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Effects of prescribed fire and fire surrogates on floral visiting insects of the blue ridge province in North Carolina

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ABSTRACT

Pollination by insects in forests is an extremely important process that should be conserved. Not only do pollinating insects help to maintain a diversity of plants within forests, but they also aid in pollinating crops found near forested land. Currently, the effects of various forest management practices on floral visiting insect abundance or diversity is unknown, so we investigated how prescribed burning, mechanical shrub control, and combination of the two affected abundance of floral visiting insects. We caught 7921 floral visitors from four orders and 21 families. Hymenoptera was the most abundant and diverse order, with Halictidae being the most abundant family. A total of 45 species of Hymenoptera representing six families were captured. We caught seven families and 35 species of Lepidoptera, six families and 33 species of Coleoptera, and two families and 13 species of Diptera. Most floral visitors were captured in the mechanical shrub control plus prescribed burn treatments, while lower numbers were caught on the mechanical shrub control only, prescribed burn only and control treatments. Overall species richness was also higher on mechanical plus burn treatments. Total pollinator abundance and the abundance of most orders and families was correlated with decreased tree basal area and increased percent herbaceous plant cover. Our study shows that floral visitors increased in abundance and species richness most from forest disturbance that reduced the density of overstory trees and increased the amount of herbaceous plant growth.

1. Introduction

Pollination by insects is vital for maintaining plant diversity in forests. Approximately 67% of all flowering plants depend on insects for pollination needs (Kearns and Inouye, 1997), and nearly 75% of all plants in a longleaf pine (*Pinus palustris*) habitat are insect pollinated (Folkerts et al., 1993). Habitat fragmentation, land-use changes, agricultural practices, use of pesticides and herbicides, and exotic species invasions are some of the threats that pollinators face (Kevan, 1975; Johansen, 1977; Kearns et al., 1998; Delaplane and Mayer, 2000; Kremen et al., 2002; Ricketts, 2004). Likewise monocultures of various crops have negative impacts on pollinators (Kearns et al., 1998; Cane and Tepedino, 2001). These monocultures lack the diversity of plants necessary to sustain bees and other pollinating insects throughout the growing season. Exotic species have also become a problem in many areas. For example, bumblebee introduction in some areas has caused declines of native species (Kearns et al., 1998) and honey bees, *Apis mellifera*, which are considered to be major pollinators of food crops, may compete for pollen and nectar with smaller native bees (Roubik, 1978; Schaffer et al., 1983; Folkerts

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et al., 1993; Paton, 1993; Goulson, 2003). Exotic crop monocultures may attract pollinators away from natives (Williams et al., 1991) or act as barriers to dispersal (Milet-Pinheiro and Schlindwein, 2005). In recent years, honeybee populations and beekeeping have declined due to parasites, insecticides, and Africanized honeybee spread (Allen-Wardell et al., 1998; Kearns et al., 1998; Kremen et al., 2002; USDA National Agricultural Statistics Service Honey Production Reports, 1977, 2006). As these declines continue, native pollinators will become more important for pollination services.

It is clear that pollinators are important for crop production and that the presence of forests and natural areas can improve pollination of nearby crops by native bees (Kremen et al., 2002; Klein et al., 2003; Ricketts et al., 2004). This increasing evidence of native bee importance as well as evidence suggesting a pollinator decline throughout the world (Janzen, 1974; Gess and Gess, 1993; Vinson et al., 1993; Buchmann and Nabhan, 1996; Kearns and Inouye, 1997) emphasizes our need to understand pollinator communities in natural areas. Currently, information about insect pollinator diversity and abundance in many areas is poorly known. This is particularly true for forested regions of the southeastern United States, due in part to a focus on tropical regions and agricultural fields.

The southern Appalachian region has a high diversity of plants and other organisms and is considered to be a hot spot for endangered species (Dobson et al., 1997), which should make this an area of high priority for ecological research. Research in other regions indicates that wild populations of pollinators have declined in numbers and have reduced ranges, which has caused some plants to show signs of pollinator limitation (Buchmann and Nabhan, 1996; Kearns and Inouye, 1997). Not only does this limit the actual population of various plants, but also may result in less vigorous offspring due to a higher percentage of seeds being produced through self-pollination or limited pollen competition due to smaller pollen loads delivered to the plant (Kearns and Inouye, 1997). A greater knowledge of the diversity, abundance, and ecology of native pollinators in forests of the southeastern United States is essential for the development of conservation strategies.

As part of this effort it is important to understand how forest management practices affect pollinators and floral visitors. For example, prescribed burning is an important management tool used in forests throughout the southeastern United States for controlling midstory trees and shrubs, restoring understory plant communities, and reducing fuel buildup and subsequent wildfire risks. However, increasing human populations in and around forested areas could make prescribed burnings unpopular in the near future (Strohmaier, 2000). Therefore, mechanical or chemical methods such as mechanical brush reduction or use of herbicides could be employed more frequently in the future to avoid problems associated with the use of prescribed fire. Due to the importance of pollinators, land management practices in forested areas should try to minimize disruption of pollinating systems. While much research that has dealt with insects and fire describes the usefulness of fire in killing or depressing insect pests, other researchers have explored the effects of fire on numerous other arthropod groups (Warren et al., 1987; Anderson et al., 1989; Fischer et al., 1996; Siemann et al., 1997; McCullough et al., 1998; Zimmer and Parmenter, 1998; Ne'eman et al., 2000; Hanula and Wade, 2003). Potts et al. (2003) showed bee communities sharply decline immediately after a fire but rebound quickly and become very diverse during the first two years post fire in a chaparral biome. However, little is known about how fire or other techniques used to reduce fuel affect pollinating insect populations and diversities in the southeastern United States.

