders and 120 families. Of these, 90% (n = 8473) belonged to our insect orders of interest, with 11% (n = 942) and 27 families being Coleoptera, 12% (n = 1027) and 29 families Diptera, 30% (n = 2511) and 33 families Hemiptera, 18% (n = 1528) and 14 families Hymenoptera, and 29% (n = 2465) and five families Orthoptera.

Treatment Only Effects

Treatment only effects on insect familial richness and relative abundance were observed for two years post-treatment, the length of time our study was conducted. Total insect relative abundance was 40% less in growing season burn than control subplots. Similarly, Hemiptera familial richness was 23% less and relative abundance 40% less in growing season burn than control sub-plots. Total insect familial richness was 15% less and total insect relative abundance 20% less in dormant season roller chop than control subplots. Hemiptera relative abundance was also 22% less in dormant season roller chop than control subplots for two years post-treatment (Table 1).

Table 1. Effects of treatment on arthropod richness and relative abundance in Florida flatwoods, 2007–2008.

Arthropod richness and abundance by treatment ^a	Treatment ($\bar{x} \pm SE$)		P
	Control	Treated	
Growing season burn			
Richness (no. of families)			
Hemiptera	2.2 ± 0.2	1.7 ± 0.2	0.021
Abundance (no. of individuals)			
Total	40.0 ± 4.2	24.0 ± 2.8	0.001
Hemiptera	6.3 ± 1.0	3.8 ± 0.7	0.002
Dormant season roller chop			
Richness (no. of families)			
Total	12.3 ± 0.6	10.4 ± 0.7	0.017
Abundance (no. of individuals)			
Total	37.0 ± 3.0	29.5 ± 3.1	0.032
Hemiptera	6.3 ± 0.7	4.9 ± 0.8	0.042

a. Only insect families with richness or relative abundance significantly ($P \leq 0.05$) affected by treatment presented.

Year*Treatment Interaction Effects

Year*treatment interaction effects on familial richness and relative abundance were observed the first year post-treatment only. Insect familial richness was 49% less and total insect relative abundance 64% less on dormant season burn than control subplots. Similarly, Diptera, Hemiptera, Hymenoptera, and Orthoptera familial richness was 64%, 62%, 45%, and 42% less, respectively, in dormant season burn than control subplots, and Hemiptera, Hymenoptera, and Orthoptera relative abundance was 74%, 73%, and 68% less, respectively, in dormant season burn than control subplots. Total insect familial richness was 56% less on growing season burn than control subplots (Table 2).

When treatment type comparisons were made, total insect familial richness was less in dormant and growing season burn and growing season roller chop compared to control subplots and total insect relative abundance was less in dormant and growing season burn compared to control subplots. Hemiptera relative abundance was less in dormant season burn and greater in growing season burn than control subplots. Hymenoptera relative abundance was less in dormant season burn and roller chop burn than control subplots. Orthoptera familial richness and abundance were less in growing season burn and dormant and growing season roller chop than control subplots. In situations where more than one treatment had an effect on familial richness or relative abundance, the effects of all treatments was similar, the exception begin Hymenoptera relative abundance, which was lower on dormant season burn than roller chop/burn subplots (Table 3).

Table 2. Effects of time*treatment interactions on arthropod familial richness and relative abundance in Florida flatwoods, 2007–2008.

