EFFECTS OF PRESCRIBED FIRE AND FIRE SURROGATES ON POLLINATORS AND SAPROXYLIC BEETLES IN NORTH CAROLINA AND ALABAMA

by

JOSHUA W. CAMPBELL

(Under the Direction of James L. Hanula)

ABSTRACT

Pollinating and saproxylic insects are two groups of forest insects that are considered to be extremely vital for forest health. These insects maintain and enhance plant diversity, but also help recycle nutrients back into the soil. Forest management practices (prescribed burns, thinnings, herbicide use) are commonly used methods to limit fuel build up within forests. However, their effects on pollinating and saproxylic insects are poorly understood. We collected pollinating and saproxylic insect from North Carolina and Alabama from 2002-2004 among different treatment plots. In North Carolina, we captured 7921 floral visitors from four orders and 21 families. Hymenoptera was the most abundant and diverse order, with Halictidae being the most abundant family. The majority of floral visitors were captured in the mechanical plus burn treatments, while lower numbers were caught on the mechanical only treatments, burn only treatments and control treatments. Overall species richness was also higher on mechanical plus burn treatments compared to other treatments. Total pollinator abundance was correlated with decreased tree basal area ($r2=0.58$) and increased percent herbaceous plant cover ($r2=0.71$). We captured 37,191 saproxylic Coleoptera in North Carolina, comprising 20 families and 122 species. Overall, species richness and total abundance of Coleoptera were not significantly different among treatments. However, total numbers of many key families, such as Scolytidae, Curculionidae, Cerambycidae, and Buprestidae, have higher total numbers in treated plots

compared to untreated controls and several families (Elateridae, Cleridae, Trogositidae, Scolytidae) showed significant differences ($p \leq 0.05$) in abundance. At the Coastal Plain site located in Alabama, we caught 10,908 floral visitors representing four orders and 26 families. Hymenoptera was the most abundant and diverse order, with Halictidae being the most abundant family. Overall, our results indicated that none of the treatments we tested were better than others for enhancing general floral insect visitor abundance or diversity. We captured 75,598 saproxylic Coleoptera, comprising 17 families and 130 species. Coleoptera abundance was not significantly different among treatments, but all treated plots had higher numbers than untreated controls. Species richness was significantly higher on thin plus burn plots compared to thin only and control plots.

INDEX WORDS: pollinators, saproxylic insects, Hymenoptera, Coleoptera, forest management, prescribed burns

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CHAPTER 1

INTRODUCTION

Forest insects are considered to be extremely vital for forest health. Among their many roles, these insects help maintain and enhance plant diversity and recycle nutrients back into the soil. Pollinating and saproxylic insects are two groups that have been recognized as essential parts of forest ecosystems.

In many cases, plant-insect relationships are specific and some plants depend on only one insect species for pollination (Kevan, 1975). In some cases, plants may actually compete for insect pollinators, which could help shape plant community structure (Heithaus, 1974, Pleasants, 1983, Levin and Anderson, 1970). Pollination by insects is also important monetarily. Approximately 30% of our food is derived from insect pollinated crops (Delaplane and Mayer, 2000, Kearns et al., 1998). A number of factors threaten pollination systems including habitat fragmentation, land-use changes, agricultural practices, use of pesticides and herbicides, and exotic species invasions (Delaplane and Mayer, 2000, Kearns et al., 1998, Johansen, 1977, Kevan, 1975). Because of their biological and monetary value, conservation of insect pollinators should be a priority.

Currently, information about insect pollinator diversity and abundance in many areas is scarce. For example, Buchmann and Nabhan (1996) estimate that less than two-thirds of the world's bee species have been described, despite the fact that bees (Apoidea) are among the more common insect pollinators. Available data, however, indicates that wild populations of pollinators have declined and have reduced ranges, resulting in many plants exhibiting signs of pollinator limitation, a condition in which plants produce limited fruit and seed set as a result of too few pollinator visits (Kearns and Inouye, 1997, Buchmann and Nabhan, 1996). Not only does this limit plant populations, but it also may result in less vigorous offspring due to higher percentages of seeds produced through self-pollination or limited pollen competition (Kearns and Inouye, 1997). Although declining populations of pollinators have been documented throughout the world (Kearns and Inouye, 1997, Gess and Gess, 1993, Vinson, et al., 1993, Janzen, 1974), little is known about pollinators in forests of the southeastern United States.

Another important forest insect group is the saproxylic beetles. Numerous saproxylic species are major forest pests. These beetles, such as the southern pine beetle (*Dendroctonus frontalis* Zimmermann), black turpentine beetle (*Dendroctonus terebrans* Olivier), beetles from the genus *Ips*, and a number of wood borers can cause extensive economic loss (Flechtmann et al., 1999). Ips beetles, black turpentine beetle, and the southern pine beetle normally attack conifers that have been weakened or felled, but they can also be found in debris left over from logging operations (Coulson and Witter, 1984). At high populations, these beetles can attack and kill healthy trees (Coulson and Witter, 1984). Wood borers, such as ambrosia beetles (Curculionidae: Scolytinae), do not do as much damage as bark beetles and only rarely attack healthy trees (Flechtmann et al., 1999).

However, the number and diversity of beneficial saproxylic beetles far outnumber the well known and publicized pest species. Saproxylic beetles are a diverse group that is dependent on dead wood for food and habitat. These beetles are important components of forest ecosystems because they decompose wood and recycle nutrients and organic matter back into the soil (Grove, 2002). Woody material is broken down by the beetles through tunneling and feeding activity, and indirectly by facilitating bacteria and fungal growth that cause wood decay

(Speight, 1989). In addition, saproxylic insects are important components of the food web supporting a variety of invertebrate and vertebrate fauna.

An important management goal in forests throughout the southern United States is to reduce fuel and subsequent wildfire risks. The most common management tool used to achieve this goal is prescribed burning (Hermann et al., 1998). However, increasing human populations in and around forested areas could make prescribed burning unpopular in the near future (Strohmaier, 2000). 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 fire. Due to the importance of pollinators and saproxylic beetles, land management practices in forested areas should try to minimize the disruption of these invertebrate communities. However, little is known about how fire or other techniques used to reduce fuel affect these insect populations. Here we present results of studies on the effects of various forest management practices designed to reduce fuel loads and wildfire risk on pollinating and saproxylic insect abundance and diversity in North Carolina and Alabama.

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CHAPTER 2

EFFICIENCY OF MALAISE TRAPS AND COLORED PAN TRAPS FOR COLLECTING FLOWER VISITING INSECTS FROM FORESTED ECOSYSTEMS[1]

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ABSTRACT Pan and malaise traps have been used widely to sample insect abundance and diversity, but no studies have compared their efficiency for sampling pollinators in forested ecosystems. Malaise trap design and color of pan traps are important parameters that influence insect pollinator catches. This paper analyzes pan trap and malaise trap catches from forests in three physiographic provinces: Piedmont, Coastal Plain, and Blue Ridge. Similarities in trap performance between sites were observed with blue pan traps being the most effective trap overall. Our results showed that various pollinator groups preferred certain pan trap colors and that adding color to malaise traps influenced insect pollinator catches. Pan traps generally caught more pollinators than malaise traps. Because of their low cost and simplicity, using several colors of pan traps is an effective way to sample relative abundance and diversity of floral visiting insects.

KEY WORDS pan trap, malaise trap, pollinator

Pollination by insects is a key process occurring in terrestrial ecosystems including forests. Air currents within a forest are less important in pollen movement for the majority of flowering plants leaving insects as the major source of pollen transport between plants (Richards 1978). Numerous insects visit flowers and many are known to be important pollinators. Kearns and Inouye (1997) estimated that approximately 67% of all flowering plants depend on insects for pollination needs. Therefore, pollination by insects is vital for maintaining plant diversity of forests.

Studying pollinators in forested environments presents considerable sampling challenges. Forests are structurally and biologically diverse often containing a herbaceous plant community, a shrub layer, midstory trees and a dominant overstory tree canopy. Even in fairly simple even-aged forests, understory communities may have a mixture of woody shrubs and herbaceous plants making sampling with sweep nets or vacuum samplers impractical. Studies on the effects of various forest management treatments that alter stand structure and/or composition further complicate sampling. Therefore, we were interested in developing a simple and effective sampling procedure for assessing the relative abundance and diversity of pollinators in forested habitats.

Flowering plants use color, fragrances, rewards (pollen/nectar) and size or shape to attract pollinators (Niesenbaum et al. 1998), with color being one of the more important attractants (Kevan 1972). Therefore, color traps are a potential method of surveying and monitoring pollinator diversity and abundance. Color traps have been used to capture many different types of insects. For example, various yellow traps have been used to catch a wide variety of phytophagous insects (Kirk 1984) and predators (Leksono et al. 2005), blue pan traps catch various Hymenoptera (Aguiar and Sharkov 1997), and white or yellow traps catch many Diptera (Disney et al. 1982). Bees and various other floral visiting insects respond to colors associated with floral rewards (pollen/nectar) (Leong and Thorp 1999) and common floral colors (Kirk 1984).

Pan traps consisting of colored pans filled with water and an additive (e.g. soap) to help break surface tension are the most common type of colored traps and yellow has been the most widely used color because it attracts a large diversity of insects (Leong and Thorp 1999). Few studies have used pan traps to estimate relative abundances of bees or other pollinators in different habitats, despite their usefulness in such studies with other insects (Southwood 1978) and their potential for comparing species richness and diversity (Leong and Thorp 1999). However, Cane et al. (2001) cautioned that pan traps may not accurately reflect the pollinator fauna because the traps poorly represented native bee fauna that visited flowering shrubs in the same area.

Malaise traps capture large numbers and diversities of flying insects including Hymenoptera (Matthews and Matthews 1970, Noyes 1989, Darling and Packer 1988) and have been used widely in surveys of insect abundance and diversity. Many different malaise trap designs have been used by past researchers, including Townes (1972) who noted that different colored parts of the trap can cause differences in catches. We compared four colors of pan traps at ground level to malaise traps to determine which captured the greatest number and diversity of floral visitors in three forested habitats: the Gulf Coastal Plain, Piedmont and Blue Ridge provinces.

Materials and Methods

We trapped at three locations; (1) Clemson Experimental Forest, near Clemson, SC in the Piedmont Region, (2) Solon Dixon Experimental Forest, near Andalusia, AL within the Coastal Plain Region, and (3) Green River Game Management Area, near Hendersonville, NC in the southern Appalachian Mountains (Blue Ridge Region). Traps were placed on 10 hectare (24.7 acre) plots at each location. The Piedmont location had 14 plots, the Coastal Plain location had 15 plots and the Blue Ridge location had 12 plots. Each plot was marked by grid points which were 50 meters apart.

The pan traps consisted of red, white, blue, or yellow plastic bowls (Solo^{TM}, 532 ml, approximately 18 cm diameter) filled approximately three-fourths full with water, to which several drops of unscented Ajax™ dishwashing detergent were added (Fig. 2.1). These colors were chosen because they represented a range of wavelengths found in the visual spectrum and are similar to flower colors. The pan traps were held approximately 0.5 meters above the ground with heavy gauge aluminum wire. The wire was inserted into the ground with the other end bent into a loop that supported the pan.

We also used canopy malaise traps from Santee Traps (Lexington, KY) with or without color panels (Fig. 2.2) at the three sites. Canopy malaise traps differed from the traditional malaise trap in that an insect could be caught from any direction and the traps had collecting containers at the top and bottom. The malaise trap measured approximately 2.7 meters tall and 1.2 meters in width. Three meter tall, metal conduit poles were used to suspend the traps. A 0.5 meter length of pipe with a larger diameter than the conduit was inserted into the ground and the trap support poles were then inserted into the metal pipe to hold the trap in place. Collecting containers were filled approximately one-third full with a soapy water solution. The colored malaise traps had four cotton cloth (red, white, blue, and yellow) color panels (0.3 m^2 each) pinned onto malaise traps so that each collection panel had a different color. Samples from the pan traps and malaise traps were immediately stored in 70% alcohol, sorted to morphologically similar groups and identified.

The Piedmont site was used as a pilot study during the summer of 2002. It was dominated by loblolly (*Pinus taeda*), shortleaf (*Pinus echinata*), and Virginia (*Pinus virginiana*) pines. We were unable to find yellow pan traps in 2002 so we used red, white, and blue pan traps, a malaise trap, and a malaise trap with red, white, blue, and yellow panels (0.3 m^2 each) attached. We trapped seven times from May to September, with each trapping period lasting seven days. Within each 10 ha plot 5 groups of pan traps were used with each group consisting of one of each color spaced approximately one meter apart. At each plot we also operated one malaise and one malaise trap with color panels. Malaise traps and groups of pan traps were placed near the center of each plot at different grid points 50 meters apart.

The Coastal Plain and Blue Ridge sites were sampled during the spring and summers of 2003 and 2004. The Coastal Plain site was dominated by mature longleaf (*Pinus palustris*) and slash pine (*Pinus eliottii*), whereas the Blue Ridge site was dominated by mature hardwood trees primarily oaks (*Quercus* sp.). The Blue Ridge site was sampled 11 times between April and October, and the Coastal Plain site was sampled 10 times between March and September during the two years. We used the same traps at the Coastal Plain and Blue Ridge sites as in the Piedmont, but we added yellow pan traps and omitted red pan traps and malaise traps without color panels. On each plot, a single malaise trap was operated near plot center and five sets of pan traps were placed at randomly selected grid points also in the central part of each plot.

Because we did not measure pollination effectiveness among the plants and insects, the insects captured can be thought of as floral visitors instead of pollinators. However, we selected insects for inclusion in our analyses based on published literature and field observations. Numerous insects (other than pollinators/floral visitors) were caught in the malaise and pan traps. We selected floral visitors we thought also were likely to be involved in pollination to some extent. If species were observed actively visiting flowers on the plots we included them in the analysis even though we were unable to find published references of this behavior. Voucher specimens are currently housed in the USDA Forest Service's collection in Athens, Georgia but they will be placed in the University of Georgia, Natural History Museum upon completion of our studies.

Data were analyzed using a one-way ANOVA with traps as the independent variable and the various pollinator groups as dependent variables. A square-root transformation was used to assure normality and homogeneity of variance. Data were analyzed with PROC GLM in SAS (SAS Institute 1985), and the Ryan-Einot-Gabriel-Welsch Multiple Range Test (REGWQ) was used to determine differences in relative abundances and diversities of pollinators between trap types. Overlap of floral visitor communities captured by the various trap types was compared using the Simplified Morisita Index (Horn 1966) to determine if different traps captured different groups of insects. Morisita's index takes into consideration both species and abundance. We compared overlap of species only among trap types by using Sørenson's quotients of similarity (Sørenson 1948, Southwood 1978). Both Sørenson and Morisita's index calculate values between 0 (no overlap) and 1 (complete overlap).

Results

Piedmont

We collected 6265 floral visitors in four orders and 21 families. Hymenoptera was the most abundant order and Halictidae was the most common family. We included 28 species from five families of Hymenoptera. Blue pan traps caught significantly more Hymenoptera than any other trap type (Table 2.1). They also worked best for the two most abundant families Halictidae and Anthophoridae. Overall, Lepidoptera was the most diverse order sampled, with nine families and 34 species caught. Coleoptera was the second most diverse order with four families and 17 species. Diptera was the least abundant and diverse of the orders, comprising only three families and 10 species.

Malaise traps with color panels added caught 781 total pollinators compared to malaise traps without color panels which caught 526 pollinators. Colored malaise traps caught more Lepidoptera than all other trap types except blue pan traps (Table 2.1). Hesperiidae, the most common family of Lepidoptera captured, were caught more frequently with blue pan traps compared to the other traps. However, Papilionidae, the second most abundant family of Lepidoptera, were captured in significantly higher numbers only in colored malaise traps. The number of Lepidoptera caught in malaise traps without colored panels was low and did not significantly differ from the white and red pan traps.

The highest numbers of Diptera were caught in blue pan traps, whereas red pan traps caught the fewest (Table 2.1). The two types of malaise traps did not differ significantly in numbers of Diptera caught although malaise traps with color panels caught more than red pan traps. Twice as many Syrphidae were caught in blue pan traps compared to any other trap type.

A total of 89 species of floral visitors were captured (34 Lepidoptera, 28 Hymenoptera, 17 Coleoptera, and 10 Diptera). White pan traps, colored malaise, and malaise traps were the most effective for Coleoptera species (Table 2.2). However, both types of malaise traps were more successful than all three pan colors tested for the family Mordellidae (one of the more common families). Conversely, colored malaise and malaise traps did not yield a single specimen of Buprestidae, which were some of the most common Coleoptera caught. Blue and white pan traps caught the most species of Hymenoptera, and the colored malaise and blue pan traps were the most effective for Lepidoptera.

Blue and white pan traps had the highest floral visitor overlap with a Morisita's index of overlap of 0.95, whereas red and colored malaise traps had the lowest with a value of 0.16 (Table 2.3). We compared the combined captures from all three pan colors to malaise traps. Pan traps and colored malaise had a Morisita's index value of overlap of 0.48, and pan traps and malaise without color panels had a 0.38 overlap. Species overlap between pan traps and malaise without color panels as measured by Sørenson's index was 0.74 while Sorenson's index was 0.77 for comparison of pan traps to malaise traps with color panels.

Coastal Plain

We caught 10,908 floral visitors representing four orders and 27 families on the Coastal Plain. Hymenoptera was the most abundant and diverse order captured in our traps, with the largest number captured from the Halictidae. Eight families and 57 species of Hymenoptera were caught, along with six families and 26 species of Coleoptera, ten families and 45 species of Lepidoptera, and three families and 16 species of Diptera.

Colored malaise traps captured 870 pollinators, blue pan traps 5017, white pan traps 3126, and yellow pan traps 1895. Blue pan traps were the most successful trap overall for Hymenoptera (Table 2.4). They also worked best for capturing Halictidae and Anthophoridae. However, colored malaise traps, white and blue pan traps were similar in effectiveness for capturing Apidae.

Lepidopterans, primarily Hesperiidae, were also caught in higher numbers with blue pan traps (Table 2.4). For Papilionidae, however, colored malaise, white and blue pan traps were equally effective.

Blue pan traps were also the most effective trap for Diptera, the majority being syrphids. However, Bombyliidae were caught in higher numbers with colored malaise traps (Table 2.4).

Overall, Coleoptera were caught most effectively with white pan traps (Table 2.4). White and blue pan traps captured Buprestidae with similar success, whereas, Mordellidae were captured with the greatest success in yellow pan traps.

A total of 144 species of floral visitors was captured (57 Hymenoptera, 45 Lepidoptera, 26 Coleoptera, and 16 Diptera). Blue pan traps caught the greater diversity of Hymenoptera and colored malaise traps captured the most Diptera species (Table 2.5). All traps except yellow pan traps captured equal numbers of species of Lepidoptera, while no one trap was more effective than others for Coleoptera. Blue and white pan traps had the highest Morisita’s index of overlap at 0.68, but blue pan traps and colored malaise traps were comparable with a Morisita’s index of 0.62 (Table 2.6). White and colored malaise had the lowest overlap at 0.18. All three pan trap colors combined and compared to malaise traps with color panels only had a Morisita’s index of 0.51. Species overlap (Sørenson’s Index) between pan traps and malaise traps with color panels was 0.82.

Blue Ridge

We caught 7921 floral visitors representing four orders and 21 families. Like the Piedmont and Coastal Plain, Hymenoptera was the most abundant order, with Halictidae being the most abundant family. We caught six families and 45 species of Hymenoptera, seven families and 35 species of Lepidoptera and six families and 33 species of Coleoptera. Diptera was the second most abundant order, but like the other two sites, were the least diverse, comprising only two families and 13 species.

The colored malaise traps captured 603 pollinators, blue pan traps 4067, white pan traps 1816, and yellow pan traps 1435. Blue pan traps were the most effective trap for Hymenoptera in general and for Halictidae and Anthophoridae specifically (Table 2.4). However, blue and white pan traps captured similar numbers of Apidae. White pan traps were the most successful trap for Sphecidae.

Blue pan traps were most effective for Lepidoptera, which were predominantly Hesperiidae, while colored malaise and blue and white pan traps captured Papilionidae with similar success. Blue pan traps were also the most effective trap for Diptera, which were primarily syrphid flies (Table 2.4).

Overall, Coleoptera were caught best with white pan traps although yellow pan traps performed equally well (Table 2.4). White pan traps captured the greatest number of Cerambycidae while equal numbers of Scarabaeidae were caught in white and yellow pan traps. Buprestids were captured most often with blue and white pan traps, while Mordellidae were captured in equal numbers in all trap types.

A total of 126 species of flower visitors were captured (45 Hymenoptera, 35 Lepidoptera, 33 Coleoptera, and 13 Diptera). Blue pan traps captured the greater diversity of Lepidoptera (Table 2.5). Blue, white, and yellow pan traps captured similar diversities of Hymenoptera. Similar numbers of Diptera and Coleoptera species were caught with colored malaise, and blue and white pan traps. All trap types had a relatively high floral visitor overlap, with blue pan traps and colored malaise having the lowest Morisita's index of 0.72 (Table 2.6). Catches from all three pan colors combined and compared with colored malaise traps had a Morisita's index of 0.77. Sørenson's Index of species overlap between all three pan traps combined and malaise traps with color panels was also high at 0.70.

Discussion

The type and color of the trap clearly influenced abundances and diversities of catches for various insect groups. Many Hymenoptera are able to discern shorter wavelengths of visible light better than longer wavelengths and many are also able to detect wavelengths in the ultra-violent (Jones and Buchmann 1974, Kevan 1979, Peitsch et al. 1992). The color blue is the lowest wavelength that we used, which may explain why Hymenoptera overall preferred the blue pan traps at all three sites. Kevan (1978) showed that bumblebees preferred flowers that reflected blue light and some bee species see white as a blue-green color (Leong and Thorp 1999). Therefore, the attraction of various groups of Hymenoptera to both white and blue pan traps may be because they cannot distinguish the difference or do not discriminate between the colors. Peitsch et al. (1992) found that many bee species can recognize the color yellow; however, fewer bees were caught in yellow pan traps at the Blue Ridge and Coastal Plain sites. Even though many bee species are attracted to the color yellow (Leong and Thorp 1999), there may be few yellow flowered plants that provide floral rewards in these areas, possibly making yellow pan traps less effective. Red pan traps were almost completely ineffective for Hymenoptera. Most Hymenoptera are considered “red blind” so they see the color red as black or dark colored (Frisch 1971). Therefore, many red flowers are tubular in shape and emit no odor, favoring pollination by birds with long beaks (Buchmann and Nabhan 1996). The malaise traps (from the Piedmont) with and without color panels were also relatively ineffective for capturing a diversity or large numbers of Hymenoptera, which may indicate some Hymenoptera were able to avoid capture in the traps. We noticed on occasion that some bees that flew into malaise traps were able to escape. Therefore, the hovering and flight ability of many bees may allow them to avoid the design of malaise traps we used. In addition, the trapping surface of our traps was approximately 0.5 meters above the forest floor so bees foraging or flying close to the ground would be less likely to be captured.

Butterflies visit a wide variety of colored flowers (Buchmann and Nabhan 1996) and are considered to have the widest visual range of any animal (Bernard 1979). However, because our results indicate they have a strong preference for blue (and white in the Coastal Plain and Blue Ridge) when given a choice, they may be able to discern the color blue better than others despite the fact that other researchers have found that they prefer the color yellow in their feeding behavior (Swihart and Gordon 1971). Many butterflies see the color red which is uncommon among insects (Bernard 1979). Visually seeing red may be used only as part of courtship behavior for butterflies (Swihart and Gordon 1971), which may explain the low catches among the red pan traps when we tested them in the Piedmont. Members of the Papilionidae were also captured with color malaise at all three sites with similar success. In the field, several papilionids were viewed visiting pan traps, but were not captured. Their large size appeared to help them avoid capture in our relatively small pan traps, which may explain why colored malaise traps outperformed pan traps for capturing these butterflies.

Diptera are considered to be the second most important order of insects that visit and pollinate flowers (Larson et al. 2001). However, despite an extremely diverse array of Diptera documented to visit flowers, the majority of floral visiting flies we sampled were syrphids and bombyliids. These two families are considered to be the most important floral visitors among flies and their attraction to flowers is well documented (Larson et. al. 2001). It appears that syrphid flies are highly attracted to blue colors based upon our results. This contradicts the fact that most flies, in general, have been shown to visit white, pink, and yellow flowers with constancy (Proctor et al. 1996). However, other groups of Diptera, such as biting flies, are attracted to dark colors (Kirk 1984). Syrphids have been caught in yellow pan traps (MacLeod 1999), while various syrphid genera also were attracted to yellow, blue or white traps (Haslett 1989). However, Chen et al. (2004) captured large numbers of syrphid flies with blue sticky traps which supports our findings. Beeflies (Bombyliidae) are commonly associated with blue flowers (Kevan 1978), so we expected blue pan traps to be more successful. However, Bombyliidae were captured in higher numbers with malaise traps with or without color panels in the Piedmont, with very few being collected from pan traps. Likewise, malaise traps with color panels caught more Bombyliidae than color pan traps in the Coastal Plain, while few beeflies were caught with any trap on the Blue Ridge site. Perhaps, bee flies were able to escape the pan traps. However, relatively few bombyliids were collected, which may indicate that all trap types we tested were somewhat inefficient for them or they have low populations within forests of the Piedmont and Coastal Plain.

We found few similarities in Coleoptera captured among the different trapping sites or trap types. The species of beetles varied among the three sites more than any other order of insect we studied, which could explain why their response to the traps varied more. Various beetle species respond to colors differently. Chrysomelids and scarabs are able to distinguish among yellows, oranges, and blues while others can discern red (Proctor et al. 1996). Responses to yellow by some beetles may imply that they are foliage seekers (Prokopy and Owens 1983). Very few beetles that we considered floral visitors were attracted to the red pan traps, which may indicate that they were unable to discern the color red. Our trap captures of Buprestidae included large numbers of *Acmaeodera* spp. that were attracted to blue and white pan traps at all three sites. Buprestids of the genus *Agrilus* have been caught successfully with purple and navy blue traps (Francese et. al. 2005) so buprestids in general may be attracted to shorter wavelengths of visible light such as blue.