Fire could affect important pollinators, such as butterflies and bees, either directly by fire-related mortality or indirectly by limiting flower resources (Hermann et al., 1998). For example, in prairie regions fire negatively affected abundance and diversity of some butterflies (Swengel, 1996). In the Mediterranean region, solitary bees were nearly absent from burned areas due to direct mortality from fire or indirectly from limited nectar sources (Ne'eman et al., 2000). However, plant diversity and growth have been shown to be positively affected by the intensity and frequency of wildfires (Kerstyn and Stiling, 1999). In some areas, periodic burnings help maintain plant diversity, protect some plant species from diseases, and allow perennial grasses and herbaceous plants to grow (Waldrop et al., 1992; Kerstyn and Stiling, 1999). Fire is also important for inducing flowering in many plants, increasing germination, and freeing mineral nutrients for plant uptake (Brewer and Platt, 1994). Nesting resources (sites and suitable soil) for many ground nesting bees could also be affected by fires. However, Potts et al. (2005) found increased abundance of ground nesting bees in recently burned areas due to increased bare ground available for nesting. Therefore, fire could benefit pollinators, but its effect on these insects has not been widely studied.

Likewise, alternatives to fire such as mechanical thinning and herbicide use could impact pollinators. The amount of sunlight received and the locality of plants may be extremely important in determining a plant's chances for being pollinated by insects (Beattie, 1971). Prescribed burns and other alternatives will undoubtedly affect the amount of sunlight reaching the forest floor and change the locations and diversity of understory plant communities.

The objectives of our study were to determine how various groups of pollinating insects vary in abundance and species richness in response to several forest management options. We were particularly interested in whether fuel reduction treatments, that act as surrogates for fire, would have similar effects as fire alone, and whether any differences we observed among treatments would be immediate or delayed. These data will provide a better understanding of interactions between insect pollinators, plants, and management within forested ecosystems.

2. Materials and methods

Our study was part of the National Fire and Fire Surrogate Study designed to examine the impacts of fuel reduction treatments on multiple components of forested ecosystems across the United States (Youngblood et al., 2005). We sampled pollinating insects on three study blocks on the Green River Game Management Area in the Blue Ridge Mountain Province near Hendersonville, NC (Polk and Henderson counties). This forest is managed by the North Carolina Wildlife Resources Commission which sponsors programs that promote conservation and wise use of the state's natural resources, and provides assistance for landowners wishing to manage wildlife on their lands. The Green River Game Land encompasses 5841 ha and is managed for game habitat and ecosystem restoration.

Twelve study plots were selected on the basis of size, stand age, cover type and management history. Each site had to be a minimum of 14 ha to allow for a 10 ha measurement area and a buffer of at least one tree length (approximately 20 m) around the measurement area. Selected sites were judged to be in danger of uncharacteristically severe wildfire due to heavy fuel loads. None had been thinned during the past 10 years and none had been burned (wild or prescribed) in at least five years. Stand ages varied from 80 to 120 years. Oaks dominated all sites including northern red oak (*Quercus rubra*), chestnut oak (*Quercus prinus*), white oak (*Quercus alba*), and black oak (*Quercus velutina*). Other common species included pignut hickory (*Carya glabra*), mockernut hickory (*Carya tomentosa*) and shortleaf pine (*Pinus echinata*). A thick shrub layer, primarily mountain laurel (*Kalmia latifolia*) and rhododendron (*Rhododendron maximum*), occurred on approximately one-half of the study area.

The study was a randomized complete block design consisting of three blocks of four treatments each. Treatments were applied to 10 ha plots and consisted of: (1) untreated, (2) mechanical (3) mechanical plus dormant season burn, and (4) dormant season burn. Although we refer to the untreated plots as a control, we consider them to be another treatment because historically this area has been burned and managed. The mechanical treatments consisted of chainsaw felling and sectioning or limbing of the shrub understory, which was primarily composed of rhododendron, mountain laurel and small diameter trees (<7.5 cm). The cut material was left in place. The mechanical plus burn plots were treated the same way and then burned. Shrubs were cut during the winter, 2001–2002, and plots that were burned were treated on March 12 or 13, 2002. One block was burned by hand ignition using spot fire and strip-headfire techniques. The other blocks were ignited by helicopter using a spot fire technique. Fire intensity was moderate to high with flame lengths of 1–2 m throughout the burn unit, but flames reached as high as 5 m in localized spots where topography or intersecting flame fronts contributed to erratic fire behavior. Each plot was marked by grid points with 50 m between points to facilitate pre- and post-treatment sampling.

We used pan traps and color malaise traps to capture pollinating insects. Details of traps and procedures are provided in Campbell (2005). Pan traps consisted of 532 ml plastic bowls (Solo™) of different colors filled approximately 3/4th full with water to which several drops of unscented dishwashing detergent was added to reduce surface tension. White, blue, and yellow bowls were chosen because they represented common floral colors and have been shown to be efficient at catching large numbers and diversities of floral visiting insects (Campbell, 2005). The bowls were held approximately 0.5 m above the ground with aluminum wire. The wire was inserted into the ground with the above ground end bent into a loop that held the bowls. We used Sante Traps (Lexington, KY) canopy malaise traps, which caught insects from all directions and had collection containers at the top and bottom. Three meter tall metal conduit poles were used to suspend the traps. A 0.5 m long pipe larger in diameter than the conduit pole was hammered into the ground and the bottom end of the 3 m conduit pole was inserted inside it to hold up the pole and malaise trap. In addition, malaise traps had four cloth, solidly colored (red, white, blue, and yellow) panels (0.3 m^2 each) pinned onto each side (one color/side) of the malaise trap. The collecting containers were filled approximately 1/3rd full with a soapy water solution. Samples from pan traps and malaise traps were immediately stored in 70% alcohol.