Arthropod richness and abundance by treatment ^a	Time ^b	Treatment ($\bar{x} \pm SE$) ^c		P
		Control	Treated	
Dorman season burn				
Richness (no. of families)				
Total	1	13.8 ± 1.1A	7.0 ± 0.9B	≤0.001
	2	12.0 ± 1.1A	14.2 ± 1.0A	
Diptera	1	1.4 ± 0.2A	0.5 ± 0.1B	0.004
	2	1.3 ± 0.3A	1.5 ± 0.2A	
Hemiptera	1	2.6 ± 0.3A	1.0 ± 0.2B	0.003
	2	2.5 ± 0.3A	2.8 ± 0.3A	
Hymenoptera	1	1.1 ± 0.1A	0.6 ± 0.1B	0.009
	2	0.8 ± 0.1A	1.0 ± 0.2A	
Orthoptera	1	1.2 ± 0.2A	0.7 ± 0.1B	≤0.001
	2	1.5 ± 0.2A	1.9 ± 0.2A	
Abundance (no. of individuals)				
Total	1	51.4 ± 9.0A	18.3 ± 3.8B	≤0.001
	2	36.2 ± 5.6A	43.8 ± 5.2A	
Hemiptera	1	8.1 ± 1.8A	2.1 ± 0.6B	0.001
	2	6.3 ± 1.1A	7.0 ± 1.2A	
Hymenoptera	1	8.3 ± 3.1A	2.2 ± 0.7B	0.028
	2	2.4 ± 0.6A	3.3 ± 1.0A	
Orthoptera	1	4.0 ± 0.7A	1.3 ± 0.4B	≤0.001
	2	4.2 ± 0.8A	6.0 ± 1.0A	
Growing season burn				
Richness (no. of families)				
Total	1	13.4 ± 0.6A	5.9 ± 1.1B	0.017
	2	11.2 ± 0.6A	10.1 ± 0.8A	

a. Only arthropod families with richness or relative abundance significantly ($P \leq 0.05$) affected by a time * treatment interaction presented.
 b. Time since treatment application (years)
 c. Means in a row followed by the same uppercase letter not significantly different ($P > 0.05$).

Table 3. Comparison of the effects of time*treatment interactions on arthropod familial richness and relative abundance in Florida flatwoods, 2007–2008.

Arthropod richness and abundance ^a	Time ^b	Treatment ($\bar{x} \pm SE$) ^c				P		
		Control	Dormant burn	Growing burn	Dormant roller chop		Growing roller chop	Roller chop/burn
Richness (no. of families)								
Total	1	13.8 ± 0.5A	7.1 ± 0.9BD	6.1 ± 1.2B	9.4 ± 0.9AC	9.3 ± 1.1BC	9.8 ± 1.9AD	≤0.001
	2	11.7 ± 0.4A	14.3 ± 0.9A	10.3 ± 0.8A	11.4 ± 0.9A	11.1 ± 1.0A	13.0 ± 1.1A	
Hymenoptera	1	1.0 ± 0.1A	0.6 ± 0.1B	0.8 ± 0.2A	0.6 ± 0.2A	0.7 ± 0.1AB	0.7 ± 0.1A	0.006
	2	0.8 ± 0.1A	1.0 ± 0.2B	0.1 ± 0.1A	0.8 ± 0.1A	0.7 ± 0.2A	1.0 ± 0.2AB	
Orthoptera	1	1.9 ± 0.1A	0.7 ± 0.1B	0.6 ± 0.3B	1.9 ± 0.2A	1.7 ± 0.2B	1.4 ± 0.3A	≤0.001
	2	1.6 ± 0.1A	1.9 ± 0.2A	1.7 ± 0.2A	2.1 ± 0.2A	2.0 ± 0.3A	2.2 ± 0.2A	
Abundance (no. of individuals)								
Total	1	48.3 ± 4.0A	18.3 ± 3.8B	23.4 ± 5.7B	26.3 ± 3.7AB	40.6 ± 16.6AB	31.6 ± 9.4AB	≤0.001
	2	34.5 ± 2.1A	43.8 ± 5.2A	24.2 ± 3.3A	32.1 ± 4.8A	24.8 ± 2.8A	42.3 ± 7.3A	
Hemiptera	1	6.7 ± 0.8A	2.1 ± 0.6BC	1.7 ± 0.7B	3.3 ± 1.0AB	2.4 ± 1.0AB	6.1 ± 2.7AC	0.001
	2	6.4 ± 0.5A	7.0 ± 1.2A	4.6 ± 0.9A	6.3 ± 1.1A	7.0 ± 1.4A	7.8 ± 1.6A	
Hymenoptera	1	5.8 ± 1.2A	2.2 ± 0.7B	12.4 ± 4.0AC	3.5 ± 1.3AC	4.6 ± 1.7AC	3.1 ± 0.8C	0.041
	2	2.9 ± 0.6A	3.3 ± 1.0A	1.9 ± 0.7A	2.4 ± 0.8A	1.4 ± 0.4A	2.2 ± 0.7A	
Orthoptera	1	6.5 ± 0.5A	1.3 ± 0.4B	1.4 ± 0.9B	7.0 ± 1.2A	3.4 ± 0.7BC	4.0 ± 1.1AC	≤0.001
	2	5.3 ± 0.4A	6.0 ± 1.0A	4.8 ± 0.9A	7.9 ± 1.4A	5.1 ± 1.0A	11.3 ± 2.0A	