Morisita's index of similarity indicated that blue and white pan traps had a high degree of overlap on all three sites. Overall, this is fairly consistent with our species richness and abundance results that showed many species preferred blue and white pan traps equally well. However, numerous differences in Morisita's index of overlap exist between sites. This was probably due to variation in species and the abundance of various species that were present at the three sites. Morisita's index of overlap between all pan traps and malaise traps was low in the Piedmont and Coastal Plain, but Sorenson's index, which only considers presence or absence of species, was relatively high at all three sites. Therefore, our pan traps and malaise traps were similar in effectiveness for sampling pollinator richness but they differed relative to abundance for the various species sampled.

It appears that each pan color and malaise design has some value for sampling the overall pollinator community. Our study demonstrates that using multiple trap types and designs improves sampling of pollinators when assessing the abundance and diversity of an area. However, other parameters (i.e. trap height, duration of trap placement, etc.) may influence trap captures and could prove useful in insect pollinator sampling. Therefore, other designs or trapping procedures may need to be explored. However, multiple colors of pan traps were easy to use, effective and inexpensive for sampling pollinators in three different forest habitats.

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Table 2.1 Mean number (SE) of flower-visiting insects from four orders, and the two most numerous families from each order, caught per plot in five different traps used on the Clemson Experimental Forest, near Clemson, SC 2002 (Piedmont, n=14).

Order and Family[1]	Trap Type[2]				
	CM	M	B	W	R
Hymenoptera	15.1(4.0)$_{c}$	9.6(2.1)$_{c}$	152.8(24)$_{a}$	85.6(16.9)$_{b}$	1.6(.37)$_{c}$
Halictidae	11.9(3.7)$_{c}$	7.1(1.7)$_{c}$	141(22.9)$_{a}$	79.4(16)$_{b}$	1.3(.30)$_{c}$
Anthophoridae	.86(.35)$_{b}$	.21(.11)$_{b}$	8.2(1.6)$_{a}$	2.4(.43)$_{b}$	.14(.10)$_{b}$
Lepidoptera	18.7(4.2)$_{a}$	5.6(.98)$_{b}$	20.3(2.0)$_{a}$	8.5(1.2)$_{b}$	1.7(.44)$_{b}$
Hesperiidae	12.4(2.8)$_{b}$	2.6(.49)$_{cd}$	18.8(1.8)$_{a}$	7.0(.97)$_{c}$	.21(.15)$_{d}$
Papilionidae	3.6(1.1)$_{a}$	.36(.17)$_{b}$	1.1(.38)$_{b}$	.71(.38)$_{b}$	.29(.13)$_{b}$
Diptera	5.5(1.5)$_{b}$	3.2(.84)$_{bc}$	11.1(2.4)$_{a}$	5.4(1.1)$_{b}$	.07(.07)$_{c}$
Syrphidae	1.6(.44)$_{b}$	1.3(.49)$_{b}$	10.7(2.3)$_{a}$	3.3(.66)$_{b}$	.07(.07)$_{b}$
Bombyliidae	3.8(1.6)$_{a}$	1.9(.65)$_{ab}$	0$_{b}$	1.9(.59)$_{ab}$	0$_{b}$
Coleoptera	16.4(3.2)$_{ab}$	19.1(3.1)$_{ab}$	26.1 (8.9)$_{a}$	34.7(8.6)$_{a}$	6.0(1.8)$_{b}$
Mordellidae	12.0(2.0)$_{ab}$	15.3(2.9)$_{a}$	5.1(1.1)$_{cd}$	8.6 (1.5)$_{cb}$	1.4(.32)$_{d}$
Buprestidae	0$_{b}$	0$_{b}$	19.8(8.1)$_{a}$	19.4(7.8)$_{a}$	3.9(1.6)$_{b}$

[1] Within each order or family, means followed by the same letter(s) are not significantly different at $P \leq 0.05$ according to the Ryan-Enoit-Gabrell-Welch multiple comparison test (REGWQ, SAS 1985).

[2] CM=malaise traps with color panels; M=malaise traps without color panels; B=blue pan trap; W=white pan traps; R=red pan traps

Table 2.2 Mean number (SE) of species from four orders of floral visitors caught per plot in various trap types tested on the Clemson Experimental Forest, near Clemson, SC 2002 (Piedmont Region, n=14).

Order[1]	Trap Type[2]				
	CM	M	B	W	R
Hymenoptera	4.9(.79)$_b$	4.1(.65)$_b$	8.5(.87)$_a$	7.8(.66)$_a$	1.3(.30)$_c$
Lepidoptera	6.6(.96)$_a$	3.7(.55)$_b$	5.0(.54)$_{ab}$	3.5(.50)$_b$	1.4(.32)$_c$
Diptera	2.1(.29)$_{ab}$	1.9(.40)$_b$	2.9(.34)$_a$	2.5(.37)$_{ab}$	.07(.07)$_c$
Coleoptera	5.1(.59)$_a$	5.3(.34)$_a$	3.4(.43)$_b$	5.2(.52)$_a$	2.1(.21)$_b$

[1] Within each order, means followed by the same letter(s) are not significantly different at *P*≤ 0.05 according to the Ryan-Enoit-Gabrell-Welch multiple comparison test (REGWQ, SAS 1985)..

[2] CM=malaise traps with color panels; M=malaise traps without color panels; B=blue pan trap; W=white pan traps; R=red pan traps

Table 2.3 Comparison of the similarity of floral visitors captured in a Piedmont forest near Clemson, SC by various pan traps (red, white or blue) or malaise traps (with or without color panels added) using the Simplified Morisita Index. Numbers indicate amount of overlap of the communities captured among trap types (0=no overlap, 1=complete overlap).

	Trap Type				
Trap Type	Red	Blue	White	Malaise	All pan traps
Red					
Blue	0.40				
White	0.47	0.95			
Malaise	0.20	0.37	0.38		0.38
Colored Malaise	0.16	0.47	0.46	0.79	0.48

Table 2.4 Mean number (SE) per plot of flower-visiting insects from four orders and the common families captured in four trap types on the Solon Dixon Experimental Forest, Alabama (Coastal Plain, n=15) and the Green River Game Management Area, near Hendersonville, NC (Blue Ridge, n=12) 2003-2004.

		Trap Type^{2}			
Location	Order and Family^{1}	CM	B	W	Y
COASTAL PLAIN	Hymenoptera	22.9(2.8)$_{c}$	158.9(18.3)$_{a}$	57.5(8.6)$_{b}$	35.9(3.9)$_{bc}$
	Halictidae	13.9(2.6)$_{b}$	116.1(17.5)$_{a}$	22.9(3.5)$_{b}$	25.7(3.4)$_{b}$
	Anthophoridae	1.0(.29)$_{b}$	11.5(1.5)$_{a}$	1.5(.41)$_{b}$	.6(.19)$_{b}$
	Apidae	6.5(1.3)$_{a}$	7.3(.98)$_{a}$	5.2(.85)$_{a}$	.93(.21)$_{b}$
	Sphecidae	.67(.29)$_{c}$	7.4(1.2)$_{ab}$	11.9(3.4)$_{a}$	2.7(.76)$_{bc}$
	Lepidoptera	14.3(1.7)$_{b}$	38.2(2.9)$_{a}$	15.7(2.0)$_{b}$	7.6(1.2)$_{c}$
	Hesperiidae	6.3(.96)$_{b}$	30.7(2.4)$_{a}$	5.9(.72)$_{b}$	2.9(.56)$_{b}$
	Papilionidae	3.7(.83)$_{a}$	5.5(.90)$_{a}$	3.9(.68)$_{a}$	.53(.24)$_{b}$
	Diptera	10.1(.87)$_{b}$	45.6(6.1)$_{a}$	7.5(.87)$_{b}$	3.4(.83)$_{b}$
	Syrphidae	4.1(.76)$_{b}$	45(6.1)$_{a}$	6.4(.83)$_{b}$	3.3(.84)$_{b}$
	Bombyliidae	5.5(.82)$_{a}$	.07(.07)$_{b}$	1.1(.24)$_{b}$	.07(.07)$_{b}$
	Coleoptera	10.7(1.8)$_{c}$	91.8(12.0)$_{b}$	127.7(21.8)$_{a}$	79.4(8.7)$_{b}$
	Mordellidae	8.7(1.6)$_{b}$	20.9(2.9)$_{b}$	24.3(3.9)$_{b}$	67.9(9.1)$_{a}$
	Buprestidae	1.3(.30)$_{b}$	69.5(12.2)$_{a}$	98.8(20.7)$_{a}$	10.7(2.2)$_{b}$
BLUE RIDGE	Hymenoptera	12.7(5.5)$_{c}$	198.1(38.3)$_{a}$	86.8(17.5)$_{b}$	77.6(12.6)$_{b}$
	Halictidae	11.2(5.5)$_{c}$	182.9(35.4)$_{a}$	69.4(13.3)$_{b}$	65.1(10.6)$_{b}$
	Anthophoridae	.58(.26)$_{b}$	6.3(1.5)$_{a}$	4.7(1.3)$_{a}$	7.0(2.0)$_{a}$
	Apidae	.83(.34)$_{b}$	6.4(1.7)$_{a}$	5.3(1.4)$_{a}$	.83(.34)$_{b}$
	Sphecidae	.083(.083)$_{b}$	.25(.25)$_{b}$	5.1(2.1)$_{a}$	2.2(.74)$_{ab}$
	Lepidoptera	6.3(1.6)$_{bc}$	26.2(3.9)$_{a}$	11.5(1.7)$_{b}$	2.5(.62)$_{c}$
	Hesperiidae	2.8(.75)$_{c}$	21.1(3.0)$_{a}$	7.3(1.0)$_{b}$	1.7(.40)$_{c}$
	Papilionidae	2.8(1.1)$_{a}$	3.7(.78)$_{a}$	3.1(.69)$_{a}$	.33(.14)$_{b}$
	Diptera	17(4.5)$_{b}$	99.3(33.4)$_{a}$	23.5(7.9)$_{b}$	15.8(4.2)$_{b}$
	Syrphidae	16(4.5)$_{b}$	98.8(33.4)$_{a}$	23.2(7.9)$_{b}$	15.7(4.2)$_{b}$
	Coleoptera	14.3(1.5)$_{b}$	15.3(3.1)$_{b}$	29.5(8.4)$_{a}$	23.8(5.6)$_{ab}$
	Mordellidae	8.0(1.3)$_{a}$	8.7(1.7)$_{a}$	5.4(1.5)$_{a}$	8.0(1.8)$_{a}$
	Buprestidae	1.4(.40)$_{b}$	3.7(1.3)$_{a}$	3.0(.67)$_{ab}$	.92(.31)$_{b}$
	Scarabaeidae	.50(.50)$_{b}$	.67(.36)$_{b}$	11.8(5.5)$_{a}$	11.8(4.1)$_{a}$
	Cerambycidae	4.0(.83)$_{b}$	2.3(.61)$_{b}$	9.3(2.9)$_{a}$	3.0(.95)$_{b}$

[1] Within each order or family, means followed by the same letter(s) are not significantly different at $P \leq 0.05$ according to the Ryan-Enoit-Gabrell-Welch multiple comparison test (REGWQ, SAS 1985).

[2] CM=malaise traps with color panels; B=blue pan trap; W=white pan traps; Y=yellow pan traps

Table 2.5 Mean number (SE) of species of four orders of floral visitors caught per plot in various trap types on the Solon Dixon Experimental Forest, Alabama 2003-2004 (Coastal Plain, n=15) and the Green River Game Management Area, near Hendersonville, NC (Blue Ridge, n=12).

		Trap Type[2]			
Location	Order[1]	CM	B	W	Y
COASTAL PLAIN					
	Hymenoptera	8.2(.68)$_c$	17.6(.67)$_a$	12.7(.90)$_b$	8.4(.54)$_c$
	Lepidoptera	7.2(.54)$_a$	8.5(.48)$_a$	8.4(.65)$_a$	5.1(.62)$_b$
	Diptera	4.6(.34)$_a$	3.1(.25)$_b$	2.9(.22)$_b$	1.8(.31)$_c$
	Coleoptera	4.4(.46)$_a$	5.1(.41)$_a$	5.1(.28)$_a$	4.1(.31)$_a$
BLUE RIDGE					
	Hymenoptera	3.4(.31)$_b$	10.8(1.0)$_a$	13.1(1.3)$_a$	11.1(1.1)$_a$
	Lepidoptera	3.6(.70)$_c$	8.4(.81)$_a$	5.8(.60)$_b$	2.2(.53)$_c$
	Diptera	3.6(.43)$_a$	3.3(.28)$_a$	3.1(.43)$_a$	1.6(.23)$_b$
	Coleoptera	7.2(.53)$_a$	5.5(.74)$_{ab}$	6.8(.91)$_a$	4.7(.45)$_b$

[1] Within each order, means followed by the same letter(s) are not significantly different at $P \leq 0.05$ according to the Ryan-Enoit-Gabrell-Welch multiple comparison test (REGWQ, SAS 1985).

[2] CM=malaise traps with color panels; B=blue pan trap; W=white pan traps; Y=yellow pan traps

Table 2.6 Comparison of the similarity of floral visitors captured by various traps on a Coastal Plain site near Andalusia, AL and a Blue Ridge site near Hendersonville, NC using the Simplified Morisita Index. Numbers indicate amount of overlap of the communities captured (0=no overlap, 1=complete overlap).

		Trap Type			
Location	Trap Type	Blue	White	Yellow	All Bowls
Coastal Plain					
	Blue				
	White	0.68			
	Yellow	0.36	0.38		
	Colored Malaise	0.62	0.18	0.34	0.51
Blue Ridge					
	Blue				
	White	0.88			
	Yellow	0.85	0.97		
	Colored Malaise	0.72	0.78	0.76	0.77

Fig. 2.1 Example of a colored pan trap used for capturing pollinators. Pan traps were approximately 0.5 meters above the ground and 18 cm in diameter.

Fig. 2.2 Malaise trap (height=2.7 m, width=1.2 m) with color panels added (arrow). Colored panels (0.3 m^2) were located on one side of each partition.

CHAPTER 3

EFFECTS OF PRESCRIBED FIRE AND FIRE SURROGATES ON FLOWER VISITING INSECTS OF THE BLUE RIDGE PROVINCE IN NORTH CAROLINA[1]

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[1] Campbell, J.W., J.L. Hanula, and T.A. Waldrop. To be submitted to Journal of Insect Conservation

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 also aid in pollinating crops that are found near forested land. Unfortunately, pollinating insect populations have shown declines in recent decades throughout the world. Currently, the effects of various forest management practices on floral visiting insect abundance or diversity is unknown. In 2003 and 2004, floral visiting insects were captured with a malaise and five groups of colored pan traps (white, blue and yellow bowls) from 10 ha plots of forest land in Blue Ridge Province of North Carolina that were prescribed burned, mechanically treated, mechanically treated and prescribed burned, or untreated. 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. Six families and 45 species of Hymenoptera were caught. 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 plus burn treatments, while lower numbers were caught on the mechanical only treatments, burn only treatments and control treatments. Overall species richness was also higher on mechanical plus burn treatments compared to other treatments. Total pollinator abundance was correlated with decreased tree basal area (r^2=0.58) and increased percent herbaceous plant cover (r^2=0.71). Our study shows that floral visitors benefited most from forest disturbance that reduced the density of overstory trees and increased the amount of herbaceous plant growth.

Key words: forest management, pollinators, bees, fuel reduction, prescribed fire, colored pan trap, malaise trap

Introduction

Pollination by insects is vital for maintaining biological 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 (Delaplane and Mayer 2000; Kearns et al. 1998; Johansen 1977; Kevan 1975). Likewise monocultures of pine forests (Kremen et al. 2002; Delaplane and Mayer 2000) and other crops (Kearns et al. 1998) have negative impacts on pollinators. 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, honey bees, *Apis mellifera*, may compete for pollen and nectar with smaller native bees (Folkerts et al. 1993; Goulson 2003; Paton 1993; Schaffer et al. 1983; Roubik 1978), while exotic plants may attract pollinators away from natives.

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; Ricketts et al. 2004; Klein et al. 2003). This increasing evidence of native bee importance as well as evidence suggesting a pollinator decline throughout the world (Kearns and Inouye 1997; Buchmann and Nabhan 1996; Gess and Gess 1993; Vinson et al. 1993; Janzen 1974) 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. 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 (Kearns and Inouye 1997; Buchmann and Nabhan 1996). Not only does this limit the actual population of various plants, but also may result in less vigorous offspring due to 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 (Hanula and Wade 2003; Ne'eman et al. 2000; McCullough et al. 1998; Zimmer and Parmenter 1998; Siemann et al. 1997; Fischer et al. 1996; Anderson et al. 1989; Warren et al. 1987). However, little is known about how fire or other techniques used to reduce fuel affect pollinating insect populations and diversities.

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, protects some plant species from diseases, and allows perennial grasses and herbaceous plants to grow (Kerstyn and Stiling 1999; Waldrop et al. 1992). Fire is also important for inducing flowering in many plants, increasing germination, and freeing mineral nutrients for plant uptake (Brewer and Platt 1994). Therefore, fire could be beneficial for 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 diversity in response to different forest management practices. 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 forest management within forested ecosystems.

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 5,841 hectares and is managed for game habitat and ecosystem restoration.

Twelve study sites, one for each treatment area, were selected on the basis of size, stand age, cover type and management history. Each site had to be a minimum of 14 hectares to allow for a 10-hectare 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 (*Q. prinus*), white oak (*Q. alba*), and black oak (*Q. velutina*). Other common species included pignut hickory (*Carya glabra*), mockernut hickory (*C. 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 hectare plots and consisted of: (1) untreated, (2) dormant season burn, (3) mechanical, and (4) mechanical plus dormant season burn. The mechanical treatments consisted of chainsaw felling and bucking 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 removed 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 to 2 meters throughout the burn unit, but flames reached as high as 5 meters 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 and Hanula (in review). Pan traps consisted of 532 ml plastic bowls (Solo^{TM}) of different colors filled approximately three-fourths 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. The bowls were held approximately 0.5 meters 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 3 m conduit pole was inserted inside it to hold up the pole and malaise trap. In addition, malaise traps had four cloth, color (red, white, blue, and yellow) panels (0.3 m^2 each) pinned onto each side of the malaise trap. The collecting containers were filled approximately one-third 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 and malaise traps were placed randomly at one of these center grid points. The bowls at any given grid point were placed approximately one meter apart. Traps were operated at 4-6 week intervals from April-October of 2003 and 2004. We trapped five times in 2003 and six times in 2004, with each trapping period lasting seven days.

Flowering plant and 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 (New et al. 1995). We also identified plants that were flowering during survey walks. We collected samples of plants we could not identify in the field. Flowering plants were classified as being (1) abundant (found throughout the plot), (2) common (sporadically found throughout a plot), and (3) rare (only a few plants present). Surveys were done between 10 A.M and 3 P.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. We determined floral visitors based upon published literature and observation in the field, and we included species in our analyses that we considered likely to be involved in pollination even if they were only likely to play a minor role as pollinators. 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.

The study was a randomized complete block design. 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 versus change in basal area and percent plant cover, and percent plant cover versus basal area.

Results

Overall abundance and diversity

We caught 7921 floral visitors from four orders (Figure 3.1) and 21 families. Hymenoptera was the most abundant and diverse order, 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, six families and 33 species of Coleoptera, and two families and 13 species of Diptera. Most floral visitors were captured in the mechanical plus burn treatments (Figure 3.2), while similar numbers were caught on the mechanical only treatments, burn only treatments and control treatments. Overall species richness was also higher on mechanical plus burn treatments compared to other treatments (Figure 3.3). Table 3.1 lists the genera and species captured during the study.

Hymenoptera

Hymenoptera were significantly higher in abundance on mechanical plus burn treated plots in 2003 and 2004 (Table 3.2). In 2003, Halictidae was the most commonly captured family of Hymenoptera, and both Halictidae ($p<0.05$) and Anthophoridae ($p\leq 0.085$) 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 3.2). Species richness of Hymenoptera was also higher on mechanical plus burn treatments (Table 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 3.2) but species richness of Diptera was similar among treatments (Table 3.3). Syrphidae was the most common family of floral visiting Diptera comprising 99% of the total caught.

Coleoptera

Coleoptera (Table 3.2) were significantly higher ($p<0.05$) in abundance on the mechanical plus burn treated plots in 2004 and 2003 ($p\leq0.079$). Species richness (Table 3.3) 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 3.2). 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.

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 3.2). Species richness was significantly higher ($p\leq0.07$) on the mechanical plus burn treatment plots than on the mechanical only or control plots (Table 3.3). Walking transect surveys of butterflies and flowering plants also showed no differences among the treatments. Hesperiidae (mostly

Thorybes spp.) was the most common family captured in traps on all treatments, but they were rarely seen during the surveys.

Regression analyses of change in basal area and percent plant cover found a relationship of increased plant cover with decreasing basal area (Figure 3.4). Total pollinator abundance also increased as basal area decreased or as percent plant cover increased (Figure 3.5 & 3.6).

Discussion

Hymenoptera are the most important order of pollinators, with many species restricted to specific groups of plants. Bees (Apoidea) are the most highly adapted insects structurally and behaviorally for pollinating flowering plants. Many native bees depend on habitats resulting from extensive land use for food and nesting sites (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 removal plus burn treatment plots, which had the greatest amount of disturbance. The mechanical plus burn treatments may have provided more bare ground, in which ground-nesting bees could build nests, which may be one reason for the increased abundance of Halictidae and other bee families on these plots. Many of the genera and species of Hymenoptera we captured nest in the ground or within the piths of plants. However, the mechanical shrub removal plus burn treated plots also had the greatest reduction in tree basal area and the resulting increase herbaceous plant growth (Figure 3.4), so the higher numbers of bees in general 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 diversity 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 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, 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 evident during our surveys 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.

As a side note, during one of the surveys (June 2004), Diana fritillary butterflies (*Speyeria diana*) were observed on all three mechanical plus burn plots visiting flowering sourwood (*Oxydendrum arboreum*). This butterfly species is considered to be a federal species of concern in North Carolina by the Fish and Wildlife Service, Asheville, NC and is also on the North Carolina Animal Watch List compiled by the North Carolina Natural Heritage Program (Legrand et al. 2004). It has been eradicated in portions of eastern North Carolina (Vaughan 2005). Our observations are consistent with Thill et al. (2003) who reported that thinning and burning on plots in Arkansas resulted in higher abundances of the Diana fritillary due to increased abundance of nectar resources.

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 removal 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 resulting in greater herbaceous plant cover. 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 diversity. In this study, the mechanical shrub removal plus burn treatments proved to be the best for increasing pollinator abundance. However, 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.

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; Kearns et al. 1998; Kremen and Ricketts 2000; Allen-Wardell et al. 1998), so research to help fill knowledge gaps about pollinator habitat requirements should be considered a priority.

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Table 3.1. Insect genera and species and total numbers captured in all traps on fire and fire surrogate treatment plots on the Green River Game Management Area near Hendersonville, NC.

Order	Family	Genus/Species	Total Captured
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
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
		Erynnis spp.	24
		Hesperia spp.	5
		Nastra spp.	16
		Poanes yehl	11
		Poanes zabulon	17
		Polites spp.	5
		Thorybes spp.	163
		Unknown sp.	3
	Lycaenidae	*Everes comyntas*	1
		Satyrium calanus	2
		Satyrium sp. 1	1
		Strymon spp.	9
	Nymphalidae	*Vanessa cardui*	1
		Phyciodes tharos	2
		Polygonia sp.	1
	Papilionidae	*Battus philenor*	8
		Eurytides marcellus	3
		Papilio glaucus	48
		Papilio troilus	60
	Pieridae	*Colias philodice*	2
	Satyridae	*Cyllopsis gemma*	2
		Enodia portlandia	1
		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

Table 3.2. Mean numbers (SE) of the orders and common families of flower visiting insects captured per plot on plots receiving four different treatments on the Green River Game Management Area near Hendersonville, NC during 2003 and 2004.

	Treatments[2]			
Orders and families[1]	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)$_b$

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

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

Table 3.3. Mean number (SE) of species of flower visiting insects captured per plot on plots receiving fire or fire surrogate treatments on the Green River Game Management Area near Hendersonville, NC during 2003 and 2004.

	Treatment[2]			
Order[1]	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)$_{b}$

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

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

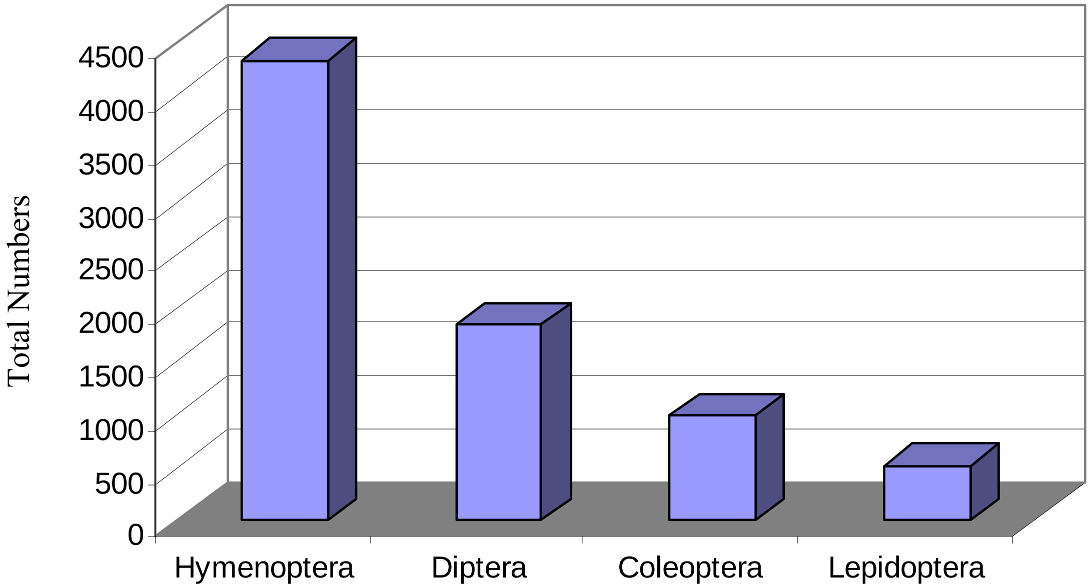

Figure 3.1. Total number of flower visitors captured during 2003 and 2004 in a forested habitat near Hendersonville, N.C.