At each plot we used five sets of bowls, with a set consisting of one bowl of each color, and one color malaise trap. The bowls and color malaise traps were all placed at different grid points near the center of each plot in order to minimize edge effects. The central grid points were chosen, and bowl or malaise traps were placed randomly at one of these center grid points. The three bowls at any given grid point were placed approximately one meter apart. Traps were operated at 4–6 week intervals from April to October of 2003 and 2004. We trapped five times in 2003 and six times in 2004 with each trapping period lasting seven days.

Butterfly surveys were conducted each time we operated the traps. The survey consisted of slowly walking four grid points (200 m) and identifying and counting each butterfly seen. Butterfly counts during transect walks have been used effectively to evaluate abundance and diversity (Pollard, 1977; New et al., 1995; Brown and Boyce, 1998). Surveys were done between 10a.m. and 3a.m. and only on days that had normal temperatures and weather (i.e., rainfall, wind, etc.) for the corresponding time of year. Butterfly surveys allowed us to note species that were not being captured in the bowl or malaise traps and to better estimate species richness for this group.

Floral visitors are organisms that visit flowers for nectar or pollen, but may or may not pollinate certain plant species. Because we did not measure pollination effectiveness among the plants and insects, the insects we captured and included in our analysis can be thought of as floral visitors. However, we use these terms interchangeably. Numerous insects (other than pollinators/floral visitors) were caught in our traps, but were not used in our analysis. We determined floral visitors based upon published literature and field observation. If certain species of insects were noticed actively visiting flowers, we included them in the analysis even if there was little evidence of flower visiting or pollination behavior in the literature. We identified captured insects to the lowest taxonomic level possible.

The density of trees remaining on the plots was estimated by measuring tree basal area (Avery, 1975) on ten 0.2 ha subplots within each 10 ha treatment plot. Basal area was measured in 2001 (pre-treatment) and in 2004–2005 (post-treatment). Because basal area should increase with time in undisturbed stands, we used change in basal area (post-treatment minus pre-treatment basal area) as an indicator of treatment effects on dominant trees. Herbaceous plant cover was estimated on 200 1 m^2 subplots within each 10 ha treatment plot and was categorized within a series of ranges: <1%, 1–10%, 11–25%, 26–50%, 51–75%, and >75%. We used the midpoint of each range to calculate plant cover per m^2 for the treatment plots.

Data were analyzed using PROC GLM (SAS, 1985) to conduct two-way ANOVAs with replications and treatments as dependent variables, and the various orders and families of floral visitors as independent variables. The Ryan–Einot–Gabriel–Welsch (REGWQ, SAS, 1985) multiple range test was used to determine differences in relative abundances and diversities of pollinators between treatments. Square-root transformation was used to assure normality and homogeneity of variance. All abundance tests were run separately for each year since the treatments were dynamic and plots changed with time. To help explain differences in pollinator abundance we used the GLM procedure to calculate simple linear regressions of total pollinators and various pollinator groups versus change in basal area and percent plant cover. We also regressed percent plant cover versus change in basal area to determine the relationship between them.

3. Results

3.1. *Overall abundance and species richness*

We caught 7921 floral visitors from four orders and 21 families. Hymenoptera was the most abundant and diverse order (56.8% of the total floral visitors captured), with Halictidae being the most abundant family. Six families and 45 species of Hymenoptera were caught. We caught seven families and 35 species of Lepidoptera (comprising 7% of the total floral visitors), six families and 33 species of Coleoptera (12.5% of the total floral visitors), and two families and 13 species of Diptera (23.6% of the total floral visitors). Table 1 lists the genera and species captured during the study.

Most floral visitors were captured in the mechanical plus burn treatments (Fig. 1), while similar numbers were caught on the mechanical only, burn only, and control treatments. Overall species richness was also higher on mechanical plus burn treatments compared to other treatments (Fig. 2).

Regression analysis of change in basal area and percent plant cover found a relationship of increased plant cover with decreasing basal area (Fig. 3). Total pollinator abundance also increased as percent plant cover increased ($r^2 = 0.71$) or as basal area decreased ($r^2 = 0.58$) (Figs. 4 and 5).

3.2. *Hymenoptera*

Hymenoptera were significantly higher in abundance on mechanical plus burn treated plots in 2003 and 2004 (Table 2). In 2003, Halictidae was the most commonly captured family of Hymenoptera, and both Halictidae ($p < 0.05$) and Anthophoridae ($p \leqslant 0.085$) were captured in significantly higher numbers on mechanical plus burn treatments in 2003. In 2004, Halictidae, Apidae, and Sphecidae were significantly higher in abundance on mechanical plus burn treatments (Table 2). Species richness of Hymenoptera was also higher on mechanical plus burn treatments (Table 3). Total Hymenoptera, and the Halitidae, Apidae, and Sphecidae, were correlated with change in basal area and percent plant cover (Table 4). In every case, abundance of the various groups increased with decreasing basal area and increasing plant cover. Only the Anthophoridae were not correlated with these variables.

3.3. *Diptera*

The mechanical plus burn treated plots had significantly higher numbers of Diptera in 2003 and 2004 compared to the other treatments (Table 2), but species richness of Diptera was similar among treatments (Table 3). Syrphidae was the most common family of floral visiting Diptera comprising 99% of the total caught. Diptera abundance was correlated with change in basal area and percent plant cover with the later explaining 70% of the variation in the data.