a. Only insect families with richness or relative abundance significantly ($P \leq 0.05$) affected by a time * treatment interaction presented.
 b. Time since treatment application (years).
 c. Means in a row followed by the same uppercase letter not significantly different ($P > 0.05$).

Season* Treatment Interaction Effects

Coleoptera relative abundance was 43% less in growing season burn than control subplots in spring and 106% greater on growing season burn than control subplots in summer. Similarly, Coleoptera familial richness was 47% less in roller chop/burn than control subplots in spring and 25% greater in roller chop/burn than con-

trol subplots in summer. Diptera familial richness was 14% greater on dormant season roller chop than control subplots in spring and 9% less on dormant season roller chop than control subplots in summer. In contrast, Diptera relative abundance was 18% less on dormant season roller chop than control subplots in spring but 28% greater in roller chop than control subplots in summer. Hymenoptera familial richness was also 7% less in dormant season roller chop than control subplots in spring (Table 4).

Table 4. Effects of season*treatment interactions on arthropod familial richness and relative abundance in Florida flatwoods, 2007–2008.

Arthropod richness and abundance by treatment ^a	Season	Treatment ($\bar{x} \pm SE$) ^b		P
		Control	Treated	
Growing season burn				
Abundance (no. of individuals)				
Coleoptera	Winter	0.7 ± 0.4A	3.1 ± 1.1A	0.003
	Spring	2.8 ± 0.5A	1.6 ± 0.6B	
	Summer	1.8 ± 0.5A	3.7 ± 1.3B	
Dormant season roller chop				
Richness (No. of families)				
Diptera	Winter	1.5 ± 0.3A	0.5 ± 0.2A	0.026
	Spring	0.7 ± 0.2A	0.8 ± 0.2B	
	Summer	1.1 ± 0.3A	1.0 ± 0.2B	
Hymenoptera	Winter	0.5 ± 0.1A	0.5 ± 0.1A	0.005
	Spring	1.5 ± 0.2A	0.5 ± 0.2B	
	Summer	1.1 ± 0.2A	1.1 ± 0.1A	
Abundance (no. of individuals)				
Diptera	Winter	2.5 ± 0.6A	0.6 ± 0.3A	0.009
	Spring	1.1 ± 0.5A	1.0 ± 0.2B	
	Summer	1.8 ± 0.5A	2.3 ± 0.7B	
Roller chop/burn				
Richness (no. of families)				
Coleoptera	Winter	0.5 ± 0.2A	1.2 ± 0.3A	0.016
	Spring	1.7 ± 0.3A	0.9 ± 0.2B	
	Summer	0.9 ± 0.2A	1.2 ± 0.2A	

a. Only arthropod families with richness or relative abundance significantly ($P \leq 0.05$) affected by a season*treatment interaction presented.

b. Means in a row followed by the same uppercase letter not significantly different ($P > 0.05$).

When treatment type comparisons were made, Hymenoptera familial richness was lower on dormant season burn, dormant season roller chop, and roller chop/burn than control subplots in spring. However, the effects of all treatments was similar (Table 5).