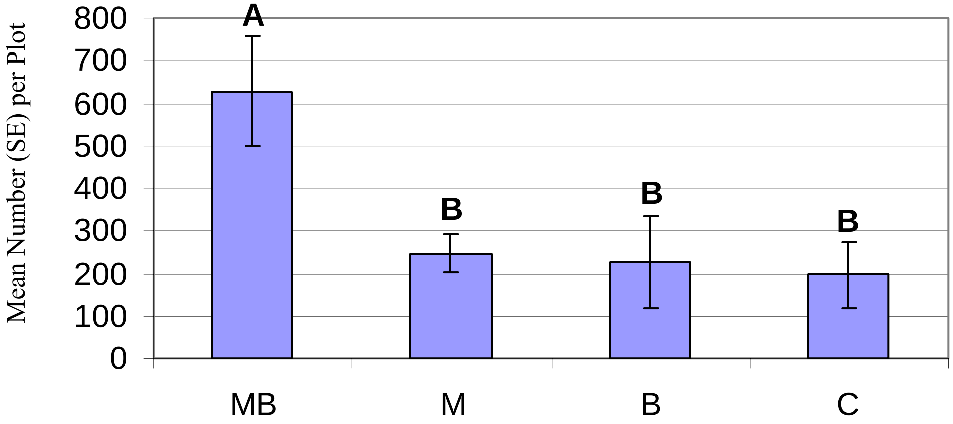

Figure 3.2. Mean number (SE) of flower visitors captured per plot during 2003 and 2004 on 10 ha plots receiving fire or fire surrogate treatments applied to a forested habitat on the Green River Game Management Area, near Hendersonville, N.C. Columns with the same letter are not significantly different at $p \leq 0.05$ (REGWQ, SAS 1985). Treatments were: MB=mechanical plus burn, M=mechanical, B=burn, C=control.

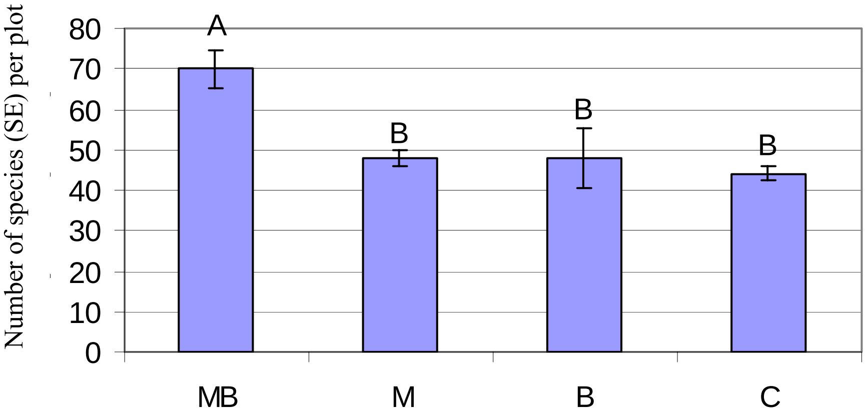

Figure 3.3. Mean number of species (SE) per plot of floral visiting insects captured in 2003 and 2004 on 10 ha plots receiving fire or fire surrogate treatments applied to forest plots near Hendersonville, N.C. Columns with the same letter are not significantly different at p=≤0.05 (REGWQ, SAS 1985). Treatments were: MB=mechanical plus burn, M=mechanical, B=burn, and C=control.

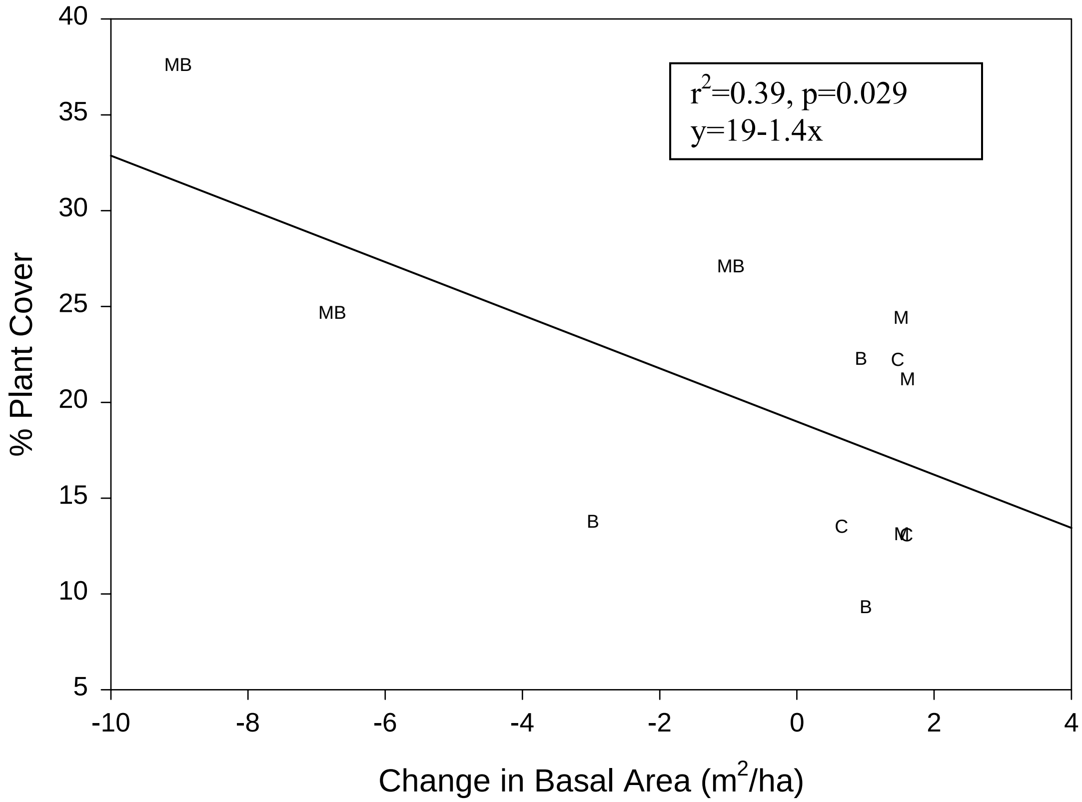

Figure 3.4. Linear regression of percent plant cover and change in basal area for 10 ha plots receiving various combinations of prescribed fire and mechanical brush removal. Negative numbers indicate a post-treatment decrease in basal area. Treatments were: MB=mechanical plus burn, B=burn only, M=mechanical only, and C=control.

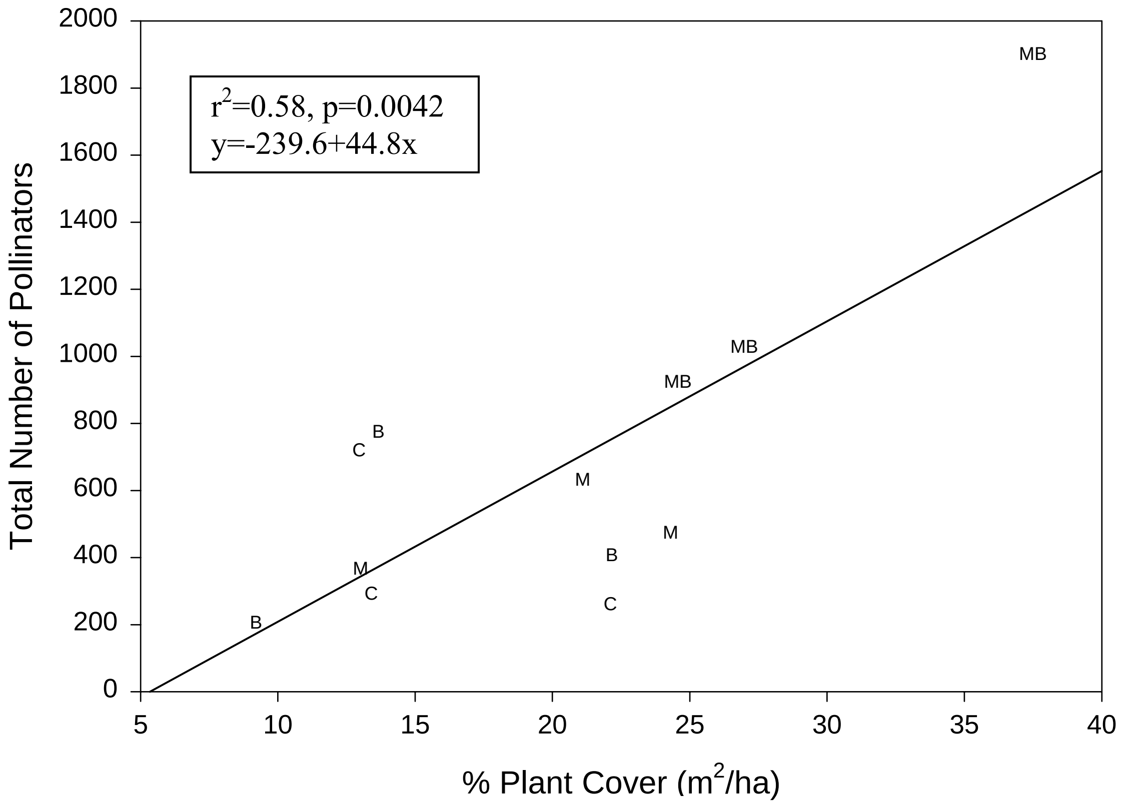

Figure 3.5. Linear regression of total pollinators captured in pan and malaise traps and percent herbaceous plant cover for 10 ha plots receiving various combinations of prescribed fire and mechanical brush removal. Treatments were: MB=mechanical plus burn, B=burn only, M=mechanical only, and C=control.

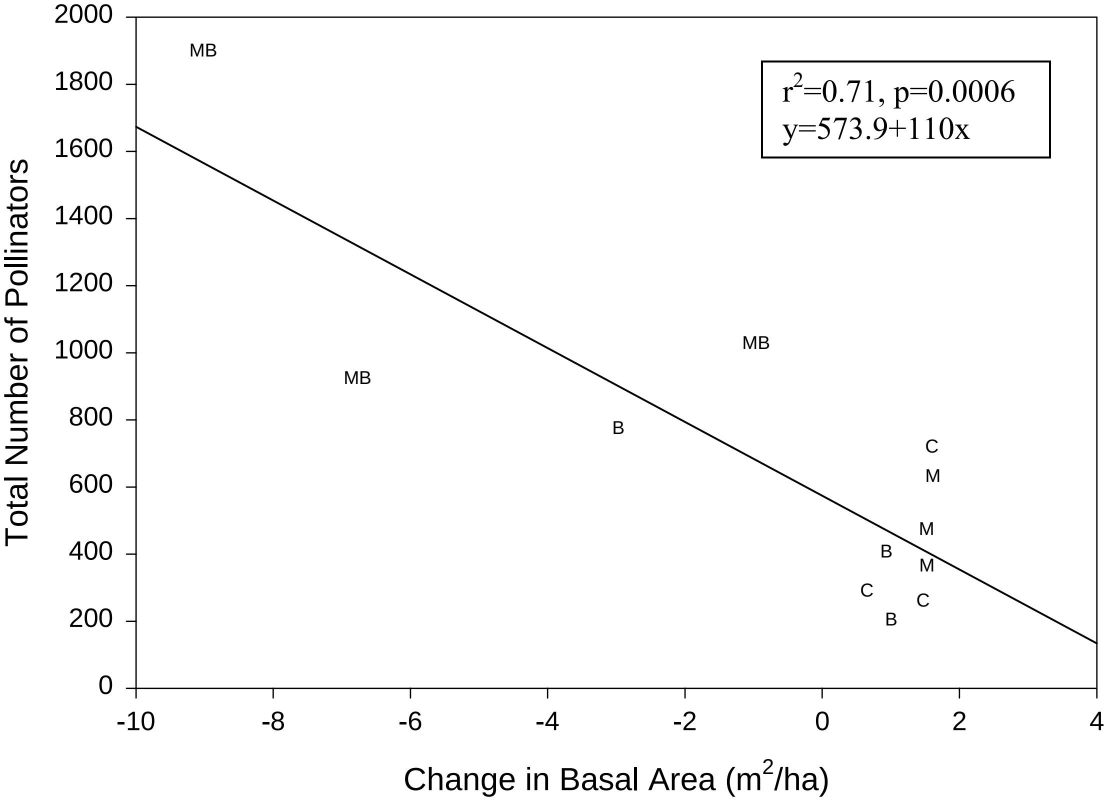

Figure 3.6. Linear regression of total pollinators captured in pan and malaise traps and change in basal area of 10 ha plots treated with various combinations of prescribed fire and mechanical brush removal. Negative numbers indicate a post treatment decrease in basal area. Treatments were: MB=mechanical plus burn, B=burn only, M=mechanical only, and C=control.

CHAPTER 4

EFFECTS OF PRESCRIBED FIRE AND FIRE SURROGATES ON FLOWER VISITING INSECTS OF THE COASTAL PLAIN PROVINCE IN ALABAMA[1]

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[1] J.W. Campbell, J.L. HanulA, K. Outcalt, and D.G. Brockway. To be submitted to Environmental Entomology

ABSTRACT

Pollination by insects in forests is an extremely important process that should be conserved. Currently, the effects of various forest management practices on floral visiting insect abundance or diversity is unknown. In 2003 and 2004, floral visiting insects were captured with malaise traps and colored pan traps from burned, thinned, thinned and burned, herbicide and burned, and untreated control plots of upland longleaf pine (*Pinus palustris*) forest in the Coastal Plain Province of Alabama. We caught 10,908 floral visitors representing four orders and 26 families. Hymenoptera was the most abundant and diverse order, with Halictidae being the most abundant family. Eight families of Hymenoptera were caught, comprising 57 species. We caught nine families and at least 41 species of Lepidoptera, six families and 26 species of Coleoptera, and only three families and 16 species of Diptera. Overall, our results indicated that none of the treatments we tested were better than others for enhancing general floral insect visitor abundance or diversity. However, Hymenoptera were more abundant on plots that were burned and Halictidae were caught in higher numbers on all disturbed plots compared to untreated controls. Mordellidae (Coleoptera) responded to thinning treatments in the second year of the study and flower visiting Scarabaeidae were also more abundant in thin only plots in 2004.

KEY WORDS: forest management, pollinators, bees, butterflies, prescribed burning, colored pan trap, malaise trap

Increasing evidence points toward declines in pollinators throughout the world. (Kearns and Inouye 1997, Buchmann and Nabhan 1996, Gess and Gess 1993, Vinson et al. 1993, Janzen 1974). Pollination by insects is vital for maintaining diversity in forests. For example, 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 pollinated by insects (Folkerts et al. 1993). Pollinators from natural areas are also important for nearby crop production (Kremen et al. 2002, Ricketts et al. 2004, Klein et al. 2003).

These facts emphasize our need to understand pollinator communities in natural areas where information about insect pollinator diversity and abundance is often lacking. This is particularly true for longleaf pine forests. A greater knowledge of the diversity, abundance, and ecology of native pollinators in these forests 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 longleaf forests throughout the southeastern United States for controlling midstory trees and shrubs, restoring understory plant communities, and reducing fuel amounts 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 thinning or use of herbicides may provide alternatives to problems associated with the use of prescribed fire while providing the same benefits. Due to the importance of pollinators, land management practices in forested areas should try to minimize disruption of pollinating systems. However, little is known about how fire or other techniques used to reduce fuel affect pollinating insect populations and diversities.

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, protects some plant species from diseases, and allows perennial grasses and herbaceous plants to grow (Kerstyn and Stiling 1999, Waldrop et al. 1992). Fire is also important for inducing flowering in many plants, increasing germination, and freeing minerals and nutrients for plant uptake (Brewer and Platt 1994). Therefore, fire could be beneficial for pollinators, but its effect on these insects has not been widely studied.

Likewise, alternatives to fire such as mechanical thinning and herbicide use could also 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. Limited herbicide use has been shown to have only minor and temporary impacts on plant communities, which appear to rebound quickly (Miller and Miller 2004) and in some cases intensive woody shrub control with herbicides increased understory richness and abundance (Miller et al. 2003).

Fires that have been ignited by natural causes and humans have helped evolve and shape ecosystems (Pyne 1982). Fire used by Native Americans for hunting and agricultural purposes was important in shaping Coastal Plain forests well before Europeans arrived (Maxwell 1910).

However, in most areas, European descendents have altered fire frequency and intensity (most notably within the last century), resulting in a reshuffling of plant and animal communities. Due to a combination of factors, longleaf pine forests have decreased significantly within its natural range being replaced by slash (*P. elliottii*) and loblolly pines (*P. taeda*) (Wright and Bailey 1982). In terms of area loss, longleaf pine forests have been reduced more drastically than any other type of forest (Simberloff 1993), declining as much as 98% since pre-settlement times (Noss 1989). The majority of biological diversity in longleaf forests is related to the groundcover of plants (Simberloff 1993), which can be greatly enhanced by burning (Lewis and Harshbarger 1976, Wright and Bailey 1982, Pack et al. 1988). Therefore, this suggests that flower visiting insect populations could be enhanced by burning and other techniques that increase herbaceous growth.

The objectives of our study were to determine how various groups of pollinating insects vary in abundance and diversity in response to prescribed burning or alternative practices. We were particularly interested in whether fire surrogate treatments would have similar effects as fire alone and whether any differences we observed among treatments would be immediate or delayed. These data will provide us with a better understanding of interactions between insect pollinators and fire or other disturbances within longleaf pine ecosystems.

Materials and Methods

This study was conducted on the Solon Dixon Experimental Forest near Andalusia, Alabama. The forest is primarily longleaf pine (*Pinus palustris*), with an understory composed mostly of yaupon holly (*Ilex vomitoria*). The experiment was laid out as a randomized complete block design consisting of three blocks of five treatments each. Treatments applied to 10 hectare plots consisted of: (1)untreated control, (2)growing season prescribed burn, (3)thin only, (4)thin plus growing season burn, and (5)herbicide plus growing season burn (Table 4.1). The thinning treatments consisted of cutting and removing co-dominant or suppressed trees to produce a residual basal area of 11.5 to 13.8 m^2/ha. The thin plus burn plots were treated the same as the thin only treatments and then burned. The herbicide plus burn plots had an application of 4.5% solution of Garlon 4™ herbicide plus Timberline 90™ surfactant and then later burned. The herbicide was applied using backpack sprayers with all woody vegetation up to approximately six feet targeted except longleaf pine seedlings and saplings. Prescribed burns were conducted on the burn only and thin plus burn treatments every two years during this study, whereas the herbicide plus burn plots were burned only once (Table 4.1). Several burning techniques, such as back fire, spot fire, and flanking, were used on each plot that was burned (Outcalt 2003). 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 and Hanula (in review). Pan traps consisted of 511 ml plastic bowls (Solo^{TM}) of different colors filled approximately three-fourths 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. The bowls were held approximately 0.5 meters 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 3 m conduit pole was inserted inside it to hold up the pole and malaise trap. In addition, malaise traps had four cloth, color (red, white, blue, and yellow) panels (0.3 m^2 each) pinned onto each side (one color per side) of the malaise trap. The collecting containers were filled approximately one-third full with a soapy water solution. Samples from pan and malaise traps were immediately stored in 70% alcohol until they were identified.

At each plot we used five groups of pan traps (one of each color/group) and one color malaise trap. The pan traps 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 pan and malaise traps were placed randomly among these center grid points. The pan traps at a given grid point were placed approximately one meter apart. Traps were operated at 4-6 week intervals from April-October of 2003 and 2004. We trapped five times each year, with each trapping period lasting seven days.

Flowering plant and 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 (New et al. 1995). We also identified plants that were flowering during survey walks. We collected samples of plants we could not identify in the field. Flowering plants were classified as being (1) abundant (found throughout the plot), (2) common (sporadically found throughout a plot), and (3) rare (only a few plants present). Surveys were done between 10 A.M and 3 P.M. 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 captured in the bowl or malaise traps 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. Since we did not measure pollination effectiveness of insects we captured and included in our analysis, they can be thought of as floral visitors. However, we use these terms interchangeably. Numerous insects other than pollinators and floral visitors were caught in our traps, so we based our decision on which insects to include on published literature and field observations. We included insects that were likely pollinators although their pollinator role may be of minor. If insects were noticed actively visiting flowers while we were working in the plots, we included them in the analysis even if there was little evidence of their 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 2003-2004 (post-treatment). Since 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 and diversity 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 independent variables, and the various orders and families of floral visitors as dependent variables. The Ryan-Einot-Gabriel-Welsch multiple range test (REGWQ) 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 versus change in basal area, percent plant cover, and species diversity of plants.

Results

Overall Abundance and Diversity

We caught 10,908 floral visitors from four orders (Fig. 4.1) and 26 families. Hymenoptera was the most abundant and diverse order, with Halictidae being the most abundant family. Eight families of Hymenoptera were caught, comprising 57 species. We caught nine families and at least 41 species of Lepidoptera, six families and 26 species of Coleoptera and only three families and 16 species of Diptera. We captured approximately equal numbers of floral visitors on all plots regardless of treatment (Fig. 4.2) and overall species richness was not significantly different among the treatments (Table 4.2). Table 4.3 lists genera and species that were captured during the study.

Hymenoptera

In 2003 the control was significantly ($p \leq 0.07$) lower in Hymenoptera abundance than all treatments except the thin only treatment and in 2004 the burn only treatment had significantly higher ($p \leq 0.05$) numbers of Hymenoptera than the control plots (Table 4.4). At the family level, only the Halictidae ($p \leq 0.05$) were significantly different among treatments. In 2003, control plots had significantly fewer Halictidae than other treatments and in 2004 the burn only plots had significantly higher numbers than plots receiving thin only, herbicide plus burn and controls. Thin plus burn plots were not significantly different from the other treatments (Table 4.4). Halictidae made up ~65% of the Hymenoptera caught, with *Dialictus* the most common genus.

Dialictus sp. 1, a common species captured, showed similar trends over the two year period (Fig. 4.3). One common species of Sphecidae (*Podium* sp.) was captured in significantly higher numbers on the control plots compared to the other treatments except the thin only plots (Fig. 4.3).

Diptera

No significant differences were observed for Diptera abundance at the order or family level. Approximately 90% were Syrphidae, with *Toxomerus* and *Chalcosyrphus* being the dominant genera (Table 4.3). *Toxomerus geminatus*, a common dipteran species, was significantly higher in abundance ($p \leq 0.05$) on herbicide plus burn plots compared to control and thin plus burn plots, but the burn only and thin only plots were not different from any treatment (Fig. 4.3). Over twice as many Diptera were captured in 2003 compared to 2004 (Table 4.4) but species richness was similar among the treatments (Table 4.2).

Coleoptera

The dominant family was Buprestidae (primarily *Acmaeodera* spp.) comprising nearly 60% of the Coleoptera catches. Mordellidae composed almost 40% of the Coleoptera catches, where as Scarabaeidae encompassed less than 2%. No differences were observed for species richness among the treatments (Table 4.2). Total numbers of Coleoptera caught were similar across all treatments in both sample years. However, Scarabaeidae were caught in higher ($p \leq 0.05$) numbers on the thin only plots in 2004 and Mordellidae were significantly higher on thin only and thin plus burn treatments (Table 4.4). *Mordellistena* sp. 1, a common mordellid captured, also showed a similar trend (Fig. 4.3). However, overall Mordellidae abundance on control plots was similar to other treatments in both years.

Lepidoptera

Most Lepidoptera caught were in the family Hesperiidae comprising approximately 60% of the total (Table 4.2). The dominant genus was *Thorybes*, which made up 40% of the Lepidoptera caught. Papilionidae comprised about 17% of the Lepidoptera.

Regression analysis of tree basal area, percent plant cover, and plant diversity versus pollinator abundance showed no significant relationships. Likewise, abundance of flowering plants was not correlated with total numbers of floral visiting insects.

Discussion

Hymenoptera are the most important order of pollinators and bees (Apoidea) are the most highly adapted for pollinating flowering plants. Many native bees depend on habitats that have been developed through extensive land use for food or nesting sites (Steffan-Dewenter 2002), which suggest that forest management may positively influence some native bee populations. However, in our study we found that disturbances such as thinning stands, burning or the two combined had little effect on bees one and two years after treatments were applied. The only differences we noted were among the Halictidae which were higher on burned plots in 2004 but occurred in approximately equal numbers on all plots except controls in 2003. This may indicate that Halictidae respond positively to prescribed burning in the year the burn is applied (2004) or it may be that the traps were more evident immediately after a fire. Most Sphecidae are ground nesters but *Podium sp.* nests aerially. Many of the treatments may have destroyed areas for aerial nesting wasps, which could have caused the untreated controls to have higher numbers.

The Diptera are considered the second most important but often overlooked floral visiting insect order (Larson et al. 2001). Syrphidae are some of the most significant floral visitors among the Diptera and, except for a few Bombyliidae and Conopidae, Syrphidae were the most common flower visiting Diptera we captured. The vegetation of the treated plots appeared to rebound fairly quickly after a treatment was applied. Many syrphid larvae (i.e. *Toxomerus* spp.) feed on aphids which, due to large amounts of new vegetation on herbicide plus burn treatments, may have enabled aphids and, hence, *Toxomerus geminatus*, to increase in abundance. They were also more abundant on the burn only and thin only plots compared to the thin plus burn treatments. It is unknown why these syrphid flies were not abundant on the thin plus burn treatments.

We also caught high numbers of floral visiting Coleoptera and Lepidoptera but saw very few treatment effects and no general trends. All plots (except controls) appeared to rebound quickly with herbaceous vegetation growth following treatment. Many studies have shown that single applications of forestry herbicides have small and only temporary impacts on plants, which recover quickly (Neary et al. 1990, Boyd et al. 1995, Miller et al. 1999, Miller and Miller 2004). Likewise, burning often stimulates herbaceous plant growth. This type of quick plant rebound was also observed on our treated areas during survey walks and may be one reason abundance and diversity among the floral visitor groups we sampled remained the same. Our plots also occurred in a mosaic of agricultural fields, recent clear cuts and young plantations which may have influenced pollinator numbers in our plots depending on the flight ability of the insects. Even though no treatment was clearly better for pollinating insects two years after treatment, prescribed burning or thinning periodically applied over a longer time frame may result in population changes. However, our study shows that pollinators were not negatively impacted by thinning, burning, or dormant season applications of herbicide to reduce shrub understory plants. In contrast, Campbell et al. (in review) found that shrub removal followed by prescribed burning resulted in increased numbers of most floral visitors studied.