3.4. *Coleoptera*

Coleoptera (Table 2) were significantly higher in abundance on the mechanical plus burn treated plots in 2003 ($p \leqslant 0.079$) and 2004 ($p < 0.05$). Species richness (Table 3) was also significantly higher on mechanical plus burn treated plots. No differences among treatments were observed at the family level except for Scarabaeidae in 2004 (Table 2). In general, other families (Mordellidae, Buprestidae, and Cerambycidae) were somewhat higher in numbers on the mechanical plus burn plots but the differences were not significant. In 2003, there was no dominant family among the catches, but in 2004 scarabs (primarily *Cremastocheilus* spp.) dominated the Coleoptera caught on mechanical plus burn treatments. All Coleoptera combined, as well as Mordellidae, and Scarabaeidae were correlated with change in basal area and percent herbaceous plant cover (Table 4). The Cerambycidae were only correlated with percent plant cover. In every case where a significant correlation occurred, beetle abundance increased with decreasing basal area and increasing herbaceous plant cover.

3.5. *Lepidoptera*

Lepidoptera were slightly higher in abundance on mechanical plus burn treated plots in both years but there were no significant differences among treatments (Table 2). Species richness was significantly higher ($p \leqslant 0.07$) on the mechanical plus burn treatment plots than on the mechanical only or control plots (Table 3). Walking transect surveys of butterflies showed no differences among the treatments. Although we only observed 15 species of butterflies during the surveys, a few species were seen that were not captured in the traps (Table 1). The majority of butterflies observed during the surveys were seen during the spring when mountain laurel (*Kalmia latifolia*) and *Rhododendron* spp. were flowering. Hesperiidae (mostly *Thorybes* spp.) was the most common family captured in traps on all treatments, but they were rarely seen during the surveys. In general, Lepidoptera abundance was correlated with change in basal area and percent herbaceous plant cover, as were the Papilionidae. However, the most abundant family, Hesperiidae, were only correlated with change in basal area. In every case they followed the same trend of increasing abundance with decreasing basal area and increasing plant cover.

Table 1 – Insect genera and species and total numbers captured in all traps or observed during butterfly transect surveys on all 10 ha plots that received various combinations of mechanical shrub control and prescribed burning on the Green River Game Management Area near Hendersonville, NC

Order	Family	Genus/species	Total captured	Total observed on walking transects
Hymenoptera	Andrenidae	*Perdita* sp. 1	2	
		Perdita sp. 2	1	
	Anthophoridae	*Anthophora abrupta*	16	
		Anthophora sp. 1	3	
		Ceratina cockerelli	125	
		Ceratina sp. 1	6	
		Melissodes sp. 1	4	
		Melissodes sp. 2	7	
		Melissodes sp. 3	54	
		Melitoma taurea	1	
		Melitoma sp. 1	3	
		Ptilothrix bombiformis	1	
		Svastra spp.	3	
	Apidae	*Apis mellifera*	9	
		Bombus impatiens	8	
		Bombus pennsylvanicus	2	
		Bombus vagans	127	
		Bombus virginica	6	
		Psithyrus variabilis	8	
	Halictidae	*Agapostemon sericeus*	2	
		Augochloropsis metallica	533	
		Dialictus sp. 1	2817	
		Dialictus sp. 2	106	
		Dialictus sp. 3	4	
		Dialictus sp. 4	104	
		Evylaeus spp.	160	
		Halictus parallelus	1	
		Lasioglossum spp.	133	
		Nomia spp.	72	
		Sphecodes sp. 1	2	
		Sphecodes sp. 2	1	
		Sphecodes sp. 3	4	
		Unknown sp.	2	
	Megachilidae	*Dianthidium* spp.	3	
		Heriades carinata	3	
		Hoplitis producta	5	
		Megachile mendeca	17	
		Megachile sp. 1	3	
		Osmia georgica	12	
		Osmia lignaria	37	
		Osmia sp. 1	1	
		Unknown sp.	1	
	Sphecidae	*Ammophila aureonotata*	48	
		Ammophila urnana	35	
		Isodontia spp.	3	
		Sphecinae sp. 1	3	
		Sphecinae sp. 2	2	
Diptera	Bombyliidae	*Anthrax argyropygus*	5	
		Anthrax irroratus	1	
		Bombylius major	16	
		Villa spp.	1	
	Syrphidae	*Chalcosyrphus* spp.	170	
		Milesia virginiensis	19	
		Ocyptamus spp.	3	
		Platycheirus quadratus	4	
		Sphegina spp.	1	
		Syrphus torvus	45	
		Syrphus sp. 1	31	
		Toxomerus geminatus	1570	
		Toxomerus sp. 1	1	

(continued on next page)

Table 1 – *continued*

Order	Family	Genus/species	Total captured	Total observed on walking transects
Coleoptera	Buprestidae	*Acmaeodera spp.*	69	
		Agrilus sp. 1	12	
		Agrilus sp. 2	1	
		Buprestis sp. 1	12	
		Brachys spp.	1	
		Chrysobothris sp. 1	13	
		Chrysobothris sp. 2	1	
	Cantharidae	*Chauliognathus*	2	
	Cerambycidae	*Cyrtophorus spp.*	9	
		Judolia cordifera	10	
		Leptura lineola	8	
		Leptura plebeja	4	
		Leptura subhamata	13	
		Leptura sp 1	6	
		Stranglia luteicornis	140	
		Stranglia sp. 1	1	
		Stranglia sp. 2	1	
		Typocerus zebratus	11	
		Typocerus sp. 1	1	
		Typocerus sp. 2	3	
		Typocerus sp. 3	15	
	Meloidae	*Epicauta pennsylvanica*	5	
	Mordellidae	*Mordella marginata*	23	
		Mordella sp. 1	54	
		Mordella sp. 2	54	
		Mordella sp. 3	1	
		Mordella sp. 4	2	
		Mordella sp. 5	1	
		Mordellistena spp.	226	
	Scarabaeidae	*Cremastocheilus* spp.	281	
		Trichiotinus spp.	2	
		Trigonopeltastes delta	10	
		Valgus spp.	3	
Lepidoptera	Hesperiidae	*Aescalapius* spp.	7	
		Amblyscirtes aesculapius	13	
		Amblyscirtes sp. 1	2	
		Atalopedes campestris	6	
		Epargyreus clarus	124	4
		Erynnis spp.	24	
		Hesperia spp.	5	
		Nastra spp.	16	
		Poanes yehl	11	
		Poanes zabulon	17	
		Polites spp.	5	
		Thorybes spp.	163	11
		Unknown sp.	3	4
	Lycaenidae	*Everes comyntas*	1	
		Satyrium calanus	2	
		Satyrium sp. 1	1	3
		Strymon spp.	9	
		Unknown sp.	0	2
	Nymphalidae	*Limenitis arthemis*	0	3
		Phyciodes tharos	2	
		Polygonia sp.	1	7
		Speyeria diana	0	4
		Vanessa atalanta	0	1
		Vanessa cardui	1	1
	Papilionidae	*Battus philenor*	8	1
		Eurytides marcellus	3	4
		Papilio glaucus	48	9
		Papilio Troilus	60	16