Discussion

Generally, total insect familial richness and relative abundance in Florida flatwoods were less following prescribed burning and roller chopping treatments. There was greater variability in response to these treatments when individual insect orders of interest were examined. However, in the majority of instances where reductions in total or order level familial richness or relative abundance was observed, changes were frequently short-lived, only occurring the first year post-treatment. In situations where total or order level familial richness or relative abundance were affected by multiple prescribed burning or roller chopping treatments, the effects of all treatments tended to be similar.

Dormant and growing season burning caused reductions in total insect familial richness and relative abundance. Within dormant season burn subplots, these reductions were relatively short-lived, occurring only during the first year post-treatment. However, within growing season burn subplots reductions in relative abundance were more prolonged, lasting for two years post-treatment. These findings do not support the suggestion that southeastern flatwoods insects survive and recolonize best following growing season burning, a period when they are most mobile (Hall and Schweitzer

Table 5. Comparison of the effects of season*treatment interactions on arthropod familial richness and relative abundance in Florida flatwoods, 2007–2008.

Arthropod richness and abundance ^a	Season	Treatment ($\bar{x} \pm SE$) ^b					P	
		Control	Dormant burn	Growing burn	Dormant roller chop	Growing roller chop		Roller chop/burn
Richness (no. of families)								
Hymenoptera	Winter	0.7 ± 0.1ABC	0.6 ± 0.1A	0.7 ± 0.2BC	0.5 ± 0.1A	1.2 ± 0.3C	1.2 ± 0.3C	0.001
	Spring	1.1 ± 0.1A	1.0 ± 0.2B	0.7 ± 0.3A	0.5 ± 0.2B	0.4 ± 0.2A	0.6 ± 0.2B	
	Summer	0.9 ± 0.1AB	0.7 ± 0.1AB	0.6 ± 0.1A	1.1 ± 0.1B	0.8 ± 0.1AB	0.9 ± 0.1AB	
Abundance (no. of individuals)								
Coleoptera	Winter	1.0 ± 0.2A	1.5 ± 0.3A	0.6 ± 0.2A	0.7 ± 0.3A	0.5 ± 0.3A	3.1 ± 1.1B	0.086
	Spring	1.8 ± 0.2A	2.4 ± 0.5A	0.7 ± 0.3A	1.4 ± 0.6A	1.4 ± 0.8A	1.6 ± 0.6A	
	Summer	3.3 ± 0.6AB	4.0 ± 0.8AB	1.3 ± 0.3A	4.3 ± 1.4AB	2.6 ± 0.7B	3.7 ± 1.3AB	

a. Only arthropod families with richness or relative abundance significantly ($P \leq 0.05$) affected by a season*treatment interaction presented.

b. Means in a row followed by the same uppercase letter not significantly different ($P > 0.05$).

1992). In contrast, insects may be better able to survive dormant than growing season burning. Insect mobility can differ between seasons. During the dormant season, many insects are in an inactive or immature phase beneath the soil (Swengel 2001). Soil has insulating properties (Pyke et al. 2010) and even when fuel loads and fire intensity are high, soils of pine flatwoods do not reach lethal temperatures (60 C; Kreye et al. 2013). Therefore, insects buried beneath the soil are likely protected from the heat of a fire (Swengel 2001). Insects that are in an inactive or immature phase beneath the bark of pine trees during the dormant season may be similarly protected from the heat of a fire, as a result of the insulating properties of their bark (Hare 1965, Fernandes 2008). During the growing season, many insects are active above the soil surface, often in the litter, where they are not protected from a fire (Swengel 2001). Studies in the oak-pine forests of the mid-South have found significant declines in litter-dwelling arthropod abundance following early growing season burning (Coleman and Rieske 2006), supporting our findings.