These studies illustrate the complexity of forest insect pollinator interactions with various forest management practices. Despite the enormous importance of pollinating systems, our understanding of these systems is far from complete and further research is needed to help fill gaps in our knowledge of pollinators in forest ecosystems.

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Table 4.1. Dates herbicide applications, thinning, and prescribed burns were applied to 12 treated plots on the Solon Dixon Experimental Forest, near Andalusia, AL.

Treatment Plot	Herbicide	Thinning	Burning
TB		Feb-02	April 5, 2002 & April 28, 2004
TB		Mar-02	May 22, 2002 & May 4, 2004
TB		Apr-02	May 1, 2002 & April 29, 2004
T		Feb-02	
T		Mar-02	
T		Apr-02	
B			April 23, 2002 & May 6, 2004
B			May 21, 2002 & July 6, 2004
B			May 15, 2002 & April 15, 2004
HB	September 23-28, 2002		April 15, 2003
HB	September 28-30, 2002		May 13, 2003
HB	October 1-2, 2002		April 16, 2003

TB=thin plus burn, T=thin, B=burn, HB=herbicide plus burn

Table 4.2. Mean number (SE) of species within pollinator orders captured per plot among five treatments in longleaf pine forests of the Coastal Plain of Alabama during 2003 and 2004.

	Treatment				
Insect Order	TB	B	T	HB	C
Hymenoptera	27.7(.88)$_a$	17.7(.67)$_a$	26(1.5)$_a$	24.7(.33)$_a$	25(1.0)$_a$
Lepidoptera	18.7(2.3)$_a$	17.7(.67)$_a$	17.7(2.2)$_a$	17(1.7)$_a$	18.3(2.7)$_a$
Diptera	7(.57)$_a$	6.7(.67)$_a$	7(.57)$_a$	7.7(.33)$_a$	7(.57)$_a$
Coleoptera	10.3(.67)$_a$	11.3(1.3)$_a$	9(1.2)$_a$	11(2.1)$_a$	8.7(.67)$_a$

Within each order, means followed by the same letter(s) are not significantly different at p=0.05. (REGWQ, SAS 1985). Treatments were: TB=thin plus burn, B=burn, T=thin, HB=herbicide plus burn, and C=control.

Table 4.3. Insect genera and species caught and total numbers captured in all traps on fire and fire surrogate treatment plots on the Solon Dixon Experimental Forest near Andalusia, AL.

Order	Family	Genus/Species	Total Captured
Hymenoptera	Andrenidae	*Perdita* sp. 1	1
		Perdita sp. 2	6
		Perdita sp. 3	1
	Anthophoridae	*Anthophora abrupta*	9
		Ceratina cockerelli	16
		Epeolus lectoides	6
		Melissodes bimaculata	16
		Melissodes comptoides	12
		Melissodes tepaneca	2
		Melissodes sp. 1	11
		Melissodes sp. 2	5
		Melitoma taurea	5
		Melitoma sp.	4
		Ptilothrix bombiformis	24
		Svastra sp.	109
	Apidae	*Apis mellifera*	89
		Bombus impatiens	47
		Bombus pennsylvanicus	15
		Bombus vagans	109
		Bombus virginica	10
		Psithyrus variabilis	3
		Xylocopa virginica	27
	Halictidae	*Agapostemon sericeus*	18
		Augochlorella striata	9
		Augochloropsis metallica	444
		Dialictus sp. 1	1901
		Dialictus sp. 2	28
		Dialictus sp. 3	16
		Dialictus sp. 4	8
		Dialictus sp. 5	2
		Evylaeus sp.	66
		Halictus parallelus	1
		Lasioglossum sp.	44
		Nomia sp.	85
		Sphecodes sp. 1	52
		Sphecodes sp. 2	3
	Megachilidae	*Dianthidium* sp.	1
		Heriades carinata	2
		Hoplitis producta	4
		Megachile campanulae	1
		Megachile georgica	2
		Megachile mendica	35
		Megachile sp. 1	1
		Megachile sp. 2	1
		Osmia albiventris	3

		Osmia georgica	29
		Osmia lignaria	32
	Scoliidae	*Campsomeris plumipes*	454
		Campsomeris quadrimaculata	5
	Sphecidae	*Ammophila aureonotata*	23
		Ammophila urnana	12
		Cerceris fumipennis	1
		Isodontia sp.	22
		Liris sp.	181
		Podium sp.	102
	Tiphiidae	*Myzinium berlyi*	5
		Myzinium caroliniana	7
Diptera	Bombyliidae	*Anthrax argyropygus*	6
		Anthrax irroratus	23
		Anthrax tigrinus	4
		Anthrax sp.	1
		Bombylius major	68
	Conopidae	*Physocephala* sp.	5
		Physoconops excisus	3
		Stylogaster sp.	7
	Syrphidae	*Allograpta obliqua*	6
		Chalcosyrphus sp.	631
		Milesia virginiensis	2
		Ocyptamus sp.	4
		Syrphus torvus	21
		Syrphus sp.	1
		Toxomerus geminatus	197
		Toxomerus sp.	21
Coleoptera	Buprestidae	*Acmaeodera pulchetta*	3
		Acmaeodera sp.	2611
		Agrilus sp.	37
		Anthaxia sp.	1
		Brachys sp.	8
		Buprestis sp. 1	2
		Buprestis sp. 2	2
		Chrysobothris sp. 1	38
		Chrysobothris sp. 2	1
		Chrysobothris sp. 3	1
		Dicera tuberculata	1
	Cantharidae	*Chauliognathus* sp.	2
	Cerambycidae	*Leptura lineola*	4
		Leptura plebeja	2
		Stranglia luteicornis	2
		Typocerus lunulatus	4
		Typocerus zebratus	37
	Meloidae	*Epicauta pennsylvannia*	6
		Lytta sp.	2
	Mordellidae	*Mordella marginata*	73

		Mordella sp. 1	41
		Mordellistena sp. 1	1667
		Mordellistena sp. 2	47
	Scarabaeidae	*Trichiotinus piger*	25
		Trichiotinus sp.	1
		Trigonopeltastes delta	29
Lepidoptera	Hesperiidae	*Achalarus lycides*	2
		Amblyscirtes aesculapius	3
		Atalides halesus	1
		Epargyreus clarus	3
		Erynnis sp.	4
		Hesperia sp.	20
		Nastra sp.	112
		Poanes yehl	16
		Poanes zabulon	6
		Polites sp.	58
		Thorybes sp.	455
		Urbanus proteus	1
		Unknown	2
	Lycaenidae	*Everes comyntas*	1
		Satyrium sp. 1	2
		Satyrium sp. 2	26
		Strymon sp.	4
		Unknown	2
	Nymphalidae	*Agraulis vanillae*	5
		Chlosyne sp.	3
		Libytheana carinenta	1
		Phycoides tharos	8
		Vanessa cardui	2
		Vanessa virginiensis	2
	Papilionidae	*Battus philenor*	37
		Eurytides marcellus	7
		Papilio glaucus	39
		Papilio palamedes	31
		Papilio troilus	89
	Pieridae	*Eurema daira*	2
		Eurema lisa	4
		Eurema nicippe	11
		Phoebis sennae	31
		Unknown	1
	Riodinidae	*Calephelis virginiensis*	26
	Satyridae	*Cyllopsis gemma*	3
		Herneuptychia sosybius	18
		Megisto cymela	12
		Satyrium sp. 1	9
		Satyrium sp. 2	1
		Unknown	6
	Sesiidae	*Synanthedon* sp.	2
		Unknown	1

Sphingidae	*Darapsa pholus*	5
	Lapara conifer	58
	Sphinx sp.	2

Table 4.4. Mean number (SE) of orders and common families of flower visiting insects captured per plot among the five treatments applied to mature longleaf pine forests on the Solon Dixon Experimental Forest, near Andalusia, AL.

	Treatment				
Order or Family	TB	B	T	HB	C
2003					
Hymenoptera*	142.3(21.7)$_{a}$	147.7(21.6)$_{a}$	108.3(17.7)$_{ab}$	145(12.5)$_{a}$	85(16.2)$_{b}$
Halictidae	95(11.8)$_{a}$	91.3(3.2)$_{a}$	72.3(15.7)$_{a}$	99.3(13.8)$_{a}$	39.3(4.9)$_{b}$
Anthophoridae	6.7(1.9)$_{a}$	7.0(2.0)$_{a}$	4.0(1.0)$_{a}$	5.7(3.3)$_{a}$	7.3(3.9)$_{a}$
Apidae	8.7(.88)$_{a}$	11.7(5.8)$_{a}$	6.7(.33)$_{a}$	11.3(2.4)$_{a}$	5.7(2.7)$_{a}$
Scoliidae	14.7(5.4)$_{a}$	13(7.5)$_{a}$	11.3(2.7)$_{a}$	14.3(.88)$_{a}$	14(4.5)$_{a}$
Sphecidae	11(5.3)$_{a}$	16.7(11.1)$_{a}$	9.3(1.9)$_{a}$	6.7(2.4)$_{a}$	13.7(2.2)$_{a}$
Lepidoptera	53.7(9.8)$_{a}$	46.7(6.3)$_{a}$	54(7.2)$_{a}$	55.7(12.0)$_{a}$	49(6.7)$_{a}$
Hesperiidae	29.7(4.7)$_{a}$	28.7(7.2)$_{a}$	32.7(7.5)$_{a}$	30.7(4.3)$_{a}$	34.3(5.2)$_{a}$
Papilionidae	11.3(3.2)$_{a}$	6.7(.33)$_{a}$	13.7(3.7)$_{a}$	11.7(2.8)$_{a}$	8.7(2.6)$_{a}$
Diptera	41.7(8.9)$_{a}$	47.3(7.3)$_{a}$	42.3(8.8)$_{a}$	78.7(18.7)$_{a}$	33.3(7.2)$_{a}$
Syrphidae	38.3(9.2)$_{a}$	43.3(7.7)$_{a}$	41(8.6)$_{a}$	73.7(17.3)$_{a}$	29.7(7.4)$_{a}$
Coleoptera	172(36.3)$_{a}$	95(20.0)$_{a}$	154(19.9)$_{a}$	172(56.0)$_{a}$	150(15.6)$_{a}$
Mordellidae	33(4.2)$_{a}$	48.7(12.9)$_{a}$	83.3(17.0)$_{a}$	41(15.5)$_{a}$	71.7(23.4)$_{a}$
Buprestidae	134.3(40.1)$_{a}$	42(7.2)$_{a}$	65(14.0)$_{a}$	127.7(52.3)$_{a}$	76.7(11.4)$_{a}$
Scarabaeidae	2(1.0)$_{a}$	1.7(.33)$_{a}$	5.5(4.5)$_{a}$	1.0(0.0)$_{a}$	1.0(0.0)$_{a}$
2004					
Hymenoptera*	195.3(66.0)$_{ab}$	210.3(35.2)$_{a}$	109.7(17.9)$_{b}$	123.7(26.2)$_{ab}$	108.3(22.5)$_{b}$
Halictidae	142.7(52.7)$_{ab}$	160.7(36.4)$_{a}$	61.3(15.9)$_{b}$	70(18.5)$_{b}$	60.3(16.9)$_{b}$
Anthophoridae	6.7(2.3)$_{a}$	11.3(6.6)$_{a}$	7.3(1.5)$_{a}$	8.0(2.3)$_{a}$	9.0(1.5)$_{a}$
Apidae	9.7(4.6)$_{a}$	11(.58)$_{a}$	10(.58)$_{a}$	11.3(.67)$_{a}$	14(4.0)$_{a}$
Scoliidae	24.3(6.7)$_{a}$	12.7(5.2)$_{a}$	16(1.2)$_{a}$	23.7(7.6)$_{a}$	9(1.0)$_{a}$
Sphecidae	7.7(4.7)$_{a}$	13.3(7.3)$_{a}$	11.7(.67)$_{a}$	9.7(2.3)$_{a}$	14(4.0)$_{a}$
Lepidoptera	25.3(3.5)$_{a}$	31(5.5)$_{a}$	22.3(4.6)$_{a}$	16.7(3.3)$_{a}$	24.7(5.8)$_{a}$
Hesperiidae	16.7(4.7)$_{a}$	21.7(3.9)$_{a}$	13.7(2.3)$_{a}$	6.7(1.9)$_{a}$	14.3(3.8)$_{a}$
Papilionidae	3(.58)$_{a}$	3(0.0)$_{a}$	3(1.0)$_{a}$	2.5(1.5)$_{a}$	7.5(3.5)$_{a}$
Diptera	11.3(3.5)$_{a}$	30.7(16.9)$_{a}$	14.3(2.3)$_{a}$	11.3(.67)$_{a}$	22(2.6)$_{a}$
Syrphidae	8(2.6)$_{a}$	27.7(16.0)$_{a}$	10(0.0)$_{a}$	7.7(.88)$_{a}$	14.7(2.4)$_{a}$
Coleoptera	257.3(106.7)$_{a}$	79(16.5)$_{a}$	205.3(28.1)$_{a}$	126.7(67.9)$_{a}$	137(6.2)$_{a}$
Mordellidae	102.3(24.3)$_{a}$	43(8.3)$_{b}$	100.7(9.6)$_{a}$	32(10.5)$_{b}$	53(15.1)$_{ab}$
Buprestidae	152.7(81.3)$_{a}$	31.7(7.3)$_{a}$	96(18.6)$_{a}$	92(56.3)$_{a}$	83.7(20.5)$_{a}$
Scarabaeidae	1.5(.50)$_{b}$	1.7(.33)$_{b}$	8.5(1.5)$_{a}$	2.0(0.0)$_{b}$	1.0(0.0)$_{b}$

Within each order or family, means followed by the same letter(s) are not significantly different at $p \leq 0.05$. Orders or families followed with an * indicate $p \leq 0.10$ (REGWQ, SAS 1985). Treatments were: TB=thin plus burn, B=burn, T=thin, HB=herbicide plus burn, and C=control.

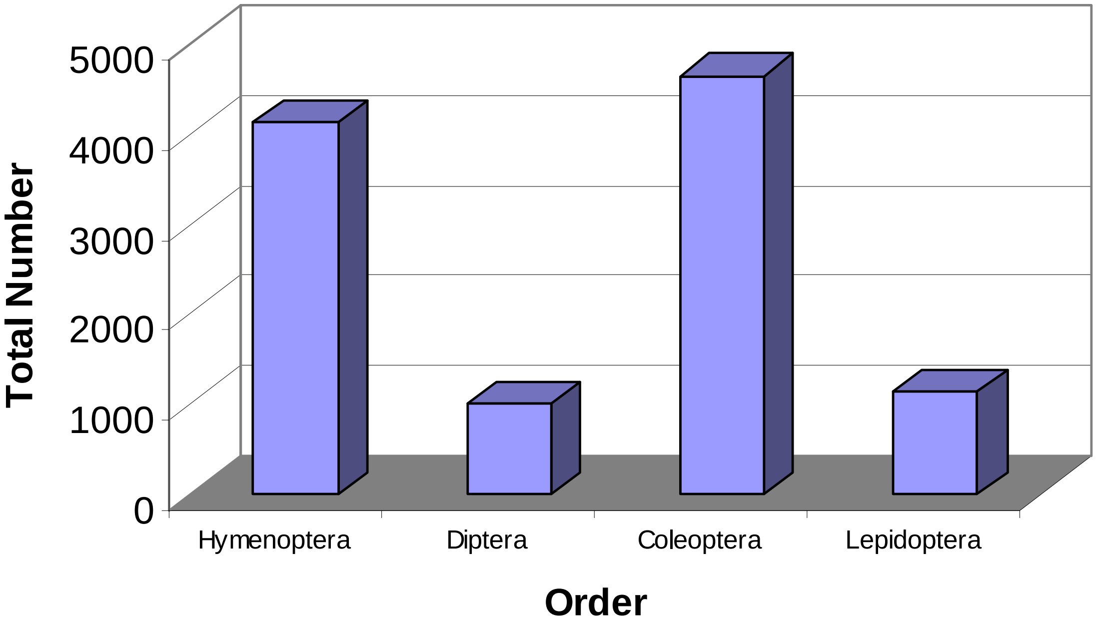

Fig. 4.1. Total number of pollinators captured during 2003 and 2004 in a longleaf pine forest near Andalusia, AL.

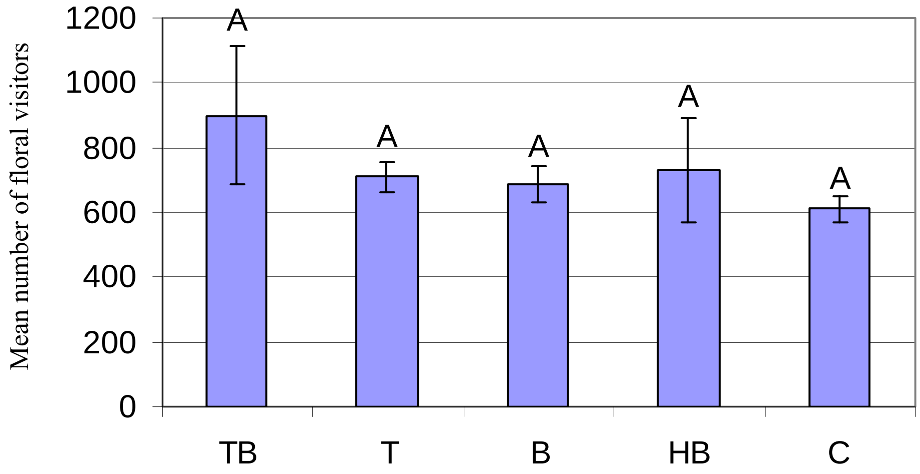

Fig. 4.2. Mean number (SE) of pollinators captured per plot during 2003 and 2004 among treatments applied to a forested habitat on the Solon Dixon Experimental Forest, near Andalusia, AL. Columns with the same letter are not significantly different at P<0.05 (REGWQ, SAS 1985). Treatments were: TB=thin plus burn, T=thin, B=burn, HB=herbicide plus burn, and C=control.

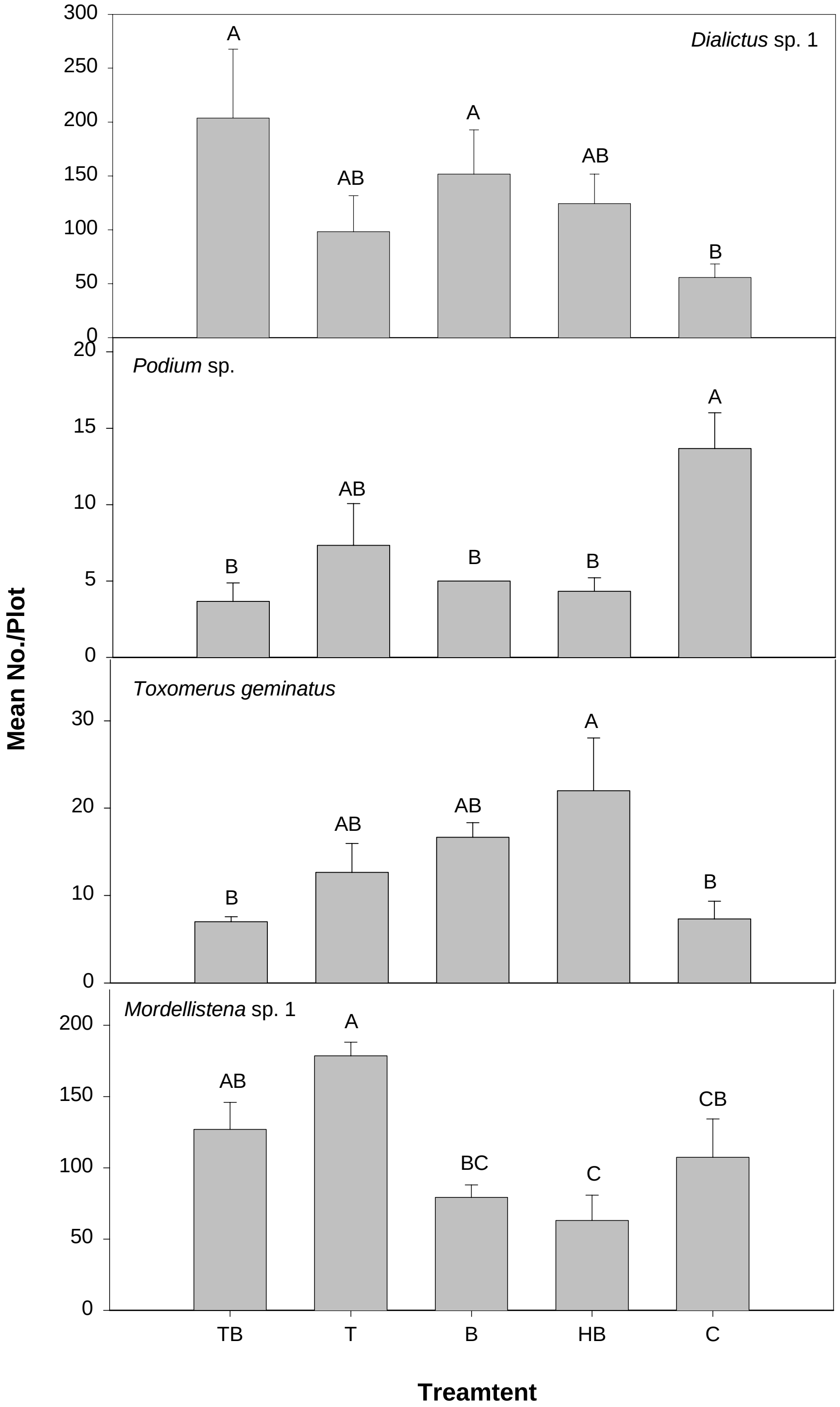

Fig. 4.3. Mean number (SE) of pollinating insect species captured per plot during 2003 and 2004 among treatments applied to a longleaf pine forest on the Solon Dixon Experimental Forest, near Andalusia, AL. Columns with the same letter are not significantly different at p=0.05 (REGWQ, SAS 1985). Treatments were: TB=thin plus burn, T=thin, B=burn, HB=herbicide plus burn, and C=control.

CHAPTER 5

EFFECTS OF PRESCRIBED FIRE AND FIRE SURROGATES ON SAPROXYLIC COLEOPTERA IN THE SOUTHERN APPALACHIANS OF NORTH CAROLINA[1]

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[1] Campbell, J.W., J.L. Hanula, and T.A. Waldrop. To be submitted to Forest Ecology and Management

Abstract

We examined the effects of forest management practices (prescribed burning, mechanical thinning, and prescribed burn plus mechanical thinning) on saproxylic forest Coleoptera in the Southern Appalachian Mountains of North Carolina. During the two-year study, we captured 37,191 Coleoptera with baited multiple-funnel traps, comprising 20 families and 122 species that were used for our analysis. Saproxylic beetle numbers increased greatly from the first year to the second year on all treatments. Species richness and total abundance of Coleoptera were not significantly affected by the treatments. However, several families (e,g,, Elateridae, Cleridae, Trogositidae, Scolytidae) were significantly more abundant on treated plots. Many species, including various species of Scolytidae, showed significant differences in abundance among the treatments. However, these species (*Hylastes salebrosus, Ips grandicollis, Xyloborinus saxeseni, Xyleborus* sp.*, Xyleborus atratus)* varied in their responses to the treatments. Other Coleoptera, *Pityophagus* sp. (Nitidulidae), *Hylobius pales* (Curculionidae), *Xylotrechus sagittatus* (Cerambycidae) also responded differently depending on treatment. Species richness was not significantly different for the spring trapping seasons, but the fall 2003 sample had a higher number of species on mechanical only and mechanical plus burn plots compared to controls. Linear regression analysis suggests that increased dead wood caused by hot fires on mechanical plus burn and burn only treatments resulted in increases among various Coleoptera families and species. We saw on evidence that the treatments negatively impacted saproylic species and in most case they benefited from the disturbances.

Key words: prescribed burn, forest management, Scolytidae, saproxylic insects, multiple funnel trap, coarse woody debris

Introduction

Saproxylic beetles are a diverse insect group that is dependent on dead wood for food and habitat. They are the most abundant of all saproxylic invertebrates (Berg et al., 1994) and comprise more than 30% of the beetle fauna found within a forest (Speight, 1989). Saproxylic beetles are an important component of a forest ecosystem because they decompose wood and recycle nutrients and organic matter back into the soil (Grove, 2002). Woody material is broken down by the beetles through tunneling and feeding action, and indirectly by facilitating bacteria and fungal growth that cause wood decay (Speight, 1989). In addition, saproxylic insects are important components of the food web supporting a variety of invertebrate and vertebrate fauna (Tanner, 1941, Harmon et al., 1986, Speight, 1989, Hanula and Horn, 2004).

Some saproxylic beetles (e.g. Scolytidae) are considered pests because they cause economic damage by degrading lumber and killing trees. However, the few pests species that are well known among landowners and researchers are greatly outnumbered by lesser known beetles that are valuable forest ecosystem components and do not have negative economic impacts. Therefore, understanding how these unique Coleoptera respond to various forest management practices is important for conserving them. In many areas, forest management is the main influence affecting forest dynamics (Kuuluvainen, 2002). The majority of saproxylic species are specialists and not very mobile, which makes them susceptible to habitat isolation resulting from large distances between pieces of dead wood (Nilsson and Baranowski, 1997, Schiegg, 2000). Forestry management practices negatively impact many saproxylic beetle species (Niemela, 1996, Kuuluvainen, 2002). Most modern forest management practices decrease dead wood within forests (Ranius et al., 2005, Wikars et al., 2005), which is perceived as a reason for a loss of biodiversity (Fridman and Walheim, 2000). Areas unaffected by forestry practices that reduce dead wood have higher diversity of saproxylic organisms (Trave, 2003).

Thinning forests and removing dead and dying trees reduce needed resources for saproxylic species. However, species are not equally affected by reductions in dead wood so some species decline while others are unaffected (Kaila et al., 1994).