Table 1 – *continued*

Order	Family	Genus/species	Total captured	Total observed on walking transects
	Pieridae	*Colias philodice*	2	
	Satyridae	*Cyllopsis gemma*	2	
		Enodia portlandia	1	3
		Hermeuptychia hermes	6	
		Unknown sp.	2	
	Sphingidae	*Darapsa pholus*	4	
		Deidamia inscripta	4	
		Hemaris diffinis	1	
		Sphecodina abbottii	1	
		Sphinx spp.	3	
		Unknown sp.	1	

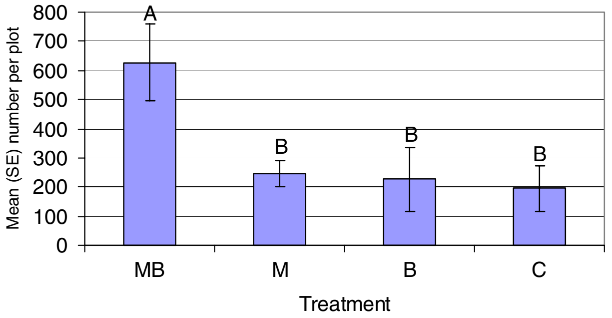

Fig. 1 – Mean number (SE) of floral visiting insects captured per plot during 2003 and 2004 on 10 ha plots receiving fire or fire surrogate treatments applied to a forested habitat on the Green River Game Management Area, near Hendersonville, N.C. Columns with the same letter are not significantly different at $p \leqslant 0.05$ (REGWQ, SAS 1985). Treatments were: MB = mechanical shrub control plus burn, M = mechanical shrub control, B = burn, C = control.

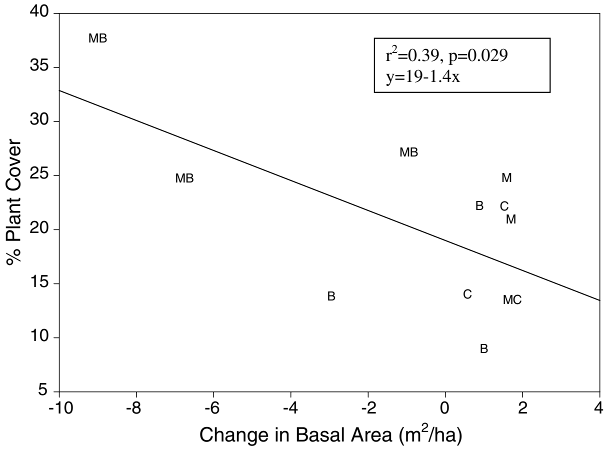

Fig. 3 – Linear regression of percent plant cover and change in basal area for 10 ha plots receiving various combinations of prescribed fire and mechanical brush removal. Negative numbers indicate a post-treatment decrease in basal area. Treatments were: MB = mechanical shrub control plus burn, B = burn only, M = mechanical shrub control, and C = control.

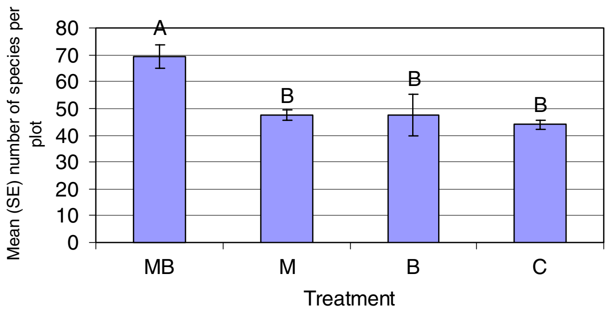

Fig. 2 – Mean number of species (SE) per plot of floral visiting insects captured during 2003 and 2004 on 10 ha plots receiving fire or fire surrogate treatments applied to a forested habitat on the Green River Game Management Area, near Hendersonville, NC. Columns with the same letter are not significantly different at $p \leqslant 0.05$ (REGWQ, SAS 1985). Treatments were: MB = mechanical shrub control plus burn, M = mechanical shrub control, B = burn, C = control.

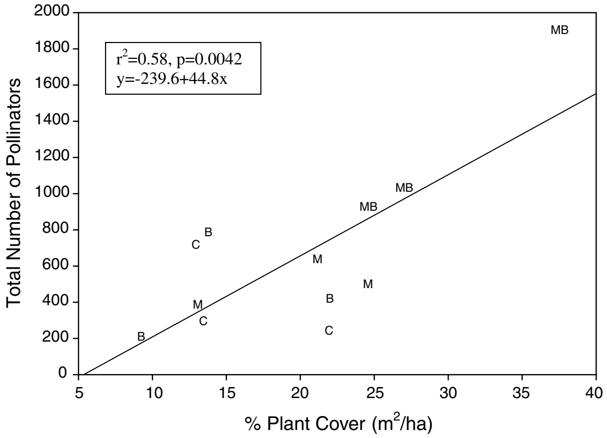

Fig. 4 – Linear regression of total pollinators captured in pan and malaise traps and percent herbaceous plant cover for 10 ha plots receiving various combinations of prescribed fire and mechanical brush removal. Treatments were: MB = mechanical shrub control plus burn, B = burn only, M = mechanical shrub control, and C = control.