Examination of insect orders of interest indicated that dormant season burning led to short-term reductions in Diptera, Hemiptera, Hymenoptera, and Orthoptera familial richness or relative abundance that lasted for the first year post-treatment, although growing season burning had a more prolonged effect on Hemiptera relative abundance that lasted for two years post-treatment. The majority of Orthopterans are voracious plant feeders and can be negatively affected by fire due to a reduction in herbaceous plant foods (Evans 1984). Dormant and growing season burning have both been found to cause reductions in graminoid and forb height and cover on pine flatwoods sites for at least the first year post-treatment (Willcox and Giuliano 2012). Reduced Orthopteran numbers following burning have also been attributed to reduced litter cover (Tester and Marshall 1961). Reductions in litter depth and cover are considerable following prescribed burning of pine flatwoods systems and can be prolonged, lasting for at least two years post-treatment (Willcox and Giuliano 2012). Accumulation of litter has been found to restore Orthoptera populations within one year of treatment (Tester and Marshall 1961). Other studies suggest that Orthoptera abundance may increase on burned sites in the first to second year post-treatment (Nagel 1973, Reed 1997, Chambers and Samways 1998). Short-term reductions in Hemiptera abundance have been observed following burning (Morris 1975, Anderson et al. 1989). Like Orthoptera, many Hemiptera are reliant on herbaceous vegetation as a food source (Warren et al. 1987) and burning significantly alters availability of graminoids and forbs (Willcox and Giuliano 2012). The majority of Hemiptera occupy above-ground, live vegetation (Warren et al. 1987) and, as a result, the loss of litter following burning may not be such a con-

cern. In other studies, Hemiptera abundance has been found to be greater on burned areas in the short and/or intermediate term (Rice 1932, Cancelado and Yonke 1970, Hurst 1971). In the case of Hymenoptera, declines in abundance have been observed in the short-term, potentially again, as a result of the loss of aboveground vegetation need by pollinating species (Bulen and Barrett 1971). However, increases in predaceous species often occur, presumably because of greater numbers and vulnerability of prey on burned areas (Van Amburg et al. 1981). Other studies indicate an increase in Hymenoptera abundance on burned areas a few months following treatment (Hurst 1971, Nagel 1973).

Dormant season roller chopping led to reductions in total insect familial richness and relative abundance and Hemiptera relative abundance that lasted for two years post-treatment. In contrast, growing season roller chopping had no effect on total or order-level familial richness or relative abundance. Roller chopping causes significant disturbance to the soil and vegetation, and significantly reduces litter depth and cover (Willcox and Giuliano 2012). As mentioned previously, during the growing season, most insects are active aboveground and are likely able to flee roller chopped areas when soil, litter, and vegetation conditions become unsuitable. However, during the dormant season, many insects are inactive or in an immature phase beneath the soil, litter, or woody debris (Swengel 2001) making them more susceptible to a passing roller chopper, and resulting unsuitable soil and litter conditions, during this period.

Roller-chopping/burning had an effect on Coleoptera richness during certain seasons with reductions observed on treated compared to control subplots in spring. However, generally this order was unaffected by prescribed burning and roller chopping treatments. Campbell et al. (2008) found prescribed fire treatments did not have an effect on Coleoptera abundance, although species richness was significantly greater on sites that were thinned and burned. However, the effects of fire and mechanical treatments on this order are equivocal with Campbell et al. (2007), who found significantly higher richness and abundance of Coleoptera on thinned and burned sites in oak forests of North Carolina, and with Niwa et al. (2002), who found that certain Coleoptera species were more abundant on unburned sites.

Management Implications

In situations where management of total insect familial richness and relative abundance, or familial richness and relative abundance of the Hemiptera, is a priority, the application of dormant season roller chopping and growing season burning should be avoided. However, as reductions are only observed the first-year post-treatment, their use may not be a concern when managing for Diptera,

Hymenoptera, and Orthoptera familial richness and relative abundance. Insect sampling at study sites was limited and results should be interpreted cautiously. However, they suggest that to help minimize the negative impacts of prescribed burning and roller chopping practices on certain orders of insects important as pollinators or avian prey, it may be best to implement treatments in a mosaic across the landscape; leaving untreated areas adjacent to treated areas to serve as refugia may be beneficial to some orders. Future research should take into account the relative value of all insects and how they are affected by prescribed burning and roller chopping activities to allow treatment application to be appropriately tailored to benefit desired orders or families.

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