Due to long-term intensive forestry, many saproxylic beetles are endangered or extinct in parts of Europe (Kaila et al., 1994, Hammond et al., 2004, Wikars et al., 2005). Other areas of the world may begin to see decreases in saproxylic beetle diversity due to increased intensity of forest management practices. Most saproxylic invertebrate fauna are poorly known and potential impacts of various forestry practices are currently not well understood for many areas (Hammond et al., 2004), including the southeastern United States. Therefore, we measured relative abundances and diversities of saproxylic beetle families and species after various forest management practices were applied in the southern Appalachian Mountains to determine how these practices might affect some early successional species.

Methods

This study was part of the National Fire and Fire Surrogate Study which is designed to examine the impacts of fuel reduction treatments on multiple components of forested ecosystems across the United States (Youngblood et al., 2005). We collected Coleoptera on the Green River Game Management Area, near Hendersonville, NC (Polk and Henderson counties) in the Southern Appalachian Mountains. This forest is managed by the North Carolina Wildlife Resources Commission and encompasses 5,841 hectares managed for game habitat and ecosystem restoration.

Twelve study sites were selected on the basis of size, stand age, cover type and management history. Each site was 14 hectares in size to allow for a 10-hectare measurement area and a buffer of at least one tree length (approximately 20 m) around the measurement area. All 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 nor had any sites 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 (*Q. prinus*), white oak (*Q. alba*), and black oak (*Q. velutina*). Other common species included pignut hickory (*Carya glabra*), mockernut hickory (*C. tomentosa*) and shortleaf pine (*Pinus echinata*). A thick shrub layer composed primarily of 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 hectare plots and consisted of: 1) untreated, 2) dormant season burn, 3) mechanical, and 4) mechanical plus dormant season prescribed burn. The mechanical treatments consisted of chainsaw felling and bucking of the shrub understory which was primarily composed of rhododendron, mountain laurel and small diameter trees (<7.5 cm). The felled material was left in place after cutting. The mechanical plus burn plots were treated the same way and then burned. 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 to 2 meters throughout the burn unit but flames reached as high as 5 meters in localized spots where topography or intersecting flame fronts contributed to erratic fire behavior. Shrubs were removed during the winter, 2001-2002 and plots that were burned were treated on March 12 or 13, 2002. Each plot was marked by grid points with 50 m between points to facilitate pre- and post-treatment sampling.

Trap design has been shown to affect the number and species of beetles captured. We used 8-unit and 12-unit multiple funnel traps (PheroTech, Delta, BC), as well as modified pipe traps (D. Miller, unpublished data) to capture flying saproxylic Coleoptera. Funnel traps are an effective trap for assessing abundance and diversity of Coleoptera (Chenier and Philogene, 1989). Pipe traps work well for certain weevils and wood borers (Cerambycidae) and capture a variety of other beetles as well (D. Miller, personal communication). One of each trap type was used on each plot. The traps were suspended on a nylon string stretched between two trees. An ultra high release α-pinene packet (PheroTech) and a 95 % ethanol packet were placed within the 12-unit funnel trap and the pipe trap, whereas only a 95% ethanol packet was placed in the 8-unit funnel trap. Collecting cups at the bottom of each trap were partially filled with propylene glycol to preserve captured insects. The pipe trap consisted of a solid, black, one meter long, 15.2 cm diameter PVC pipe in place of the funnels and a large diameter collecting funnel (Miller, unpublished data). Alpha-pinene is one of the common monoterpenes found in the resin of most pine species (Mirov, 1961), whereas ethanol is a general attractant for a variety of bark and wood boring beetles (Fatzinger 1985, Fatzinger et al., 1987). Traps were placed near the center of each plot 50 meters apart. In 2003 we trapped during the spring and fall for 10 weeks each time, and in 2004 we trapped during the spring for 12 weeks. A 2004 fall sample was not obtained because traps were damaged by hurricane Ivan. During each trapping period, the trap samples were gathered and collecting cups were refilled with propylene glycol every three to four weeks. Samples were stored in 70% ethyl alcohol until they were identified.

We also used canopy malaise traps (Sante Traps, Lexington, KY) which caught flying 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 3 m conduit pole was inserted inside it to hold up the pole and malaise trap. In addition, malaise traps had four cloth, color (red, white, blue, and yellow) panels (0.3 m^2 each) pinned onto each side of the malaise trap (one color panel per side), which were used to attract pollinating insects (Campbell and Hanula, unpublished data). However, numerous wood inhabiting Coleoptera were captured along with the pollinators so we examined them in a separate analysis to see how these traps compared to the baited traps. The collecting containers were filled approximately one-third full with a soapy water solution. Traps were operated at 4-6 week intervals from April-October of 2003 and 2004. We trapped five times in 2003 and six times in 2004, with each trapping period lasting seven days. Samples from malaise traps were immediately stored in 70% alcohol.

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). Since 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. Decreases in basal area were the result of treatment related tree mortality.

Data were analyzed using PROC GLM (SAS, 1985) to conduct two-way ANOVAs with replications and treatments as dependent variables, and the various families, genera or species of Coleoptera as independent variables. The Ryan-Einot-Gabriel-Welsch multiple range test was used to determine differences in relative abundances and diversities of Coleoptera between treatments. Square-root transformation was used to assure normality and homogeneity of variance. For statistical analysis we compared the numbers caught and species richness of spring 2003, fall 2003, spring 2004 separately, all data together, and malaise trap catches. We used the

GLM procedure to calculate simple linear regressions of families and species versus change in basal area.

Results

During the two-year study we captured 37,191 saproxylic Coleoptera and associated predators comprising 20 families and 122 species (Table 5.1). Overall, species richness (Fig. 5.1) and total numbers of saproxylic Coleoptera (Fig. 5.2) were not significantly different among treatments, but differences in abundance were observed at the family and species level (Table 5.2). For example, Elateridae were significantly higher in samples from mechanical plus burn treatments than controls in spring 2003 and in spring 2004 the mechanical plus burn and mechanical only plots had more elaterids than burn only and control plots (Table 5.2). Trogositidae were captured in higher numbers on mechanical only treatment plots compared to burn only plots in spring 2003 but not in other trapping periods. Cleridae abundance in spring 2004 was significantly higher on mechanical plus burn treatments compared to all other treatments. Overall, Scolytidae numbers increased greatly from the first year to the second in all treatments (Fig. 5.3). In fall 2003, Scolytidae were captured in higher numbers on mechanical plus burn treatment plots compared to other treatments, but they did not differ significantly during other sample periods (Fig. 5.3, Table 5.2).

In 2003, four species of Scolytidae were significantly different in abundance among treatments (Table 5.1). *Hylastes salebrosus* (p=0.06) were caught in higher numbers on the burn only plots compared to control plots in spring 2003 but in fall 2003 they were captured in higher numbers (p=0.07) on mechanical only treatment plots compared to the other three treatments. *Ips grandicollis* were caught in higher numbers on mechanical only treatment plots in spring 2003 but in fall 2003 more were caught on the mechanical plus burn treatment. In spring 2004, *I. grandicollis* numbers were higher on the mechanical plus burn and mechanical only treatment plots than on the burn only plots and the mechanical plus burn plots had more than the controls. In spring 2003, *Xyloborinus saxeseni* and *Xyleborus* sp. 1 were more abundant on mechanical treatments compared to burn only and mechanical plus burn. In the spring 2004, *Xyleborus* sp. 1 followed the same pattern but *X. saxeseni* were more abundant on the mechanical plus burn treatment compared to the control.

Species richness was not significantly different for either spring trapping season (Fig. 5.4). The fall 2003 sample had the lowest species richness of the three trapping periods but the number of species was significantly higher on mechanical only and mechanical plus burn plots compared to controls during this trapping period. The burn only plots were not significantly different from other treatments.

Malaise traps caught significantly more saproxylic Coleoptera and associated predators on the mechanical plus burn plots compared to controls but mechanical only and burn only treatment plots were not significantly different from other treatments (Fig. 5.5). Species richness in the malaise trap catches was similar among treatments during the two-year trapping period (Fig. 5.6). However, 18 beetle genera and species were captured with the canopy malaise traps that were not captured in the other traps (Table 5.3).

Linear regression analysis showed that the number of Scolytidae captured was correlated with change in basal area (r^2=0.47, p≤.01), but the relationship was primarily the result of a single beetle, *Xyleborinus saxeseni* (Fig. 5.7). When *X. saxeseni* were removed, Scolytidae were no longer correlated with change in basal area (Fig. 5.7). Among the Scolytidae, *Dendroctonus terebrans* was also correlated with change in basal area (r^2=0.61, p≤.002) Cleridae (r^2=0.40,

$p \leq .05$) and Elateridae ($r^2=0.45$, $p \leq .01$) were also correlated with change in basal area, whereas Cerambycidae ($r^2=0.23$, $p \leq .10$) was only weakly correlated (Fig. 5.7).

Discussion

Overall saproxylic beetle abundance and species richness were not affected by our treatments but some families or species were affected. However, they responded differently to the various treatments and in some cases species abundance varied with sampling period. For example, *Hylastes salebrosus* was captured in higher numbers in burn only plots than in control plots in spring 2003 but higher numbers were caught in the mechanical only treated plots in fall 2003. Bark beetles and other wood dwelling Coleoptera comprise a wide range of niches in woody material within forests, so differential response to the treatments was not unexpected.

Mechanical plus burn treatments resulted in higher captures of several wood dwelling beetle species in the fall 2003 and spring 2004. In all cases, the beetles affected by our treatments were species that utilize weakened, dying, or recently dead trees or prey upon species in these habitats. All of the mechanical plus burn treatment plots and one of the burn only plots had a reduction in overstory tree basal area (Fig. 5.7) following treatment because hot fires on those plots caused significant tree mortality. One of the most abundant scolytids, *Xyleborinus saxeseni*, was strongly correlated with change in basal area but so was *Dendroctonus terebrans* which occurred in much lower numbers. *X. saxeseni* is an ambrosia beetle that utilizes a wide variety of host tree species that includes both hardwoods and conifers (USDA Forest Service, 1985) while *D. terebrans* only utilizes pines. Likewise, Cleridae, Elateridae, and Cerambycidae were correlated with change in basal area and were more abundant on plots with reduced basal area and more dead trees. Those groups included species that utilized dead pine or hardwood trees as habitat or preyed upon species in those habitats.

For most species we sampled little is known about their response to the treatments we tested, but in some cases published information does exist. For example, *H. salebrosus* and *H. tenuis* were more abundant on the mechanical only treatment in the fall of 2003. Both species utilize pines (USDA Forest Service, 1985) and can be found in stumps and roots. In a previous study (Hanula et al., 2002), *H. salebrosus* was caught in much higher numbers on unburned control areas compared to extensive areas that experienced low to high wildfire severity, so these results might indicate that this beetle is less likely to occur in burned areas. However, in spring 2003 it was more abundant on burned areas than on the controls and Sullivan et al. (2003) found *H. salebrosus* was attracted to small burned plots, so factors other than fire alone likely affected *H. salebrosus* populations in this study. Likewise, *D. terebrans* abundance increased as basal area decreased. In all plots with high *D. terebrans* populations, fire was the cause of the mortality. In comparison, Hanula et al. (2002) caught fewer *D. terebrans* in recently burned areas that were part of a 15,000 ha wildfire. Our lack of capture success for *Ips* species could be a bias in the funnel traps. Smith et al. (1993) showed that some species of *Ips*, such as *Ips avulsus* and *Ips calligraphus* were not highly attracted to ethanol or turpentine.

Increased abundance of *X. saxeseni* in spring 2003 may have been a result of fire reducing the available habitat. This species was probably able to utilize the cut rhododendron and mountain laurel since it has been found feeding on nearly all genera of deciduous trees (Furniss and Johnson, 2002). The mechanical only treatment plots had an abundance of freshly cut wood in 2003 and the controls had normal background levels of newly dead material. On the other hand, prescribed burns were applied right before our spring 2003 trapping period and reduced the amount of wood from the cut shrubs and small trees or may have rendered it unacceptable as host material. By 2004 beetles were likely emerging from the fire killed trees on the mechanical plus burn plots. Also, our traps may have competed with the scents released by the freshly cut wood and recently fire-killed trees in 2003 but by 2004 this competition should have ceased. Thus, newly emerged brood and reduced competition between traps and freshly cut wood might explain the large numbers of *X. saxeseni* captured in 2004 compared to 2003. Since we do not know host plants of *Xyleborus* sp.1, increased abundance could also be due to increased amounts of dead rhododendron and mountain laurel. The higher Elateridae abundance in 2004 probably resulted from the increased dead wood availability or emergence of brood from the previous year.

An introduced species that has a wide host range, *Xylosandrus crassiusculus* was captured in large numbers during this study. First discovered in South Carolina in 1974, it is considered a major pest in nurseries (Oliver and Mannion, 2001) and a potential problem in forests because they can attack healthy trees (Atkinson et al., 1988). The spring 2003 sample contained very few *Xylosandrus crassiusculus* but captures increased in the fall 2003 and by spring 2004 our samples contained large numbers. Due to the probably increase in scents from cut and burned wood, our traps may have competed with these odors in 2003, whereas in 2004 the scents had dissipated and our traps were much more effective. The increase in cut wood in 2003 would have allowed for more beetles breed and possibly resulted in a large emergence by 2004, which could also explain the rise in numbers of *X. crassiusculus* and other beetle in 2004. However, captures of this species were not correlated with decreasing basal area resulting from fire caused tree mortality, nor did any of the treatments result in higher numbers so the reasons for the population increase are unclear. Like *X. crassiusculus, X. saxeseni* and *X. atratus* are non-native species. Because *X. crassiusculus* and *X. saxeseni* comprised the large majority (~60%) of our captures of Scolytidae, it raises the question of whether these species are displacing native insects. *Pityophagus sp.* (Nitidulidae) was captured on burn only and controls in significantly higher numbers compared to mechanical plus burn plots in spring 2003. It is unknown why its abundances would be affected by these treatments. This genus is predatory on bark beetles and has only rarely been found in the southeastern United States.

Because we used three traps per plot and our plots were relatively close to each other, the proximity of the plots and large amount of α-pinene and ethanol released from our traps may have attracted beetles from outside the treatment plots or they may have been able to move from one treatment plot to the next with ease. Future studies may want to consider using only one funnel trap per plot, using larger plots, or passive traps like the malaise traps which caught fewer beetles but exhibited significant differences among treatments consistent with the amount of dead wood associated with those treatments.

Conclusions

Species varied in their responses to the treatments but, in general, treatments that created the most tree mortality resulted in greater numbers of saproxylic species. The re-introduction of fire into forests where it has been excluded should initially benefit saproxylic organisms. Our samples included primarily early successional species and dead wood created by these treatments should be an important resource for later successional species for some time. However, because the stands were "thinned" by fire it is unlikely that much additional tree mortality will occur in the near future because the fire reduced competition and tree vigor should improve. Future research should focus on long-term changes among Coleoptera assemblages, the effects of intermittent versus continuous inputs of dead wood on saproxylic species, and the impacts of non-native species on native saproxylic fauna.

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Table 5.1
Coleoptera genera and species and total numbers captured with multiple funnel traps on fire and fire surrogate treatments on the Green River Game Management Area near Hendersonville, NC.

Family	Genus/Species	Total Number Captured
Anobiidae	*Hadrobregmus* sp.	58
	Hemicoelus sp.	68
	Trichodesma sp.	2
Anthribidae	sp. 1	38
	sp. 2	80
	Eurymycter fasciatus	7
	Toxonotus sp.	2
Bostrichidae	*Amphicerus bicaudatus*	1
	sp. 1	8
	Xylobiops sp. 1	8
Brentidae	*Arrhenodes minutus*	5
Buprestidae	*Acmaeodera* sp.	1
	Agrilis sp. 1	2
	Agrilis sp. 2	1
	Buprestis salisburyensis	1
	Buprestis sp. 1	9
Cerambycidae	*Acanthocinus obseletus*	11
	Acanthocinus pusillus	3
	Acanthocinus sp.	1
	Aneflomorpha sp.	19
	Arhopalus rusticus	3
	Brachysomida bivittata	5
	Clytus marginicollis	4
	Clytus ruricola	351
	Cyrtophorus verrurosus	90
	Gaurotes cyanipennis	17
	Judolia cordifera	6
	Knulliana cincta	3
	Leptostylus sp.	7
	Leptura plebeja	1
	Leptura sp. 1	1
	Megacyllene caryae	3
	Microclytus sp.	1
	Microgoes oculatus	9
	Monochamous titillator	15
	Neoalosterna capitata	1
	Neoclytus acuminatus	10
	Neoclytus mucronatus	1
	Neoclytus sp.	2
	Phymatodes sp.	22
	Phymatodes varius	1
	Pidonia aurata	4
	Purpuricenus humeralis	1

	Rhagium inquisitor	14
	Saperda lateralis	1
	Sarosethus fulminans	1
	Spondylis sp. 1	145
	Spondylis sp. 2	37
	Stenosphenus notatus	1
	Stenosphenus sp.	2
	Strangalepta abbreviata	6
	Stranglia sp.	1
	Strophiona nitens	3
	Tilloclytus geminatus	2
	Tylonotus sp.	4
	Typocerus sp.	1
	Xylotrechus sagittatus	417
	Xylotrechus sp.	40
Cleridae	*Cymatoderma* sp.	99
	Enoclerus ichneumoneus	10
	Thanasimus dubius	89
	Zenodosus sp.	25
Colydidae	*Namunaria guttulatus*	1
	Pycnomerus sp.	25
Cucujidae	*Catogenus* sp. 1	15
	Catogenus sp. 2	4
	Cucujus clavipes	6
	Laemophloeus sp.	21
	Silvanus bidentatus	4
Curculionidae	*Cossonus corticola*	29
	Cryptorhynchus sp. 1	60
	Cryptorhynchus sp. 2	1
	Curculio sp.	4
	Cyrtepistomus sp.	23
	Dryophthorus sp.	27
	Hylobius pales	1538
	Pachylobius picivorus	18
	Pissodes sp.	180
Elateridae	*Alaus myops*	27
	Alaus oculatus	25
	Ampedus sp.	17
	Ctenicera trivittatus	18
	sp. 1	1696
	sp. 2	4
	Hemirhipus sp.	8
	Lacon sp.	128
Histeridae	*Euspilotus* sp.	9
	Hippocaccus sp.	6
	Hister sp.	4
	sp. 1	44
	sp. 2	14
	Hololepta sp.	53
	Platysoma sp.	7

Lagriidae	*Anthromacra aenoe*	4
Lucanidae	*Platycerus virescens*	137
Nitidulidae	*Amphotis* sp. 1	7
	Amphotis sp. 2	1
	sp. 1	150
	Pityophagus sp.	310
Platypodidae	*Platypus flavicornis*	4
	Platypus sp.	5
Pyrochroidae	*Neopyrochroa* sp.	1
Scolytidae	*Dendroctonus terebrans*	153
	Hylastes salebrosus	1488
	Hylastes tenuis	1577
	Hylurgops rugipennis	853
	Ips grandicollis	154
	Ips pini	4
	sp. 1	24
	sp. 2	24
	Xyleborinus saxeseni	10561
	Xyleborus affinis	30
	Xyleborus atratus	745
	Xyleborus sp. 1	5795
	Xyleborus sp. 2	251
	Xyleborus sp. 3	850
	Xylosandrus crassiusculus	7925
Tenebrionidae	*Bolitotherus* sp.	16
	Corticeus sp.	16
	Tarpela sp.	19
Trogositidae	*Temnochila virescens*	46
	Tenebriodes sp.	244

Table 5.2

Mean number (SE) of families and common species of saproxylic species captured per plot with multiple funnel traps on plots receiving fire or fire surrogate treatments on the Green River Game Management Area in the Southern Appalachian Mountains near Hendersonville, NC.

Family[1]	Genera/Species[1]	Treaments[2]			
		MB	M	B	C
2003 Spring					
Anobiidae		6.0 (6.0)^{a}	7.0 (4.4)^{a}	1.7 (1.2)^{a}	0.7 (1.2)^{a}
Anthribidae		3.0 (1.7)^{a}	1.7 (0.9)^{a}	2.7 (1.5)^{a}	6.3 (3.2)^{a}
Bostrichidae		0.3 (0.3)^{a}	1.3 (0.9)^{a}	2.0 (1.5)^{a}	0.3 (0.3)^{a}
Cerambycidae		23.0 (7.0)^{a}	16.3 (4.3)^{a}	15.0 (1.5)^{a}	14.3 (0.3)^{a}
	Cyrtophorus verrurosus	6.7 (3.8)^{a}	5.0 (1.5)^{a}	2.7 (0.7)^{a}	2.7 (2.2)^{a}
	Xylotrechus sagittatus	3.7 (1.5)^{a}	2.7 (1.8)^{a}	2.3 (0.3)^{a}	2.7 (1.3)^{a}
Cleridae		5.3 (1.8)^{a}	4.0 (2.1)^{a}	2.0 (0.6)^{a}	5.0 (1.2)^{a}
Cucujidae		3.7 (0.9)^{a}	3.3 (1.8)^{a}	2.3 (0.9)^{a}	3.3 (1.5)^{a}
Curculionidae		52.7 (4.5)^{a}	61.3 (13.1)^{a}	86.3 (22.0)^{a}	52.0 (25.1)^{a}
	Hylobius pales	44.3 (3.8)^{a}	53.3 (14.7)^{a}	79.7 (21.2)^{a}	46.0 (25.0)^{a}
Elateridae**		149.7 (54.0)^{a}	52.7 (14.9)^{ab}	74.0 (3.2)^{ab}	41.3 (2.7)^{b}
Histeridae		3.3 (0.9)^{a}	4.3 (1.9)^{a}	5.7 (2.4)^{a}	3.7 (2.7)^{a}
Lucanidae	*Platycerus virescens*	3.7 (2.3)^{a}	6.7 (2.7)^{a}	3.0 (2.0)^{a}	10.3 (4.4)^{a}
Nitidulidae		9.3 (6.4)^{a}	15.0 (3.1)^{a}	20.7 (5.8)^{a}	23.3 (11.6)^{a}
	*Pityophagus sp.**	9.0 (6.0)^{b}	15.0 (3.1)^{ab}	20.7 (5.8)^{a}	23.3 (11.6)^{a}
Scolytidae		153.0 (58.5)^{a}	241.3 (59.0)^{a}	168.7 (44.3)^{a}	192.0 (12.8)^{a}
	Dendroctonus terebrans	7.0 (2.5)^{a}	5.7 (2.3)^{a}	4.0 (0.6)^{a}	4.3 (2.4)^{a}
	*Hylastes salebrosus**	50.3 (17.3)^{ab}	45.7 (12.2)^{ab}	80.7 (34.5)^{a}	37.7 (16.9)^{b}
	Hylastes tenuis	54.7 (34.7)^{a}	50.3 (7.6)^{a}	39.3 (9.8)^{a}	53.3 (34.7)^{a}
	*Ips grandicollis***	1.7 (1.2)^{ab}	3.0 (1.0)^{a}	1.7 (0.9)^{ab}	0.7 (0.3)^{b}
	Xyleborus atvatus	7.3 (2.9)^{a}	13.0 (1.5)^{a}	9.3 (2.2)^{a}	11.7 (2.4)^{a}
	*Xyleborinus saxeseni**	6.7 (1.8)^{b}	25.7 (7.3)^{a}	8.3 (3.5)^{b}	17.3 (4.5)^{ab}
	*Xyleborus sp. 1***	8.3 (2.3)^{b}	41.7 (12.3)^{a}	12.3 (5.5)^{b}	32.7 (4.9)^{ab}
	Xylosandrus crassiusculus	0^{a}	0^{a}	3.0 (3.0)^{a}	3.3 (2.0)^{a}
Tenebrionidae		2.0 (1.5)^{a}	1.0 (1.0)^{a}	1.0 (1.0)^{a}	1.7 (1.7)^{a}
Trogositidae**		13.0 (5.5)^{ab}	20.7 (4.2)^{a}	4.7 (1.5)^{b}	11.7 (2.3)^{ab}
2003 Fall					
Cerambycidae		26.3 (6.3)^{a}	20.0 (7.8)^{a}	15.7 (5.0)^{a}	11.7 (4.1)^{a}
	Xylotrechus sagittatus	26.0 (6.2)^{a}	18.7 (7.3)^{a}	14.3 (4.4)^{a}	10.7 (3.4)^{a}
Cleridae		10.7 (8.2)^{a}	6.7 (0.9)^{a}	3.3 (1.8)^{a}	1.7 (0.9)^{a}
Curculionidae		4.0 (0.6)^{a}	8.0 (3.8)^{a}	4.0 (0.6)^{a}	4.3 (0.9)^{a}
	Hylobius pales	3.3 (0.9)^{a}	4.0 (2.0)^{a}	2.0 (0.6)^{a}	3.7 (1.2)^{a}
Elateridae		2.0 (1.5)^{a}	4.3 (0.3)^{a}	1.3 (0.7)^{a}	2.3 (0.3)^{a}
Scolytidae**		304.3 (45.0)^{a}	130.7 (13.5)^{b}	114.0 (29.8)^{b}	93.0 (19.3)^{b}
	*Hylastes salebrosus**	18.0 (3.5)^{b}	41.7 (8.0)^{a}	22.7 (7.3)^{b}	18.0 (3.8)^{b}
	*Hylastes tenuis***	4.3 (0.9)^{b}	14.0 (3.5)^{a}	4.0 (1.5)^{b}	3.3 (1.9)^{b}
	*Ips grandicollis***	2.6 (0.9)^{a}	0.3 (0.3)^{b}	0^{b}	0^{b}
	Xyleborinus saxeseni	75.3 (33.4)^{a}	20.7 (9.6)^{a}	34.7 (14.4)^{a}	45.7 (29.8)^{a}
	Xylosandrus crassiusculus	74.3 (46.5)^{a}	12.7 (7.8)^{a}	26.7 (10.8)^{a}	12.7 (3.9)^{a}
2004 Spring					
Anobiidae		6.7 (3.7)^{a}	12.7 (5.0)^{a}	3.7 (2.0)^{a}	4.0 (1.2)^{a}
Anthribidae		0.0 (0.0)^{a}	8.0 (8.0)^{a}	4.7 (1.5)^{a}	16.0 (6.9)^{a}
Cerambycidae		79.7 (12.4)^{a}	65.0 (7.2)^{a}	70.3 (13.9)^{a}	65.0 (20.6)^{a}

	Clytus ruricola	14.7 (2.6)^{a}	20.7 (6.4)^{a}	41.3 (12.2)^{a}	35.7 (14.5)^{a}
	Cyrtophorus verrurosus	3.3 (1.5)^{a}	2.7 (0.9)^{a}	3.3 (0.9)^{a}	3.7 (3.2)^{a}
	*Xylotrechus sagittatus**	19.3 (2.3)^{a}	15.3 (0.9)^{ab}	11.3 (1.5)^{b}	12.0 (2.6)^{b}
Cleridae**		19.7 (5.0)^{a}	6.0 (1.5)^{b}	5.3 (1.9)^{b}	4.7 (0.3)^{b}
Cucujidae		0.0 (0.0)^{a}	1.7 (1.2)^{a}	2.0 (1.5)^{a}	0.3 (0.3)^{a}
Curculionidae		83.7 (19.9)^{a}	75.3 (18.3)^{a}	115.7 (22.5)^{a}	79.3 (8.9)^{a}
	*Hylobius pales**	62.7 (17.6)^{ab}	47.7 (8.2)^{b}	100.7 (19.1)^{a}	65.3 (8.4)^{ab}
Elateridae**		112.0 (2.5)^{a}	115.0 (5.1)^{a}	49.3 (1.5)^{b}	37.0 (8.9)^{b}
Histeridae		4.7 (2.3)^{a}	7.7 (1.2)^{a}	7.3 (1.9)^{a}	8.3 (5.8)^{a}
Lucanidae	*Platycerus virescens*	4.3 (1.7)^{a}	5.3 (1.9)^{a}	5.3 (2.8)^{a}	7.0 (2.3)^{a}
Nitidulidae		17.3 (2.8)^{a}	29.0 (3.0)^{a}	27.3 (9.9)^{a}	11.3 (5.6)^{a}
	Pityophagus sp.	5.3 (0.9)^{a}	10.0 (4.7)^{a}	10.0 (3.6)^{a}	8.7 (3.2)^{a}
Scolytidae		2984.0 (756.8)^{a}	2125.0 (123.3)^{a}	2270.7 (664.9)^{a}	1368.0 (164.4)^{a}
	Dendroctonus terebrans	10.7 (1.7)^{a}	6.3 (2.9)^{a}	5.7 (2.0)^{a}	2.7 (1.2)^{a}
	Hylastes salebrosus	53.0 (18.4)^{a}	43.0 (14.0)^{a}	44.7 (17.4)^{a}	40.7 (24.3)^{a}
	Hylastes tenuis	110.3 (38.7)^{a}	93.0 (0.0)^{a}	68.0 (21.6)^{a}	31.0 (10.8)^{a}
	*Ips grandicollis***	19.7 (2.9)^{a}	12.7 (3.8)^{ab}	3.0 (1.2)^{c}	6.0 (2.0)^{bc}
	*Xyleborus atvatus***	48.7 (3.7)^{ab}	48.0 (2.5)^{ab}	72.0 (10.0)^{a}	36.0 (3.1)^{b}
	*Xyleborinus saxeseni***	1506.3 (740.5)^{a}	675.0 (272.9)^{ab}	733.3 (156.3)^{ab}	371.3 (186.3)^{b}
	*Xyleborus sp. 1**	350.0 (158.1)^{b}	645.3 (129.3)^{a}	513.7 (116.4)^{ab}	327.7 (99.4)^{b}
	Xylosandrus crassiusculus	815.3 (563.8)^{a}	512.0 (247.3)^{a}	756.0 (550.2)^{a}	432.0 (205.1)^{a}
Tenebrionidae		0.7 (0.3)^{a}	3.0 (2.0)^{a}	2.0 (2.0)^{a}	2.3 (1.9)^{a}
Trogositidae		9.3 (0.9)^{a}	13.3 (0.9)^{a}	8.0 (1.5)^{a}	14.3 (4.9)^{a}

[1] Within each family or genera/species, means followed by the same letter(s) are not significantly different ($p \leq 0.05$) according to the Ryan-Enoit-Gabriel-Welsch multiple comparison test (SAS 1985). Families or genera/species followed with an ** indicates $p \leq 0.05$ and * indicates $p \leq 0.10$.