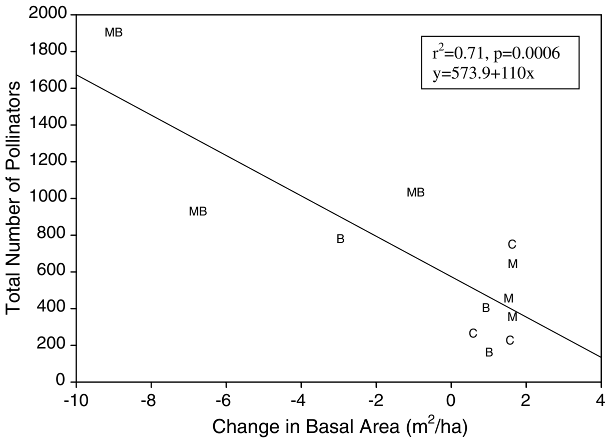

Fig. 5 – Linear regression of total pollinators captured in pan and malaise traps and change in basal area of 10 ha plots treated with various combinations of prescribed fire and mechanical brush removal. Negative numbers indicate a post treatment decrease in basal area. Treatments were: MB = mechanical shrub control plus burn, B = burn only, M = mechanical shrub control, and C = control.

4. Discussion

Hymenoptera are the most important order of pollinators, and bees (Apoidea) are the most highly adapted insects for pollinating flowering plants. For food and nesting sites, many native bees depend on habitats resulting from extensive land use (Steffan-Dewenter, 2002), which suggests that forest management may benefit some native bee populations. In our study, bees were most abundant on the mechanical shrub control plus burn treatment plots, which had the greatest amount of disturbance. The mechanical shrub removal plus burn treated plots had hotter fires compared to burn only plots due to the increased fuel on the forest floor (Phillips and Waldrop, 2006). These hotter fires may have provided more bare ground, for ground-nesting bees to nest in, which may be one reason for the increased abundance of Halictidae and other ground nesting bees on these plots. This would be consistent with the findings of Potts et al. (2005) that bee communities depend on and become more abundant with increased bare ground. Many of the genera and species of bees we captured nest in the ground or within the piths of plants. However, the mechanical shrub control plus burn

Table 2 – Mean numbers (SE) of the orders and common families of flower visiting insects captured per 10 ha plot that received various combinations of mechanical shrub control and prescribed burning on the Green River Game Management Area near Hendersonville, NC during 2003 and 2004

Orders and families[A]	Treatments[B]			
	MB	B	M	C
2003				
Hymenoptera	$287.7(43.3)_a$	$115.7(30.1)_b$	$141.7(31.7)_b$	$135(55.1)_b$
Halictidae	$238.7(37.0)_a$	$104.3(25.2)_b$	$122.7(33.0)_b$	$118(52.9)_b$
Anthophoridae*	$14.3(4.5)_a$	$4.7(2.7)_b$	$5.3(1.9)_b$	$4.0(2.0)_b$
Apidae	$16(1.2)_a$	$5.0(2.0)_a$	$7.7(4.7)_a$	$5.0(1.0)_a$
Sphecidae	$9.0(1.2)_a$	$1.0(0.0)_a$	$2.0(1.0)_a$	$4.0(0.0)_a$
Lepidoptera	$32(11.2)_a$	$17.3(4.8)_a$	$14(4.0)_a$	$17(4.6)_a$
Hesperiidae	$25(6.1)_a$	$13.7(3.5)_a$	$7.7(1.5)_a$	$11.3(4.9)_a$
Papilionidae	$8.5(6.5)_a$	$3.5(.50)_a$	$5.0(2.5)_a$	$5.3(1.5)_a$
Diptera	$270(125.3)_a$	$55.7(23.1)_b$	$77.3(12.2)_b$	$50.7(22.8)_b$
Syrphidae	$269.3(125.7)_a$	$54.3(23.0)_b$	$77.3(12.2)_b$	$50.3(22.5)_b$
Coleoptera*	$61.7(10.2)_a$	$23(9.5)_b$	$26.7(7.2)_b$	$20(9.5)_b$
Mordellidae	$24(3.1)_a$	$13(5.2)_a$	$14(3.5)_a$	$15(7.5)_a$
Cerambycidae	$15.7(3.5)_a$	$10.5(3.5)_a$	$8.7(3.0)_a$	$3.0(1.2)_a$
Scarabaeidae	$11.7(7.2)_a$	$2.0(1.0)_a$	$1.5(.50)_a$	0_a
2004				
Hymenoptera	$387(105.4)_a$	$161.7(75.3)_b$	$143(42.1)_b$	$129(56.0)_b$
Halictidae	$341.7(96.4)_a$	$152.3(73.0)_b$	$130(41.6)_b$	$106.7(44.2)_b$
Anthophoridae	$14.7(1.2)_a$	$5.7(.88)_a$	$8.0(1.0)_a$	$17.7(11.2)_a$
Apidae	$13.3(4.5)_a$	$2.0(1.0)_b$	$3.7(.67)_b$	$3.0(1.0)_b$
Sphecidae	$14.7(2.6)_a$	$2.0(.58)_b$	$2.0(0.0)_b$	$1.5(.50)_b$
Lepidoptera	$36.3(9.4)_a$	$27(14.5)_a$	$26.3(2.7)_a$	$15.7(3.8)_a$
Hesperiidae	$20.7(6.8)_a$	$20.7(10.7)_a$	$21.0(2.0)_a$	$11.3(2.7)_a$
Papilionidae	$10.3(3.0)_a$	$4.0(2.5)_a$	$4.3(1.9)_a$	$4.0(0.0)_a$
Diptera	$87.3(19.6)_a$	$27.7(18.2)_b$	$27.7(3.5)_b$	$26(17.0)_b$
Syrphidae	$86.7(20.1)_a$	$26.3(17.4)_b$	$26.7(3.5)_b$	$23.7(16.2)_b$
Coleoptera	$116.7(9.5)_a$	$29.3(6.8)_b$	$29(3.6)_b$	$25.3(4.7)_b$
Mordellidae	$28.3(8.1)_a$	$9.0(2.6)_a$	$9.7(2.0)_a$	$7.3(2.6)_a$
Cerambycidae	$17.3(9.6)_a$	$8.0(1.0)_a$	$10.7(4.8)_a$	$4.0(1.5)_a$
Scarabaeidae	$61.7(20.8)_a$	$15.5(8.5)_b$	$5.0(1.0)_b$	$14(4.0)_b$

A Within each order or family, means followed by the same letter(s) are not significantly different ($p \leqslant 0.05$) according to the Ryan–Enoit–Gabriel–Welsch multiple comparison test (SAS, 1985). Orders or families followed with an * indicates $p \leqslant 0.10$.
B MB = mechanical shrub removal plus burn, B = burn, M = mechanical shrub removal, C = control.

Table 3 – Mean number (SE) of species of flower visiting insects captured per 10 ha plot that received various combinations of mechanical shrub control and prescribed burning on the Green River Game Management Area near Hendersonville, NC during 2003 and 2004

Order[A]	Treatment[B]			
	MB	B	M	C
Hymenoptera	29(2.1)$_{a}$	15(1.5)$_{b}$	17(2.1)$_{b}$	17.7(.67)$_{b}$
Lepidoptera*	17(2.1)$_{a}$	13.7(2.3)$_{ab}$	11(1.5)$_{b}$	11(0.0)$_{b}$
Diptera	6.3(.33)$_{a}$	6.7(1.9)$_{a}$	6.7(.33)$_{a}$	4.7(.88)$_{a}$
Coleoptera	17.7(.88)$_{a}$	12.7(2.0)$_{b}$	13.3(.67)$_{b}$	10.7(1.2)$_{b}$

[A] Within each order, means followed by the same letter(s) are not significantly different ($p \leqslant 0.05$) according to the Ryan–Enoit–Gabriel–Welsch multiple comparison test (SAS 1985). Orders followed with an * indicates $p \leqslant 0.10$.

[B] MB = mechanical shrub removal plus burn, B = burn, M = mechanical shrub removal, C = control.

Table 4 – Linear regression analyses of floral visiting insect groups and the change in overstory tree basal area or percent herbaceous plant cover on 10 ha plots that received various combinations of mechanical shrub control and prescribed burning

Taxonomic group		Change in tree basal area[a]			% Herbaceous plant cover		
Order	Family	R^2	Slope (SE)	P	R^2	Slope (SE)	P
Hymenoptera		0.58	−51.0 (13.74)	0.004	0.48	20.9 (6.93)	0.013
	Halictidae	0.55	−43.6 (12.36)	0.006	0.45	17.8 (6.21)	0.017
	Anthophoridae	–	–	NS	–	–	NS
	Apidae	0.59	−2.3 (0.63)	0.006	0.70	1.2 (0.27)	0.001
	Sphecidae	0.65	−2.2 (0.53)	0.003	0.64	1.0 (0.24)	0.003
Lepidoptera		0.66	−5.5 (1.25)	0.001	0.44	2.0 (0.73)	0.02
	Hesperiidae	0.67	−3.6 (0.81)	0.001	–	–	NS
	Papilionidae	0.42	−1.4 (0.54)	0.02	0.47	0.7 (0.23)	0.01
Diptera		0.71	−39.0 (7.91)	0.0006	0.59	16.0 (4.26)	0.004
Coleoptera		0.78	−14.6 (2.42)	0.0001	0.62	5.8 (1.46)	0.003
	Mordellidae	0.52	−3.4 (1.05)	0.009	0.63	1.7 (0.41)	0.002
	Cerambycidae	–	–	NS	0.35	1.0 (0.43)	0.04
	Scarabaeidae	0.78	−8.3 (1.55)	0.0007	0.44	2.7 (1.09)	0.04

[a] Change in basal area = post treatment basal area − pretreatment basal area.

treated plots also had the greatest reduction in tree basal area with the resulting increased herbaceous plant cover (Fig. 3). Those plots also had higher species richness for understory vegetation compared to other treatments (Hutchinson and Phillips, in press). Therefore, the higher numbers and species richness of bees may be due to increased vegetation and flowering. Likewise, the increased numbers of Sphecidae on the mechanical plus burn plots could have been a result of increased pollen and nectar for adults and/or increased prey (insects and spiders) available to feed larvae.