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

Table 5.3
Coleoptera genera and species and total numbers captured with canopy malaise traps that were not captured with funnel traps on fire or fire surrogate treated plots on the Green River Game Management Area in the Southern Appalachian Mountains near Hendersonville, NC.

Family	Genus/Species	Total Captured
Apionidae	*Apion* sp.	4
Cerambycidae	*Anelaphus* sp.	7
	Leptorhabdium pictum	3
	Leptura lineola	19
	Leptura subhamata	11
	Liopinus sp.	2
	Neoclytus jouteli	4
	Stranglia luteicornis	2
	Typocerus sp. 2	3
Cleridae	*Cymatoderma bicolor*	15
	Cymatoderma sp. 2	7
	Cymatoderma sp. 3	4
	Enoclerus sp.	1
Cupedidae	*Cupes* sp.	25
Curculionidae	*Myrmex* sp.	1
	Nicentrus sp.	5
Elateridae	*Pitylobius* sp.	2
Tenebrionidae (Lagriinae)	sp. 1	7

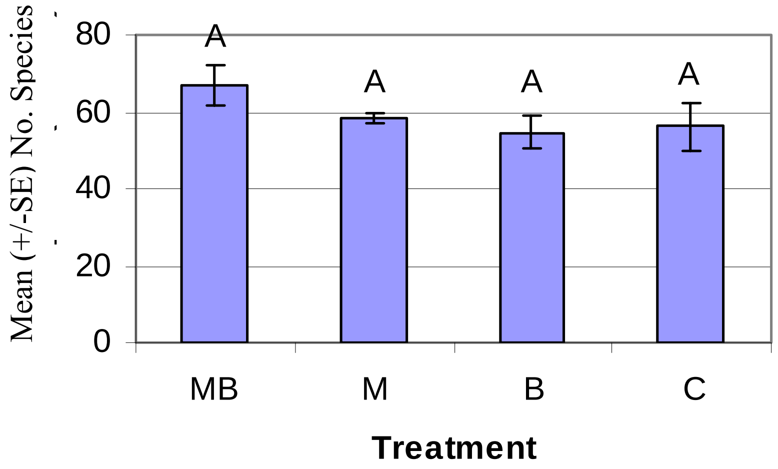

Fig. 5.1. Mean number of species (+/-SE) of Coleoptera captured per plot with funnel traps in 2003 and 2004 on 10 ha forest plots near Hendersonville, N.C. that received fire or fire surrogate treatments. Columns with the same letter are not significantly different (p≤0.05; REGWQ, SAS 1985). Treatments were; MB=mechanical shrub removal plus burn, M=mechanical shrub removal, B=burn, C=control.

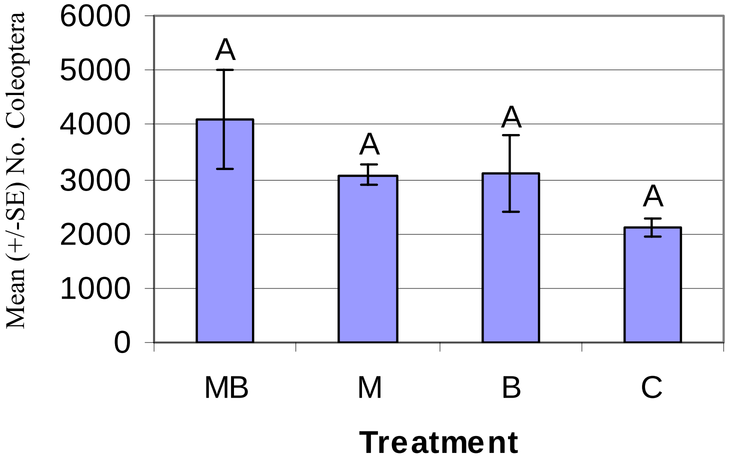

Fig. 5.2. Mean number (+/-SE) of Coleoptera captured per plot with multiple funnel traps during 2003 and 2004 on plots receiving fire or fire surrogate treatments on the Green River Game Management Area in the Southern Appalachian Mountains near Hendersonville, N.C. Columns with the same letter are not significantly different at p≤0.05 (REGWQ, SAS 1985). Treatments were: MB=mechanical shrub removal plus burn, M=mechanical shrub removal, B=burn, C=control.

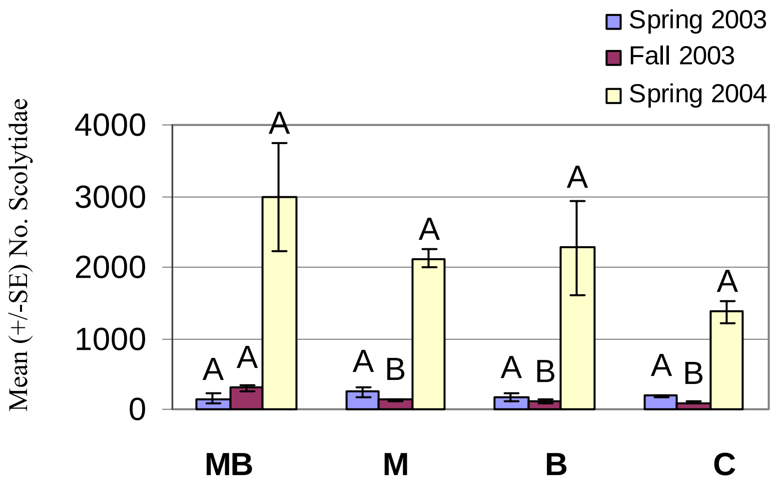

Fig. 5.3. Mean number (+/-SE) of Scolytidae captured per plot for each trapping period with multiple funnel traps during the three trapping periods among the plots that received fire or fire surrogate treatments. Columns of the same trapping period with the same letter are not significantly different (p=≤0.05; REGWQ, SAS 1985). Treatments were: MB=mechanical shrub removal plus burn, M=mechanical shrub removal, B=burn, C=control.

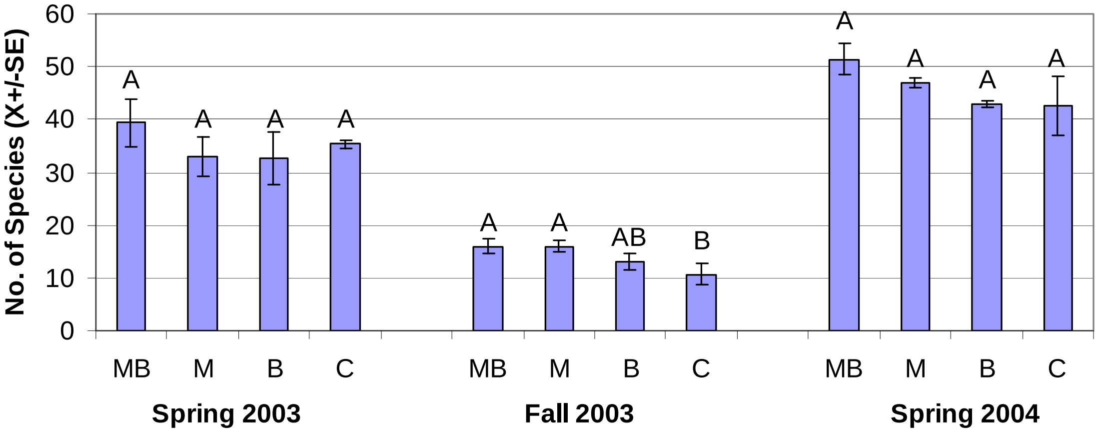

Fig. 5.4. Mean number (+/-SE) of Coleoptera species captured per plot with funnel traps in 2003 and 2004 on 10 ha forest plots near Hendersonville, N.C. that received fire or fire surrogate treatments. Columns of the same date with the same letter are not significantly different (p=≤0.05; REGWQ, SAS 1985). Treatments were: MB=mechanical shrub removal plus burn, M=mechanical shrub removal, B=burn, and C=control.

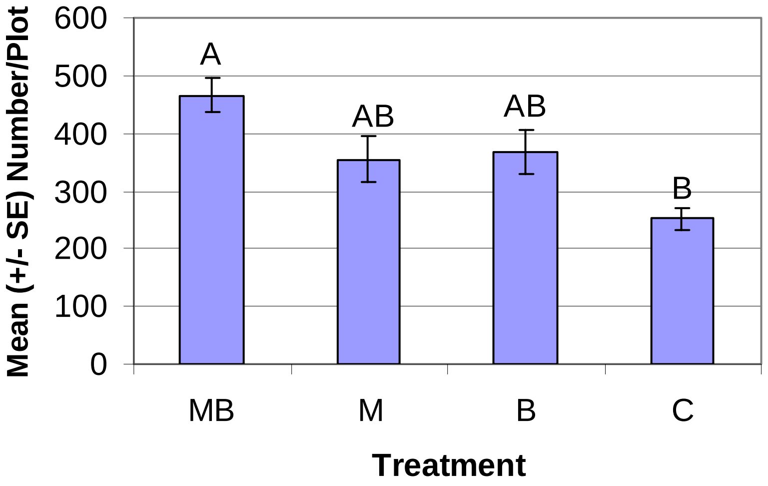

Fig. 5.5. Mean number (+/-SE) of wood inhabiting Coleoptera captured per plot with malaise traps during 2003 and 2004 on plots receiving fire or fire surrogate treatments on the Green River Game Management Area in the Southern Appalachian Mountains near Hendersonville, N.C. Columns with the same letter are not significantly different at $p \leq 0.05$ (REGWQ, SAS 1985). Treatments were: MB=mechanical shrub removal plus burn, M=mechanical shrub removal, B=burn, and C=control.

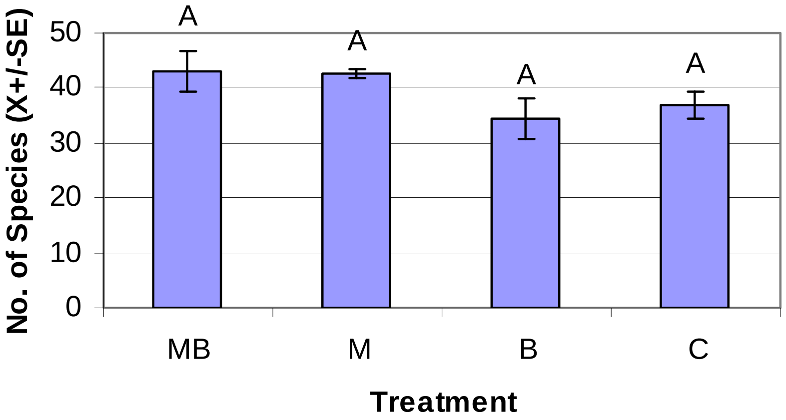

Fig. 5.6. Mean number (+/-SE) of wood inhabiting Coleoptera species captured per plot with malaise traps in 2003 and 2004 on 10 ha forest plots in the Southern Appalachian Mountains near Hendersonville, N.C. that received fire or fire surrogate treatments. Columns with the same letter are not significantly different (p=≤0.05; REGWQ, SAS 1985). Treatments were: MB=mechanical shrub removal plus burn, M=mechanical shrub removal, B=burn, and C=control.

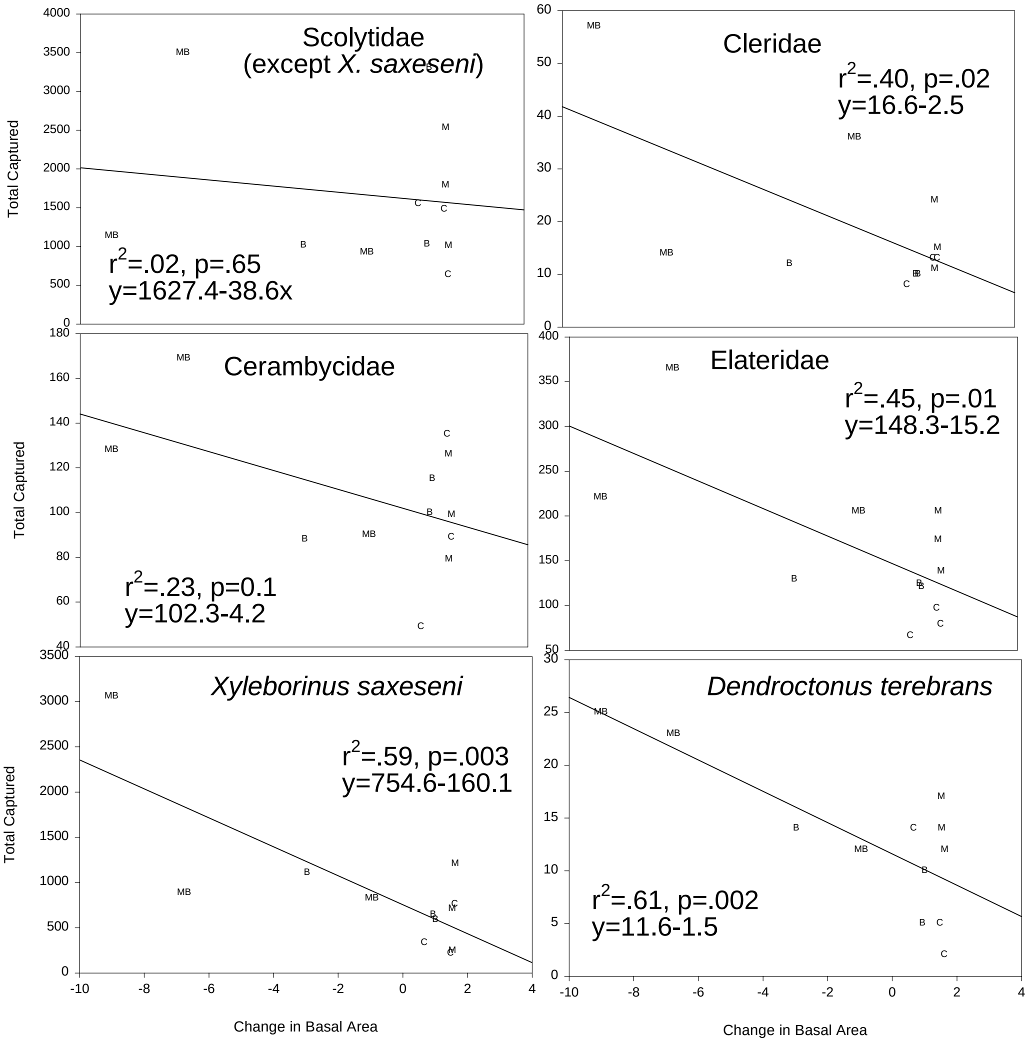

Fig. 5.7. Linear regressions of various saproxylic Coleoptera captured in funnel traps and change in basal area of 10 ha plots treated with various combinations of prescribed fire and mechanical brush removal. Negative numbers indicate a post treatment decrease in basal area (more dead wood on plots). MB=mechanical plus burn, M=mechanical, B=burn, C=control

CHAPTER 6

EFFECTS OF PRESCRIBED FIRE AND FIRE SURROGATES ON TREE MORTALITY, BARK BEETLES, AND OTHER SAPROXYLIC COLEOPTERA OF LONGLEAF PINE (*PINUS PALUSTRIS*) ON THE COASTAL PLAIN OF ALABAMA[1]

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[1] Campbell, J.W., J.L. Hanula, and K.W. Outcalt. To be submitted to Forest Management and Ecology

Abstract

Fire or fire surrogate treatments were applied to 10 hectare plots of mature longleaf pine (*Pinus palustris*) on the Coastal Plain of Alabama and consisted of: 1) untreated control, 2) growing season prescribed burn, 3) thin only, 4) thin plus growing season burn, and 5) herbicide plus growing season burn. From 2002 to 2004, we captured 75,598 Coleoptera in multiple funnel traps comprising 17 families and 130 species. Overall, Coleoptera abundance was not significantly different among treatments, but all treated plots had higher numbers than untreated controls. Species richness was significantly higher on thin plus burn plots compared to thin only and control plots. Scolytidae were more abundant on thin plus burn plots compared to control plots ($p=0.08$) in Fall 2002 but in Fall 2003 ($p\leq0.05$) they were more abundant on thin plus burn, thin only, and herbicide plus burn compared to controls. Among the Scolytidae, *Dendroctonus terebrans, Xyleborinus saxeseni, Xyleborus* sp. 3, and *Hylastes tenuis,* showed varying responses to the treatments. Curculionidae were significantly more abundant on thin only and herbicide plus burn plots compared to all other treatments ($p\leq0.05$) in Spring 2003 and in Spring 2004 they were more abundant on herbicide plus burn plots compared to thin plus burn treatments ($p\leq0.05$). *Pachylobius picivorus* was more abundant in Fall 2002 on thin plus burn plots compared to herbicide plus burn and control treatments ($p\leq0.05$), and in Spring 2004 they were more abundant on herbicide plus burn plots compared all other treatments ($p=0.06$). Among the Cerambycidae, *Xylotrechus sagittatus* was higher in Fall 2003 on thin plus burn plots compared to all other treatments except herbicide plus burn plots ($p\leq0.05$). Within the predator complex, Trogositidae were higher on thin plus burn plots compared to all other treatments except thin only plots ($p\leq0.05$) in Spring 2003, and Cleridae abundance was higher in Spring 2004 on burn only plots compared to all other treatments ($p\leq0.05$). Thin plus burn plots had significantly higher tree mortality compared to burn only and control plots and, overall, fire was the primary cause of tree death. Linear regression analysis of dead trees per plot versus various Coleoptera showed captures of Buprestidae, Cerambycidae, Trogositidae, *Aranthocinus nodosus*, *Temnochila virescens*, *Xyleborinus saxeseni* increased with increasing number of dead trees. Our results show that the treatments tested did not cause increased bark beetle related tree mortality and they did not have a negative effect on populations of early successional saproxylic beetle fauna.

key words: bark beetles, forest management, coarse woody debri, prescribed fire, Cerambycidae, Trogositidae, multiple funnel trap, malaise trap

Introduction

Numerous bark beetle species are major forest pests but many are also considered beneficial because they recycle nutrients back into the forest floor. The pine bark beetle complex or guild in the southeastern United States includes the southern pine beetle (*Dendroctonus frontalis*), black turpentine beetle (*Dendroctonus terebrans*), and three species of engraver beetles (*Ips avulsus, I. grandicollis, and I. calligraphus*). Black turpentine beetle, *Ips* beetles, and the southern pine beetle normally attack conifers that have been weakened or felled, but *Ips* can also be found in debris left over from logging operations and black turpentine beetles can be found in stumps (Coulson and Witter, 1984). At high populations these beetles can attack and kill healthy trees (Coulson and Witter, 1984). Of the numerous bark and wood boring beetles associated with pines in the southeastern United States, the southern pine beetle causes the most tree mortality. *Ips* species are less aggressive and usually attack recently killed, weakened or dying trees. Black turpentine beetles usually attack injured trees or freshly cut stumps and, like southern *Ips* spp., large outbreaks are rare. Ambrosia beetles are wood-boring scolytids that do little damage in the southeastern United States and rarely attack healthy trees (Flechtmann et al., 1999). Most losses from ambrosia beetles are from the degradation of lumber. Tree mortality due to bark beetles results in the loss of millions of dollars each year (Wood, 1982).

Pine reproduction weevils are also important tree pests in the southeastern United States. *Hylobius pales* and *Pachylobius picivorus*, the most common pine weevils in this region, breed in stumps and roots of recently cut or killed pines and adults feed on bark of seedlings, saplings and small branches of large trees. Increases in these weevils can negatively affect pine regeneration through adult feeding on pine seedlings (Fox and Hill, 1973).

Other beetles, such as Cerambycidae and Buprestidae, have larvae that bore into stems and branches of trees. Most cerambycids and buprestids do not infest logs that have been debarked (Price, 2001), while other beetles, such as Bostrichidae and Anobiidae, can attack dry, debarked logs and wood reducing it to a powder.

Many other beetles that are associated with bark beetles are considered beneficial. For example, some members of the Cleridae, Colydidae, Cucujidae, Histeridae, Nitidulidae, and Trogositidae prey on bark beetles and other wood borers. Some,such as *Thanasimus dubius* (Cleridae), actually follow aggregations of bark beetles (Vite and Williamson, 1970). These predators found within the bark beetle complex are considered to be important regulatory factors for bark beetle populations (Schroeder 1996, Reeve, 1997, Turchin et al., 1999). Numerous other saproxylic beetles contribute to overall forest biodiversity and are considered to be important components of a healthy forest ecosystem because they aid in the recycling of nutrients and organic matter back into the soil (Speight, 1989).

Infestations of pine beetles usually begin in disturbed areas (lightning, road building, logging, etc.), as well as in areas where over-dense pine stands exist (Hedden, 1978). Dense pine stands correlate well with pine beetle outbreaks because competition for water, space, and sunlight can stress trees resulting in increased susceptibility to pine beetle attack (Hedden, 1978). Once established, pine beetles are able to spread quickly in dense pine stands (Bennett, 1968, Hedden and Billings, 1979). Factors affecting southern pine beetle attacks (stand, site, and tree characteristics) have been shown differ across physiographic provinces in the south (Belanger et al., 1993). In general, the southern pine beetle prefers overmature or weakened trees (Turchin et al., 1999). Young trees are rarely attacked (Thatcher et al., 1981) because they cannot support large beetle colonies and they are able to produce defensive compounds. Another concern is that bark beetle activity can cause a buildup of fuel which can result in large fires (Thatcher et al., 1981).

Beetles associated with dead and dying trees are known to increase after logging operations. However, residual trees in thinned areas have greater resin flow and thicker bark (Matson et al., 1987) that can inhibit bark beetle attacks. Thinning pine forests reduces competition among trees for light, water, and nutrients, which can result in fewer bark beetle outbreaks (Belanger et al., 1993).

Numerous techniques can be used to limit pine beetle attacks, including salvage of infested trees, cut and leave, or felling and burning infested areas (Thatcher et al., 1981). Some promising and preventive techniques are thinning (Belanger et al., 1993, Turchin et al., 1999), prescribed burning, and herbicide treatments all of which can increase stand vigor (Hedden, 1978). In the Coastal Plain Province, periodic burnings increase the availability of phosphorus and other nutrients within the soil (McKee, 1992), which should also increase stand vigor.

However, little research has been done that examines the effects of prescribed burnings or other techniques in southern pines on populations of saproxylic beetles in general. We examined how relative abundances and diversities of these beetles and their associates are affected by growing season prescribed burning and alternatives for restoring and maintaining healthy longleaf pine (*Pinus palustris*) stands.