Diptera are considered the second most important, but often overlooked, pollinating or floral visiting insect order (Larson et al., 2001), and Syrphidae are some of the most significant floral visitors among the Diptera. Except for a few Bombyliidae, most of the flower visiting Diptera we captured were Syrphidae. In many cases syrphids require pollen for ovary development (Schneider, 1969) and possibly sperm production (Larson et al., 2001). In some areas, species of syrphids are considered the most important pollinators of various plants and have increased in abundance due to anthropogenic changes (Kwak et al., 1996). Most syrphid flies have short proboscides but can gather nectar and pollen from a wide variety of flower types and shapes (Kevan and Baker, 1983; Larson et al., 2001). This ability to use many types of flowers may be one reason for the lack of species richness among the syrphid flies we captured, i.e., a few species occurring in great abundance are able to occupy the available niches. Again, the increased herbaceous plant cover on mechanical shrub removal plus burn treated plots may have favored syrphids. Not only would they benefit from more adult food but many syrphid larvae feed on aphids, such as *Toxomerus* spp., which we frequently caught in our traps. Other syrphid larvae feed on dead plant matter which was also higher in the mechanical plus burn treatments as evidenced by the reduction in live tree basal area caused by fire mortality. Reemer (2005) reported increased occurrences of saproxylic species of Syrphidae in the Netherlands and attributed their findings to changes in Dutch forestry including the tendency of leaving more dead wood. Bee flies (Bombyliidae) are another well known group of floral visitors with specialized proboscides for nectar feeding (Proctor et al., 1996; Larson et al., 2001). Despite their adaptation for nectar feeding, we only captured a few individuals on any treatment over a two year period. Many species of bombyliid flies prefer open sunny areas (Proctor et al., 1996), so the forest we studied may not have been ideal habitat for these flies.

Coleoptera are considered to be the most primitive pollinators (Kevan and Baker, 1983). They transport pollen by a "mess and soil" method, in which they blunder through a flower eating pollen or nectar and defecating, so a single species of flower is rarely dependent on one beetle species for pollination (Buchmann and Nabhan, 1996). The increased herbaceous growth resulting from the mechanical plus burn treatment may have contributed to the greater beetle numbers in our traps in 2004 and the higher species richness in those treatment areas. The large number of *Cremastocheilus* spp. in 2004 may have resulted from increased ant colonies where larvae and adults of these beetles are commonly found. Once inside an ant nest, adult beetles feed on ant larvae and beetle larvae gain protection from predators and desiccation (Hölldobler and Wilson, 1990). Increased herbaceous vegetation growth and species richness, dead wood, or the greater disturbances and exposure of the mineral soil on mechanical plus burn plots could have provided more food and/or nesting habitat for ants and subsequently their parasites.

As adults, most Lepidoptera feed on nectar from flowers, but some feed on other liquids or pollen (Kevan and Baker, 1983). Butterflies visit flowers diurnally, whereas most moths that visit flowers do so nocturnally. Despite the increased understory herbaceous growth on the mechanical plus burn plots, we found no significant differences in Lepidoptera abundance between treatments. This may have been because control and some mechanical only treatment plots still had an abundance of *Rhododendron* spp. and mountain laurel which flowered early in our sampling period. Otherwise, very little flowering was observed in the summer or early fall. Lepidoptera may also have specific larval host plant requirements (Rathcke and Jules, 1993). Butterfly abundance and diversity may depend on host plant attributes (Dennis et al., 2004) rather than the amount or diversity of flowering plants so, if their host plants were absent, they may only have been itinerant visitors to our plots. The most common butterflies we collected (*Thorybes* spp.) have poorly known life cycles and host plants. This genus is also difficult to identify because of morphological variation within individual species, hence many are identified based on behavior while others can only be identified by dissection. Therefore, our catches probably consisted of more than one species of this genus. Most butterflies prefer sunlight to raise their body temperature in order to achieve flight, which may make dense forested areas less attractive, and interior forest areas in general may not support large numbers or diversities of butterflies. For example, in Thailand, Ghazoul (2002) found no changes in species richness of pollinating butterflies in logged areas compared to un-logged areas, which suggests butterflies may not be able to easily colonize areas surrounded by dense forests. Other researchers have shown that some butterflies can reach higher densities in habitat patches that are connected by corridors compared to isolated patches of habitat (Haddad and Baum, 1999). However, forest management that creates and maintains open stands that allow more sunlight to reach the forest floor and provide corridors for movement and dispersal, may favor butterfly colonization over time. The mechanical plus burn treatments may provide part of their habitat needs, but the short time period between treatment and sampling may not have been long enough for populations to respond.

Pollinator abundance was correlated with change in basal area, i.e., plots with the greatest reduction in basal area had the highest numbers of pollinators. Mechanical shrub control plus burn treatments caused the greatest changes in basal area of trees because increased fuel loads on the plots resulted in hotter fires and more tree mortality. The combination of removing the dense understory of mountain laurel and rhododendron combined with some overstory tree mortality allowed more sunlight to reach the forest floor. Likewise, removal of competing shrubs and some trees probably increased nutrient availability. The combination of increased light and nutrient availability likely contributed to the greater herbaceous plant cover we observed, and is consistent with previous studies in eastern forests (Gilliam and Roberts, 2003). Although it is unclear what caused the increased numbers of pollinators, a combination of factors, such as increased plant diversity and abundance, availability of nesting habitat and microclimate, are likely to be important in sustaining pollinator populations in forests.

Clearly, forest management practices can be used to positively influence pollinating insect abundance and species richness. In this study, the mechanical shrub control plus burn treatments proved to be the best for increasing pollinator abundance. Continued burning, periodic thinning or both over time might be as effective as the mechanical plus burn treatments in providing conditions that favor pollinators over the long term. Although fire is a natural component of southern Appalachian ecosystems, misuse or overuse of fire could be detrimental to some pollinators. Therefore, other parameters (time of burn, burn frequency, etc.) could show different results and should be explored.

Despite the enormous importance of pollinators, our understanding of their habitat needs is far from complete. Unfortunately, much of the current research dealing with pollination systems points toward an ongoing ecological crisis (Buchmann and Nabhan, 1996; Allen-Wardell et al., 1998; Kearns et al., 1998; Kremen and Ricketts, 2000), so research to help fill knowledge gaps about pollinator habitat requirements should be considered a priority.

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