Methods

This study was conducted on the Solon Dixon Experimental Forest near Andalusia, Alabama. The forest is primarily longleaf pine, with an understory composed mostly of yaupon holly (*Ilex vomitoria*). The experiment was laid out as a randomized complete block design consisting of three blocks of five treatments each. Treatments applied to 10 hectare plots consisted of: 1) untreated control, 2) growing season prescribed burn, 3) thin only, 4) thin plus growing season burn, and 5) herbicide plus growing season burn (Table 6.1). In the thinning treatments, co-dominant or suppressed trees were removed to produce a residual basal area of 11.5 to 13.8 m^2/ha. The thin plus burn plots were treated the same as the thin only and then burned. The herbicide plus burn plots had an application of 4.5% solution of Garlon 4™ (triclopyr) herbicide plus Timberline 90™ surfactant and then burned. The herbicide was applied using backpack sprayers with all woody vegetation up to approximately two meters targeted except longleaf pine seedlings and saplings. Growing season prescribed burns were conducted on the burn only and thin plus burn treatments every two years during this study, where as the herbicide plus burn plots were burned only once (Table 6.1). Several burning techniques, such as back fire, spot fire, and flanking were used on each plot that was burned (Outcalt, 2003). Each plot was marked by grid points with 50 m between points to facilitate pre- and post-treatment sampling.

We used 8-unit and 12-unit multiple funnel traps (PheroTech, Delta, BC), and pipe traps (1 meter in length and 15.2 cm diameter) (Miller, unpublished data) to capture saproxylic Coleoptera. Multiple funnel traps are effective for capturing and assessing abundance and diversity of certain forest Coleoptera (Chenier and Philogene, 1989) and the pipe traps are effective for Cerambycidae and Curculionidae as well as other beetle species (D. Miller, personal communication). One of each trap type was used on each plot. The traps were hung on a nylon string stretched between two trees. An ultra high release α-pinene packet (PheroTech) and a 95% ethanol packet were placed within the 12-unit funnel trap and the pipe trap, and a 95% ethanol packet was placed in the 8-unit funnel trap. Collecting cups at the bottom of each trap were partially filled with propylene glycol to preserve captured insects. α-pinene is one of the common monoterpenes found within the resin of most pine species (Mirov, 1961), where as ethanol is a general attractant for a variety of bark and wood boring beetles (Fatzinger 1985, Fatzinger et al., 1987). Traps were placed near the center of each plot 50 meters apart and operated in fall 2002, spring and fall 2003, and spring 2004. We trapped during the spring and fall 2002 and 2003 for 10 weeks and in 2004 we trapped during the spring for 12 weeks. A 2004 fall sample was not obtained because plots were damaged by hurricane Ivan. During each trapping period the trap samples were gathered and collecting cups were refilled with propylene glycol every three to four weeks. Samples were stored in 70% ethyl alcohol until they were identified.

We also used canopy malaise traps (Sante Traps, Lexington, KY) which caught flying insects from all directions and had collection containers at the top and bottom for flying insects. 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 3 m conduit pole was inserted inside it to hold up the pole and malaise trap. In addition, malaise traps had four cloth color (red, white, blue, and yellow) panels (0.3 m^2 each) pinned onto each side (one color panel per side) which were used to attract pollinating insects (Campbell and Hanula, unpublished data). However, numerous wood inhabiting Coleoptera were captured along with the pollinators and were included in a separate analysis. The collecting containers were filled approximately one-third full with a soapy water solution. Traps were operated at 4-6 week intervals from April-October of 2003 and 2004. We trapped five times in 2003 and five times in 2004, with each trapping period lasting seven days. Samples from malaise traps were immediately stored in 70% ethyl alcohol.

Tree mortality surveys were also accomplished during each trapping period (twice per year). Surveys were begun in December 2001 (before treatments were applied) and were continued through March 2004. During these surveys, grid lines were walked and every tree within the 10 ha plots was visually inspected for damage. Once a dead or dying tree was located, it was tagged and diameter, tree species, cause of death, and types of beetles attacking it were recorded.

Data were analyzed using PROC GLM (SAS, 1985) to conduct two-way ANOVAs with replications and treatments as independent variables, and the various families and species of Coleoptera as dependent variables. The Ryan-Einot-Gabriel-Welsch multiple range test (REGWQ) was used to determine differences in relative abundances and diversities of Coleoptera between treatments. Square-root transformation was used to assure normality and homogeneity of variance. All abundance tests were run separately for trapping period since the treatments were dynamic and plots changed with time. To help explain differences in Coleoptera abundance we used the GLM procedure to calculate simple linear regressions of various families and species versus dead trees per plot (obtained during tree surveys).

Results

During the two year study we captured 75,598 Coleoptera in traps, comprising 17 families and 130 species that were used for our analysis (Table 6.2). Overall, Coleoptera abundance was not significantly different among treatments, but all treated plots had slightly higher numbers than untreated controls (Fig. 6.1). Species richness was significantly higher on thin plus burn plots compared to thin only and control plots (Fig. 6.2).

Numerous Coleoptera families and species had significant differences in abundance, but many of these showed varying responses to treatments (Table 6.3). Scolytidae were higher in abundance on thin plus burn plots compared to control plots ($p=0.08$) in Fall 2002 but in Fall 2003 ($p \leq 0.05$) they were more abundant on thin plus burn, thin only, and herbicide plus burn plots compared to controls. Among the Scolytidae, *D. terebrans* were more numerous on thin plus burn compared to herbicide plus burn and controls ($p \leq 0.05$) in Fall 2002, but by Fall 2003 they were higher in abundance on herbicide plus burn plots compared to controls ($p=0.08$). *Xyleborinus saxeseni* were more abundant on thin plus burn plots compared to burn only, herbicide plus burn, and controls ($p \leq 0.05$) in Spring 2003 and in Spring 2004 they were more abundant on thin plus burn, thin only, and herbicide plus burn plots compared to burn only and control treatments ($p \leq 0.05$). *Xyleborus* sp. 3 were significantly higher in abundance on thin plus burn and thin only plots compared to all other treatments ($p \leq 0.05$) in Spring 2003 and Fall 2003, and in Spring 2004 they were higher on thin only and burn only plots compared to control treatments ($p \leq 0.05$). In Spring 2003 *Hylastes tenuis* were higher in abundance on herbicide plus burn compared to thin only, and thin plus burn plots and control plots were higher in abundance than thin and burn plots ($p \leq 0.05$).

Curculionidae were significantly more abundant on thin only and herbicide plus burn plots compared to all other treatments ($p \leq 0.05$) in Spring 2003 and in Spring 2004 they were more abundant on herbicide plus burn plots compared to thin plus burn treatments ($p \leq 0.05$). Among the Curculionidae, *Pachylobius picivorus* were more abundant in Fall 2002 on thin plus burn plots compared to herbicide plus burn and control treatments ($p \leq 0.05$) and in Spring 2004 they were more abundant on herbicide plus burn plots compared all other treatments ($p=0.06$). Cerambycidae were higher in abundance overall in Fall 2003 on thin plus burn plots compared to burn only and control plots ($p \leq 0.05$). Among the Cerambycidae, *Xylotrechus sagittatus* were higher in Fall 2003 on thin plus burn plots compared to all other treatments except herbicide plus burn plots ($p \leq 0.05$). Buprestidae were significantly higher on thin plus burn plots in Spring 2004 compared to thin only treatments ($p=0.06$). Within the saproxylic beetle predator complex, Trogositidae were higher on thin plus burn plots compared to all other treatments except thin only plots ($p \leq 0.05$) in Spring 2003.

We captured 1,138 wood inhabiting Coleoptera with malaise traps, comprising 16 families and 72 species (Table 6.4). The thin only plots had significantly higher saproxylic beetle captures in malaise traps ($p \leq 0.05$) compared to control and burn only plots (Fig. 6.3). The thin plus burn and herbicide plus burn plots were not significantly different from other treatments.

Tree mortality was higher in thin plus burn plots compared to burn only and control plots. The herbicide plus burn treated plots had the second highest tree mortality but the number of dead trees was not significantly different from other treatment (Fig.6.4). Both the thin plus burn and herbicide plus burn had large increases in tree mortality after the prescribed fire was applied (Fig. 6.5) and fire was the leading cause of tree mortality throughout the study (Fig. 6.6).

Linear regression analysis of dead trees per hectare versus various Coleoptera groups showed several positive relationships (Fig. 6.7). Buprestidae (r^2=.60, p=0.0007), Cerambyidae (r^2=.47, p=0.007), and Trogositidae (r^2=.35, p=0.02) were correlated with dead trees per plot. Species that showed positive relationships with tree mortality were *Aranthocinus nodosus* (r^2=.34, p=0.02), *Temnochila virescens* (r^2=.34, p=0.02) and *Xyleborinus saxeseni* (^{2}=.38, p=0.01).

Discussion

Tree mortality was higher on plots that were thinned and prescribed burned than on the control or prescribed burn only plots, but thin plus burn plots were not significantly different from the thin only and the herbicide plus prescribed burning treatments. The thin plus burn treatments resulted in a loss of approximately 9 trees per hectare compared to normal background levels of 1-2 trees per hectare on the control plots. This increased mortality was the result of additional fuel loads from logging slash or herbicide killed shrubs that resulted in hot fire (Fig. 6.4). We found that over 72% of the tree mortality was caused by fire while lightning, the second most common cause of tree mortality, only accounted for 10% of tree deaths (Fig. 6.7). Mechanical damage was the result of thinning operations or old wounds caused by previous turpentine operations on some of the stands we measured. Insects and diseases caused very little direct mortality. Although fire was the number one cause of mortality, the mortality was not uniformly distributed in time (Fig. 6.5) or space. In fact, one plot experienced much higher mortality than the others (Fig. 6.7) and there was considerable variation in tree mortality within the thin plus burn and herbicide plus burn treatments. Even within plots, high fire intensities resulted in localized pockets of dead trees. This variation in distribution of dead trees within plots, between plots, and over time makes interpretation of beetle abundance and diversity results difficult. Likewise, bark beetles and other deadwood inhabiting Coleoptera occupy a wide range of niches in woody material. In the southeastern United States, little is known about how these beetles respond to alteration of their niche or habitat when it is fire scorched or partially burned.

Therefore, it is not surprising that beetle species responded differently to the treatments. Overall, saproxylic beetle species richness was higher on thin plus burn treated plots than on the control or thin only treatments. Because thinning alone did not result in higher species richness compared to controls, it appears that burning was the primary reason for increased species richness. In fact, thin plus burn treated plots were not significantly richer than the other burn treatments. Since burn only plots had significantly fewer dead trees than thin plus burn plots, the higher species richness we observed is not likely due only to increased abundance of deadwood on those plots. However, how burning might influence species richness of saproxylic beetles is unclear.

Numbers of saproxylic Coleoptera captured in baited multiple funnel and pipe traps were not affected by the various treatments. However, captures of the family Scolytidae were higher on the thin plus burn treated plots in Fall 2002, and on the thin plus burn and herbicide plus burn plots in Fall 2003, which is consistent with the increased amount of deadwood resulting from those treatments. Examination of Table 3 suggests that the overall effect of these treatments was the result of a general increase in the numbers of most scolytid species we sampled rather than to one dominant species. Although we suspect that increased numbers of dead trees on the plots contributed to greater numbers of Scolytidae, only *X. saxeseni* were correlated with numbers of dead trees. Reasons for the higher numbers of Scolytidae on the herbicide plus burn, thin plus burn and the thin only plots in Fall 2003 are less clear. The herbicide plus burn plots experienced increased tree mortality following the prescribed burns applied in April and May 2003, but the thin only plots and the thin and burn plots did not. Although fire caused the greatest mortality, thinning created stumps and logging debris for species to breed in. For example, *D. terebrans* numbers were highest in Fall 2002 and low in Fall 2003 in thin plus burn plots. Black turpentine beetles have a preference for trees weakened by fire and logging operations (Smith and Lee, 1972). Likewise, *H. tenuis* and *H. salebrosus* numbers declined during the same period. Both species utilize pines (USDA Forest Service, 1985) and can be found in stumps and roots. *Hylastes tenuis*, which was found in significantly higher numbers on burn only plots in Spring 2003, has been shown to be attracted to burned areas (Sullivan et al., 2003). However, why this species was not found in elevated numbers on other treatments that had burning applied is unknown.

Xyleborinus saxeseni was more abundant on thin plus burn plots in Spring 2003 and on thin plus burn, thin only, and herbicide plus burn plots in spring 2004. With the exception of the thin only treatment these results appear to be due to increased dead wood availability within these treated plots, which is supported by the linear regression showing correlation in total numbers caught and tree mortality. This beetle has been found feeding on a wide range of deciduous hosts (Furniss and Johnson, 2002) and conifers (Atkinson and Peck, 1994). Because thinned plots had a number of small deciduous trees cut but not removed, these plots would have also had an abundance of host material. *X. saxeseni* and *Xylosandrus crassiusculus,* which were two of the most commonly captured Scolytidae, are both non-native species, comprising 33% of our beetle captures. The large numbers of these beetles raises concerns over whether they are displacing native saproxylic beetles.

Other economically important Scolytidae, such as *Ips* were not significantly affected by the treatments. However, we captured only one species, *Ips grandicollis*, in significant numbers. The lack of success for other species could be a bias in the traps. *Ips avulsus* (few captured) and *Ips calligraphus* (none captured) are not attracted to ethanol or turpentine (Smith et al., 1993).

Overall Curculionidae had significantly higher numbers on herbicide plus burn plots in Spring 2003, which correlates with the application of fire on these plots. Among the Curculionidae, *Pachylobius picivorus* had elevated abundances on the thin plus burn plots and herbicide plus burn plots in Fall 2002 and Spring 2004, respectively. The hotter fires and higher tree mortality associated with the thin plus burn and herbicide plus burn plots probably caused this result. These beetles have been shown to be attracted to areas that have been severely burned by wildfire (Hanula et al., 2002), moderately burned by prescribed fire, (Sullivan et al., 2003) and to areas that have been thinned and later burned (Fox and Hill, 1973). Stumps created by the thinning process and prescribed fires would have attracted this weevil because they deposit eggs within freshly cut pine stumps or roots of recently killed trees where the larvae feed beneath the bark.

Cerambycidae were found in significantly higher abundances in Fall 2003 and high numbers in Spring 2003, which correlates with increased dead trees after the application of the fire in Spring 2002. Most Cerambycidae we captured, including *Xylotrechus sagittatus*, act as scavengers on dead and dying trees. These opportunistic Coleoptera would be expected to increase in abundance with increased dead trees through attraction to an area from outside and subsequent emergence following brood development.

Higher abundance of Trogositidae on thin plus burn and thin only in Fall 2002 and on thin plus burn plots in Spring 2003 is most likely a result of these predators following bark beetle prey. Linear regressions indicate that these predators are positively correlated with number of dead trees which should be where higher numbers of prey subsist. Many predators of bark beetles have been shown to follow their prey (Vite and Williamson, 1970). However, why they did not follow similar trends during other trapping periods (when prey was also high in number) is unknown.

The southern pine beetle (*Dendroctonus frontalis*) was not captured in any of our traps during this study which is consistent with the low abundance of this beetle in south Alabama from 2002-2004 and the poor effectiveness of multiple funnel traps baited only with α-pinene. Outbreaks of this beetle are cyclic (Price, 2001) and when present, attack in extreme large numbers (Reeve et al., 1998).

Conclusion

Our results varied depending on the treatment, season, and species. Most genera or species that showed significant increases in abundance were on one of the treated plots, primarily the thin plus burn and herbicide plus burn. These two treatments had the higher tree mortality among the treatments. Therefore, the forest management practices we evaluated can result in initially higher tree mortality and more wood dwelling Coleoptera. However, none of the treatments we tested resulted in a reduction of a beetle population and the increase in black turpentine beetles did not result in significant tree mortality caused by these beetles. This study focused on early successional species and it is unlikely that higher abundances of these wood-dwelling Coleoptera would continue to be found on treated plots compared to untreated controls as the amount of newly created dead wood decreases over time. Future research should focus on long-term changes among saproxylic Coleoptera assemblages and the impacts of non-native species.

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Table 6.1
Dates herbicide applications, thinnings, and prescribed burns were applied to 12 treated plots on the Solon Dixon Experimental Forest, near Andalusia, AL.

Treatment Plot[1]	Herbicide	Thinning	Burning
TB		Feb-02	April 5, 2002 & April 28, 2004
TB		Mar-02	May 22, 2002 & May 4, 2004
TB		Apr-02	May 1, 2002 & April 29, 2004
T		Feb-02	
T		Mar-02	
T		Apr-02	
B			April 23, 2002 & May 6, 2004
B			May 21, 2002 & July 6, 2004
B			May 15, 2002 & April 15, 2004
HB	September 23-28, 2002		April 15, 2003
HB	September 28-30, 2002		May 13, 2003
HB	October 1-2, 2002		April 16, 2003

[1] TB=thin plus burn, T=thin, B=burn, HB=herbicide plus burn

Table 6.2
Coleoptera genera and species and total numbers captured in funnel traps on plots receiving fire or fire surrogate treatments on the Solon Dixon Experimental Forest near Andalusia, AL.

Family	Genus/Species	Total Captured
Anobiidae	*Hemicoelus* sp.	39
	sp. 1	1
	Trichodesma sp.	5
Anthribidae	sp. 1	33
	sp. 2	345
	sp. 3	1
	sp. 4	1
	sp. 5	1
	Toxonotus sp.	9
Bostrichidae	*Amphicerus bicaudatus*	34
	sp. 1	2
	sp. 2	27
	Xylobiops sp. 1	4
	Xylobiops sp. 2	22
Buprestidae	*Acmaeodera* sp.	2
	Buprestis lineata	14
	Buprestis maculativentris	2
	Buprestis salisburyensis	1
	Buprestis sp. 1	20
	Buprestis sp. 2	1
	Buprestis sp. 3	2
	Chalcophora georgiana	3
	Chalcophora virginiensis	29
	Chrysobothris sp. 1	1
	Chrysobothris sp. 2	2
	Chrysobothris sp. 3	1
	Chrysobothris sp. 4	1
Cerambycidae	*Ancylocera bicolor*	7
	Aneflomorpha sp. 1	92
	Aneflomorpha sp. 2	14
	Aranthocinus nodosus	142
	Aranthocinus obseletus	173
	Arhopalus rusticus	70
	Astylopsis sp.	1
	Ataxia sp.	4
	Curious dentatus	6
	Cyrtophorus sp.	10
	Cyrtophorus verrurosus	4
	Euderces picipes	1
	Euderces pini	1
	Heterachthes sp.	13
	Knulliana cincta	47
	Leptostylus sp. 1	88
	Leptostylus sp. 2	19
	Liopinus sp. 1	11

	Liopinus sp. 2	2
	Monochamus titillator	205
	Neoclytus acuminatus	12
	Neoclytus jouteli	1
	Neoclytus mucronatus	16
	Neoclytus sp.	1
	Obrium sp.	26
	Parandra sp.	1
	Parelaphidion sp.	12
	Prionus sp. 1	1
	Prionus sp. 2	1
	Rhagium inquisitor	5
	Saperda sp.	3
	sp. 1	2
	sp. 2	10
	Spondylis sp.	18
	Stenosphenus sp.	1
	Stranglia luteicornis	2
	Strophiona nitens	2
	Tragidion coquus	1
	Typocerus zebra	7
	Xylotrechus sagittatus	727
	Xylotrechus sp.	10
Cleridae	*Cymatodera* sp.	13
	Enoclerus ichneumoneus	2
	Neorthopleura thoracica	1
	Thanasimus dubius	67
Colydiidae	*Colydium* sp.	2
	Pycnomerus sp.	11673
Cucujidae	*Catogenus* sp. 1	52
	Catogenus sp. 2	3
Curculionidae	*Cossonus corticola*	32
	Cryptorhynchus sp. 1	31
	Cryptorhynchus sp. 2	7
	Curculio sp.	3
	Dryophthorus sp.	99
	Hylobius pales	4019
	Nicentrus sp.	3
	Pachylobius picivorus	1413
	Pissodes sp.	27
	sp. 1	1
	sp. 2	1
Elateridae	*Alaus myops*	392
	Alaus oculatus	7
	Lacon sp.	5
	sp. 1	1000
Histeridae	*Hister* sp.	1
	Platysoma sp. 1	31
	sp. 1	9
	sp. 2	8

	sp. 3	1
	sp. 4	167
Nitidulidae	*Amphotis* sp. 1	1
	Amphotis sp. 2	1
	sp. 1	216
Passalidae	*Odontotaenius disjunctus*	1
Platypodidae	*Platypus flavicornis*	210
Scolytidae	*Dendroctonus terebrans*	5947
	Hylastes salebrosus	10072
	Hylastes tenuis	3261
	Hylurgops rugipennis	1
	Hypotheamus crudiae	601
	Ips avulsus	52
	Ips grandicollis	4392
	sp. 1	60
	sp. 2	60
	sp. 3	396
	sp. 4	19
	sp. 5	3
	Xyleborinus saxeseni	9497
	Xyleborus atratus	28
	Xyleborus sp. 1	244
	Xyleborus sp. 2	5
	Xyleborus sp. 3	1779
	Xylosandrus crassiusculus	15723
Tenebrionidae	*Alobates pennsylvanica*	1
	Alobates sp.	2
	Corticeus sp.	641
	Glyptotus sp.	4
Trogositidae	*Airora* sp.	1
	Temnochila sp.	1
	Temnochila virescens	736
	Tenebriodes collaris	126
	Tenebriodes marginatus	4
	Tenebriodes sp. 1	39
	Tenebriodes sp. 2	32

Table 6.3

Mean (SE) numbers of families and common genera/species of saproxylic beetles captured with multiple funnel traps on plots receiving growing season prescribed burns or alternative treatments on the Solon Dixon Experimental Forest near Andalusia, AL

Family[1]	Genus/Species[1]	Treatment[2] TB	T	B	HB	C
Fall 2002						
Buprestidae		1.3 (0.3) ^{a}	1.3 (0.3)^{a}	0.7 (0.7)^{a}	0.0 (0.0)^{a}	0.0 (0.0)^{a}
Cerambycidae		31.3 (1.2)^{a}	25.7 (10.7)^{a}	34.3 (5.4)^{a}	34.7 (6.9)^{a}	33.0 (10.1)^{a}
	Aranthocinus nodosus	1.7 (1.7) ^{a}	0.7 (0.3)^{a}	3.0 (2.5)^{a}	0.0 (0.0)^{a}	0.0 (0.0)^{a}
	Xylotrechus sagittatus	12.3 (3.7)^{a}	13.7 (6.6)^{a}	23.3 (7.3)^{a}	23.7 (3.9)^{a}	27.7 (7.8)^{a}
Cleridae		1.7 (0.3) ^{a}	0.3 (0.3)^{a}	1.3 (0.9)^{a}	0.3 (0.3)^{a}	0.3 (0.3)^{a}
Colydidae		223.3 (85.8)^{a}	608.3 (259.2)^{a}	627.7 (276.1)^{a}	580.0 (85.3)^{a}	514.0 (73.1)^{a}
Curculionidae		157.0 (45.7)^{a}	141.3 (34.9)^{a}	159.7 (22.0)^{a}	156.3 (22.6)^{a}	174.7 (37.0)^{a}
	Hylobius pales	139.7 (45.3)^{a}	127.0 (31.1)^{a}	148.0 (19.1)^{a}	150.0 (23.5)^{a}	167.3 (36.7)^{a}
	*Pachylobius picivorus***	14.3 (2.7)^{a}	10.0 (1.7)^{ab}	6.0 (0.6)^{ab}	5.3 (2.2)^{b}	4.0 (1.2)^{b}
Elateridae		2.3 (0.3)^{a}	4.7 (0.9)^{a}	2.7 (0.9)^{a}	2.3 (0.3)^{a}	1.7 (0.7)^{a}
Scolytidae*		808.3 (236.7)^{a}	581.3 (36.4)^{ab}	496.7 (116.7)^{ab}	359.7 (26.0)^{ab}	271.0 (36.4)^{b}
	*Dendroctonus terebrans***	263.0 (73.1)^{a}	151.0 (18.9)^{ab}	150.7 (40.7)^{ab}	36.0 (8.0)^{b}	51.3 (10.7)^{b}
	Hylastes tenuis	62.7 (11.1)^{a}	52.0 (14.2)^{a}	34.3 (7.2)^{a}	65.7 (6.8)^{a}	30.7 (7.3)^{a}
	Hylastes salebrosus	194.0 (54.9)^{a}	237.3 (40.5)^{a}	119.7 (38.4)^{a}	140.7 (23.4)^{a}	94.0 (22.5) ^{a}
	Ips grandicollis	22.3 (8.4)^{a}	8.7 (1.9)^{a}	16.0 (4.2)^{a}	17.3 (3.8)^{a}	13.3 (6.1)^{a}
	Xyleborinus saxeseni	204.0 (113.7) ^{a}	82.3 (25.6) ^{a}	102.7 (8.2) ^{a}	65.0 (11.6) ^{a}	40.0 (11.1) ^{a}
	Xyleborus sp. 3	5.0 (4.5) ^{a}	0.3 (0.3)^{a}	2.0 (1.2)^{a}	2.7 (1.8)^{a}	2.3 (0.3)^{a}
	Xylosandrus crassiusculus	30.0 (14.6) ^{a}	13.7 (1.7) ^{a}	28.7 (13.3) ^{a}	11.3 (1.2) ^{a}	18.3 (5.8) ^{a}
Trogositidae**		9.3 (3.5) ^{a}	5.0 (2.0) ^{ab}	9.0 (2.5) ^{a}	0.7 (0.3) ^{b}	2.3 (0.3)^{ab}
	*Temnochila virescens***	5.0 (1.5) ^{a}	3.0 (1.5) ^{ab}	1.7 (0.7) ^{abc}	0.0 (0.0) ^{c}	0.3 (0.3)^{cb}
Spring 2003						
Buprestidae		6.7 (2.3) ^{a}	2.7 (2.2)^{a}	1.7 (0.9)^{a}	1.7 (0.3)^{a}	0.7 (0.3)^{a}
Cerambycidae		67.0 (20.4) ^{a}	52.0 (20.6)^{a}	36.3 (11.9)^{a}	26.7 (3.4)^{a}	22.7 (8.7)^{a}
	Aranthocinus nodosus	11.7 (5.8) ^{a}	8.0 (2.3)^{a}	3.7 (0.9)^{a}	1.0 (1.0)^{a}	2.3 (1.2)^{a}
	Xylotrechus sagittatus	5.0 (2.6)^{a}	6.0 (4.0)^{a}	4.0 (1.5)^{a}	3.3 (1.2)^{a}	2.7 (1.2)^{a}
Cleridae		2.0 (0.6) ^{a}	2.0 (1.5)^{a}	4.0 (1.0)^{a}	0.7 (0.3)^{a}	2.3 (1.9)^{a}
Colydidae		110.3 (12.4)^{a}	104.0 (28.0)^{a}	164.7 (22.5)^{a}	81.3 (16.0)^{a}	110.7 (30.4)^{a}
Curculionidae**		57.3 (0.7)^{c}	95.3 (2.2)^{ab}	67.3 (3.8)^{cb}	114.7 (15.6)^{a}	72.7 (4.3)^{cb}

	Hylobius pales	29.3 (13.0)^{a}	35.3 (12.1)^{a}	34.7 (6.4)^{a}	57.0 (17.1)^{a}	32.7 (7.0)^{a}
	Pachylobius picivorus	24.0 (12.1)^{a}	55.0 (9.8)^{a}	30.0 (5.3)^{a}	54.7 (2.7)^{a}	37.7 (2.4)^{a}
Elateridae		37.7 (5.7)^{a}	62.7 (16.8)^{a}	49.3 (7.1)^{a}	46.7 (11.7)^{a}	33.0 (6.8)^{a}
Scolytidae		1860.0 (236.7)^{a}	1767.0 (59.9)^{a}	1910.7 (66.1)^{a}	1287.3 (254.0)^{a}	1357.0 (208.5)^{a}
	Dendroctonus terebrans	120.7 (32.2)^{a}	84.7 (19.6)^{a}	87.7 (22.5)^{a}	137.0 (58.2)^{a}	35.7 (10.2)^{a}
	*Hylastes tenuis***	68.7 (19.8)^{c}	87.7 (21.1)^{bc}	109.0 (34.9)^{abc}	164.3 (44.4)^{a}	145.7 (47.7)^{ab}
	Hylastes salebrosus	298.0 (90.4)^{a}	373.3 (114.7)^{a}	287.3 (68.6)^{a}	300.0 (37.5)^{a}	298.0 (27.5)^{a}
	Ips grandicollis	95.7 (21.2)^{a}	73.7 (12.9)^{a}	156.7 (65.9)^{a}	132.3 (20.1)^{a}	88.0 (19.6)^{a}
	*Xyleborinus saxeseni***	479.3 (82.6)^{a}	371.7 (28.7)^{ab}	217.3 (15.2)^{b}	216.7 (53.1)^{b}	232.0 (15.6)^{b}
	*Xyleborus sp. 3***	54.3 (17.3)^{a}	42.0 (5.3)^{a}	21.3 (4.4)^{b}	18.0 (4.5)^{b}	18.7 (2.8)^{b}
	Xylosandrus crassiusculus	705.3 (245.0)^{a}	684.7 (137.4)^{a}	996.0 (190.7)^{a}	298.0 (106.8)^{a}	501.7 (186.7)^{a}
Trogositidae**		76.7 (13.7)^{a}	39.0 (6.5)^{ab}	20.3 (2.6)^{b}	17.0 (5.5)^{b}	17.3 (8.4)^{b}
	*Temnochila virescens***	61.3 (9.8)^{a}	29.7 (4.7)^{ab}	13.3 (2.4)^{b}	12.7 (6.4)^{b}	14.0 (7.9)^{b}
Fall 2003						
Buprestidae		0.3 (0.3)^{a}	0.3 (0.3)^{a}	0.0 (0.0)^{a}	0.0 (0.0)^{a}	0.0 (0.0)^{a}
Cerambycidae**		28.0 (7.6)^{a}	14.0 (4.6)^{ab}	8.7 (3.7)^{b}	21.0 (11.9)^{ab}	10.3 (5.3)^{b}
	Aranthocinus nodosus	0.0 (0.0)^{a}	0.7 (0.7)^{a}	0.7 (0.7)^{a}	1.0 (0.6)^{a}	0.0 (0.0)^{a}
	*Xylotrechus sagittatus***	25.0 (7.8)^{a}	9.3 (5.6)^{b}	6.7 (2.7)^{b}	14.3 (8.4)^{ab}	9.7 (5.2)^{b}
Cleridae		2.0 (0.0)^{a}	2.6 (2.6)^{a}	4.0 (1.0)^{a}	0.7 (0.3)^{a}	2.3 (1.9)^{a}
Colydidae		125.3 (47.1)^{a}	105.3 (26.0)^{a}	157.0 (54.0)^{a}	74.0 (27.7)^{a}	80.7 (32.0)^{a}
Curculionidae		26.7 (12.3)^{a}	62.7 (7.7)^{a}	78.0 (31.8)^{a}	53.7 (5.7)^{a}	59.7 (7.2)^{a}
	Hylobius pales	23.3 (11.7)^{a}	58.7 (8.5)^{a}	74.3 (31.7)^{a}	44.3 (6.4)^{a}	57.0 (8.0)^{a}
	Pachylobius picivorus	3.0 (0.6)^{a}	1.7 (0.9)^{a}	2.3 (0.7)^{a}	3.7 (2.3)^{a}	1.7 (0.7)^{a}
Elateridae		1.0 (0.6)^{a}	2.0 (1.5)^{a}	0.7 (0.3)^{a}	0.7 (0.3)^{a}	0.3 (0.3)^{a}
Scolytidae**		361.7 (55.8)^{a}	371.0 (64.6)^{a}	222.7 (41.0)^{ab}	387.3 (49.3)^{a}	154.3 (37.6)^{b}
	*Dendroctonus terebrans**	88.0 (30.1)^{ab}	124.3 (60.0)^{ab}	54.3 (19.6)^{ab}	211.3 (56.4)^{a}	34.0 (15.0)^{b}
	Hylastes tenuis	14.0 (4.2)^{a}	15.0 (7.5)^{a}	11.3 (1.2)^{a}	20.0 (5.7)^{a}	9.7 (2.2)^{a}
	Hylastes salebrosus	47.0 (13.1)^{a}	59.7 (19.8)^{a}	53.0 (7.0)^{a}	67.7 (29.6)^{a}	22.3 (5.8)^{a}
	Ips grandicollis	1.3 (0.7)^{a}	0.3 (0.3)^{a}	1.3 (0.9)^{a}	0.0 (0.0)^{a}	2.0 (0.6)^{a}
	Xyleborinus saxeseni	74.7 (20.7)^{a}	42.3 (22.2)^{a}	31.7 (11.9)^{a}	37.7 (10.2)^{a}	41.7 (6.4)^{a}
	*Xyleborus sp. 3***	87.3 (41.1)^{ab}	90.7 (14.3)^{a}	46.7 (14.9)^{abc}	16.0 (6.4)^{c}	22.0 (12.2)^{cb}
	Xylosandrus crassiusculus	27.7 (7.4)^{a}	27.0 (11.5)^{a}	13.3 (5.8)^{a}	22.7 (5.5)^{a}	12.7 (2.0)^{a}
Trogositidae		1.3 (0.7)^{a}	0.7 (0.3)^{a}	0.7 (0.3)^{a}	2.7 (2.2)^{a}	1.7 (1.2)^{a}
	Temnochila virescens	1.0 (0.6)^{a}	0.3 (0.3)^{a}	0.3 (0.3)^{a}	2.7 (2.2)^{a}	1.0 (1.0)^{a}
Spring 2004						

Buprestidae*		3.3 (1.3) ^{a}	0.3 (0.3)^{b}	2.0 (0.6)^{ab}	2.7 (0.9)^{ab}	0.7 (0.3)^{ab}
Cerambycidae		32.3 (5.4) ^{a}	22.7 (7.4)^{a}	32.0 (5.5)^{a}	32.3 (6.1)^{a}	24.7 (4.3)^{a}
	Aranthocinus nodosus	1.0 (0.6) ^{a}	1.7 (1.7)^{a}	3.7 (0.7)^{a}	5.3 (1.2)^{a}	1.3 (0.9)^{a}
	Xylotrechus sagittatus	14.3 (6.2)^{a}	8.3 (3.2)^{a}	10.3 (3.8)^{a}	9.7 (2.6)^{a}	13.0 (4.0)^{a}
Cleridae**		0.3 (0.3) ^{b}	0.0 (0.0)^{b}	2.3 (0.3)^{a}	0.0 (0.0)^{b}	0.7 (0.3)^{b}
Colydidae		43.3 (18.4)^{a}	42.3 (10.4)^{a}	63.0 (4.5)^{a}	41.3 (4.1)^{a}	35.0 (6.8)^{a}
Curculionidae**		52.0 (4.5)^{b}	69.7 (7.1)^{ab}	75.7 (17.8)^{ab}	125.7 (16.0)^{a}	78.7 (17.0)^{ab}
	Hylobius pales	6.0 (0.6)^{a}	29.0 (3.1)^{a}	34.0 (16.7)^{a}	47.7 (15.4)^{a}	44.3 (13.9)^{a}
	*Pachylobius picivorus**	41.7 (5.4)^{b}	36.0 (11.4)^{b}	35.7 (7.8)^{b}	72.0 (2.6)^{a}	32.3 (4.7)^{b}
Elateridae		26.7 (8.4)^{a}	52.7 (12.2)^{a}	54.0 (12.1)^{a}	37.7 (4.4)^{a}	49.3 (13.1)^{a}
Scolytidae		1147.3 (121.9)^{a}	1069.3 (183.8)^{a}	961.7 (37.0)^{a}	1173.3 (88.9)^{a}	832.3 (180.2)^{a}
	Dendroctonus terebrans	94.7 (45.2)^{a}	36.0 (14.2)^{a}	92.3 (12.3)^{a}	85.7 (7.8)^{a}	44.0 (15.3) ^{a}
	Hylastes tenuis	28.3 (8.0)^{a}	48.3 (18.8)^{a}	41.0 (6.0)^{a}	44.0 (6.7)^{a}	34.7 (8.4)^{a}
	Hylastes salebrosus	165.3 (69.3) ^{a}	129.0 (45.7) ^{a}	143.3 (19.0) ^{a}	237.0 (67.7) ^{a}	90.7 (49.6) ^{a}
	Ips grandicollis	182.0 (37.4)^{a}	163.0 (11.0)^{a}	150.7 (62.5)^{a}	175.7 (12.0)^{a}	163.7 (48.5)^{a}
	*Xyleborinus saxeseni***	254.0 (75.4) ^{a}	196.3 (24.3) ^{a}	97.3 (16.5) ^{b}	253.3 (37.0) ^{a}	125.7 (17.3) ^{b}
	*Xyleborus sp. 3***	40.0 (8.7) ^{ab}	49.3 (11.1)^{a}	44.7 (12.7)^{a}	19.0 (5.1)^{ab}	10.7 (2.9)^{b}
	Xylosandrus crassiusculus	367.7 (33.3) ^{a}	432.0 (93.5) ^{a}	370.7 (46.6) ^{a}	336.0 (14.0) ^{a}	343.7 (136.0)^{a}
Trogositidae		23.3 (6.1)^{a}	6.3 (3.4)^{a}	22.0 (2.6)^{a}	36.7 (17.8)^{a}	21.0 (2.9)^{a}
	Temnochila virescens	19.3 (6.7) ^{a}	6.0 (3.6) ^{a}	18.7 (3.3) ^{a}	36.0 (17.5) ^{a}	19.0 (3.5)^{a}

[1]Within each family or genus/species, means followed by the same letter(s) are not significantly different ($p \leq 0.05$) according to the Ryan-Enoit-Gabriel_Welsch multiple comparison test. Families or genera/species followed with an ** indicates $p \leq 0.05$ and * indicates $p \leq 0.10$.

[2]TB=thin plus burn, B=burn, T= thin, HB=herbicide plus burn, C=control

Table 6.4

Coleoptera genera and species, and total numbers captured with canopy malaise traps on fire and fire surrogate treated plots on the Solon Dixon Experimental Forest near Andalusia, AL.

Family	Genus/Species	Total Captured
Anobiidae	*Hadrobregmus* sp.	1
Anthribidae	sp. 1	23
Bostrichidae	*Xylobiops* sp. 2	1
Brentidae	*Arrhenodes* sp.	1
Buprestidae	*Anthaxia* sp.	1
	Buprestis lineata	2
	Buprestis sp. 1	2
	Buprestis sp. 2	2
	Chalcophora virginiensis	51
	Chrysobothris sp.	8
	Dicera sp.	1
	Dicera tuberculata	1
Cerambycidae	*Aneflomorpha* sp.	65
	Anelaphus sp.	8
	Anous nyops	1
	Aranthocinus obsoletus	7
	Arhopalus rusticus	2
	Leptura plebeja	2
	Liopinus sp.	3
	Microclytus sp.	1
	Monochamus titillator	3
	Neoclytus macronatus	6
	Neoclytus sp. 1	1
	Phymatodes sp.	1
	Prionus sp. 1	3
	Prionus sp. 2	3
	Spondylis sp.	1
	Stranglia luteicornis	1
	Tilloclytus geminatus	7
	Typocerus lunulatus	2
	Unknown	8
	Xylotrechus sagittatus	4
	Xylotrechus sp.	2
Cleridae	*Cymatoderma bicolor*	5
	Cymatoderma sp. 1	6
	Cymatoderma sp. 2	1
	Enoclerus ichneumoneus	3
	sp. 1	1
	Thanasimus dubius	3
Colydiidae	*Pycnomerus* sp.	6
Cucujidae	*Catogenus* sp.	1

Curcuilionidae	*Cossonus corticola*	19
	Cryptorhynchus sp.	20
	Curculio sp.	6
	Dryophthorus sp.	8
	Hylobius pales	8
	Pachylobius piscivorous	15
Elateridae	*Alous oculatus*	2
	sp. 1	422
	sp. 2	1
Histeridae	*Platysoma* sp.	1
	sp. 1	1
	sp. 2	5
Platypodidae	*Platypus flavicornis*	3
Scolytidae	*Dendroctonus terebrans*	9
	Hylastes salebrosus	4
	Hylastes tenuis	10
	Hylurgops rugipennis	7
	Ips avulsus	2
	Ips grandicollis	7
	sp. 1	3
	sp. 2	3
	sp. 3	5
	Xyleborus atratus	5
	Xyleborus saxeseni	133
	Xyleborus sp. 2	41
	Xyleborus sp. 3	121
	Xylosandrus crassiusculus	18
Tenebrionidae	*Alobates pennsylvannica*	1
Trogositidae	*Temnochila virescens*	3
	Tenebriodes marginatus	2
	Tenebriodes sp. 1	2

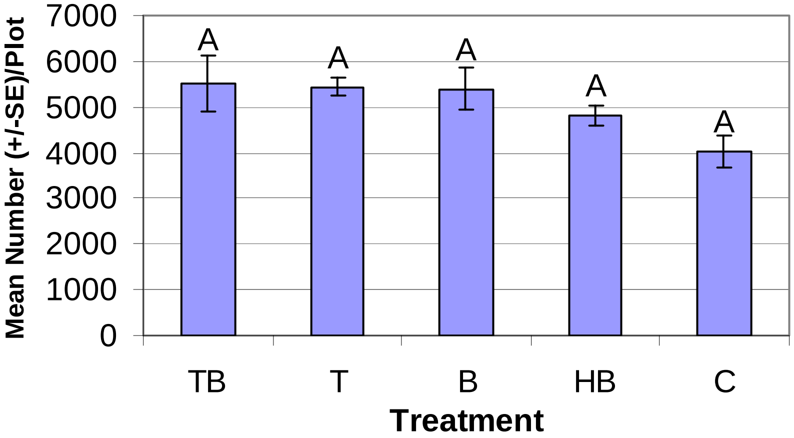

Fig. 6.1. Mean number of saproxylic Coleoptera captured with multiple funnel traps from Fall 2002 to Spring 2004 on plots treated with growing season prescribed burns or alternatives to them on the Solon Dixon Experimental Forest, near Andalusia, AL. Columns with the same letter are not significantly different at $p \leq 0.05$ (REGWQ, SAS 1985). Treatments were: TB=thin plus burn, T=Thin, B=burn, HB=herbicide plus burn, and C=control.

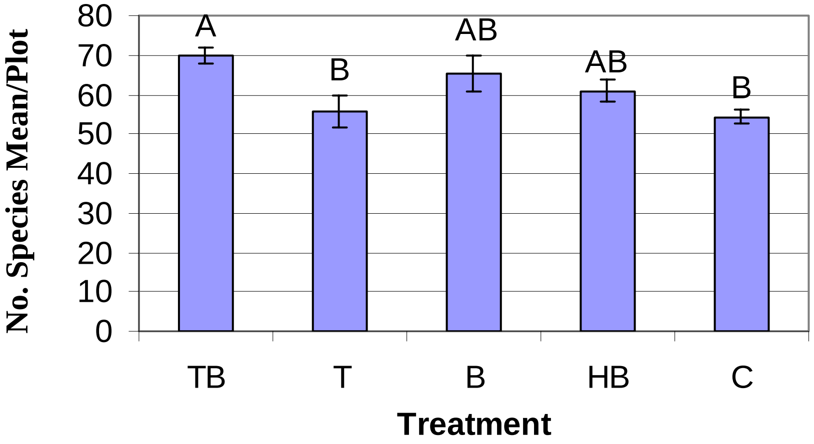

Fig. 6.2. Mean number of species of Coleoptera captured with funnel traps from Fall 2002 through Spring 2004 on 10 ha plots treated with growing season prescribed burns or alternatives to them within the Solon Dixon Experimental Forest, near Andalusia, AL. Columns with the same letter are not significantly different (p=≤0.05; REGWQ, SAS 1985). Treatments were; TB=thin plus burn, M=thin, B=burn, HB=herbicide plus burn, and C=control.

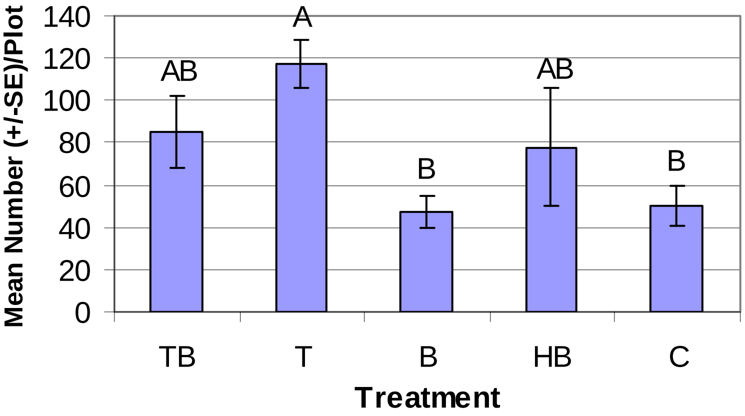

Fig. 6.3. Mean numbers of wood inhabiting Coleoptera captured with malaise traps Spring 2003 through and Fall 2004 on plots receiving growing season prescribed burns or alternatives to them on the Solon Dixon Experimental Forest, near Andalusia, AL. Columns with the same letter are not significantly different at $p \leq 0.05$ (REGWQ, SAS 1985). Treatments were: TB= thin plus burn, T= thin, B=burn, HB=herbicide plus burn, and C=control.

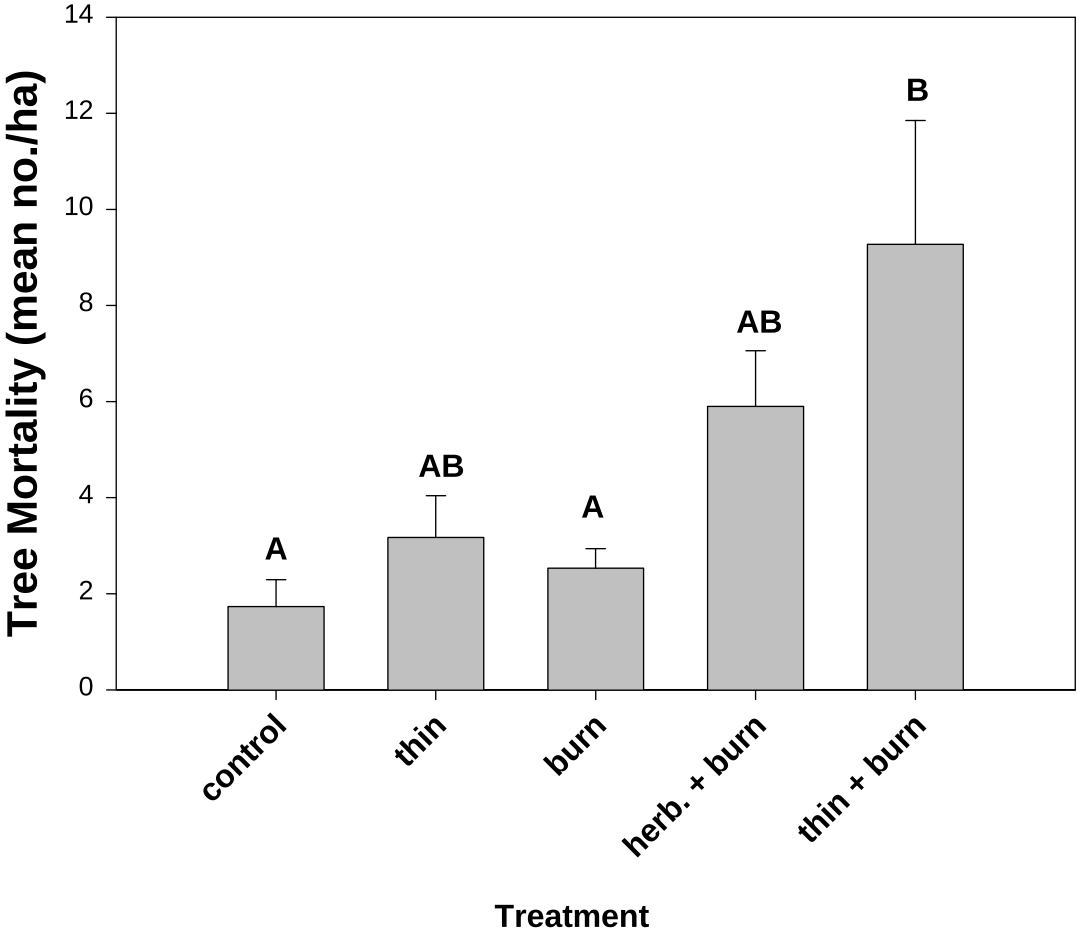

Fig. 6.4. Tree mortality from 2002-2004 on all fire and fire surrogate treated plots on the SolonDixon Experimental Forest, near Andalusia, AL. Columns with the same letter are not significantly different at p=0.05 (Tukey's Post Hoc Test, SAS, 1985).

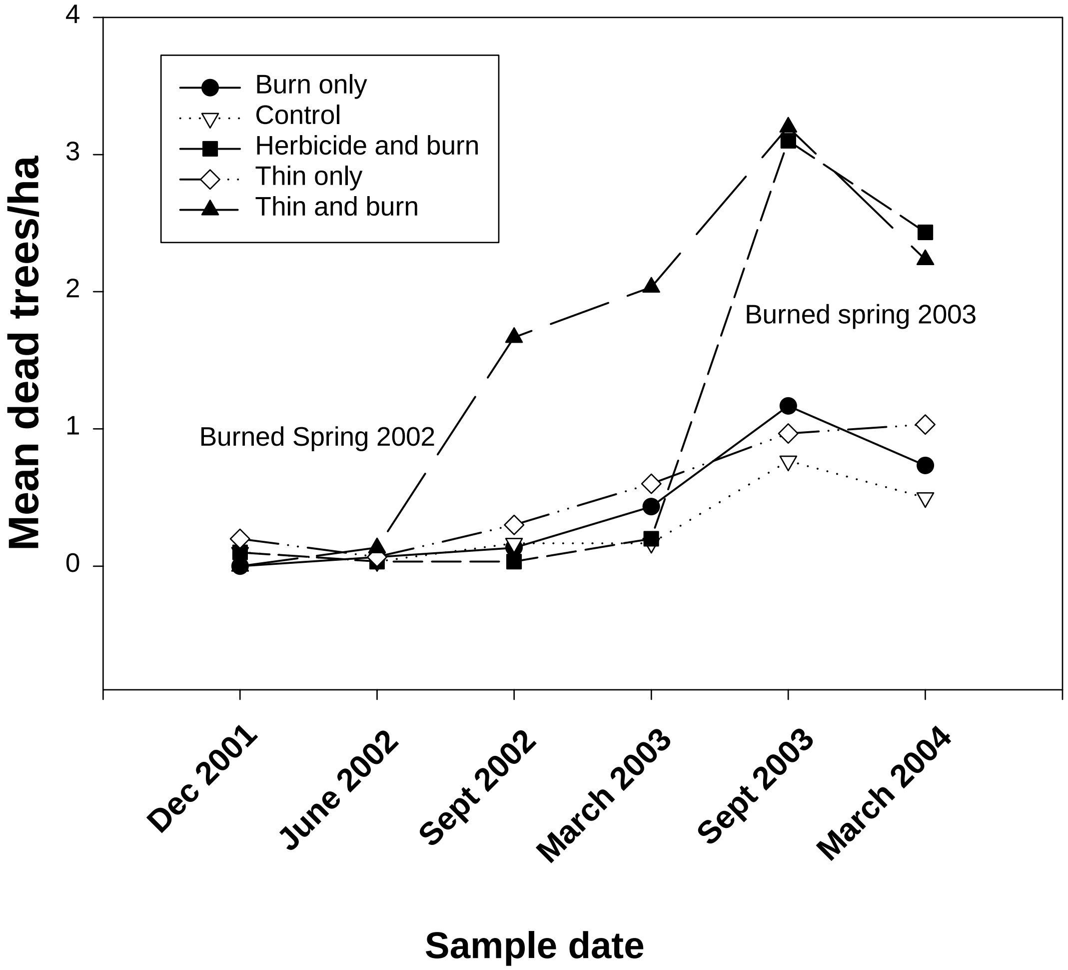

Fig. 6.5. Mean number of dead trees per hectare on fire and fire surrogate treatment plots within each sampling period on the Solon Dixon Experimental Forest, near Andalusia, AL.

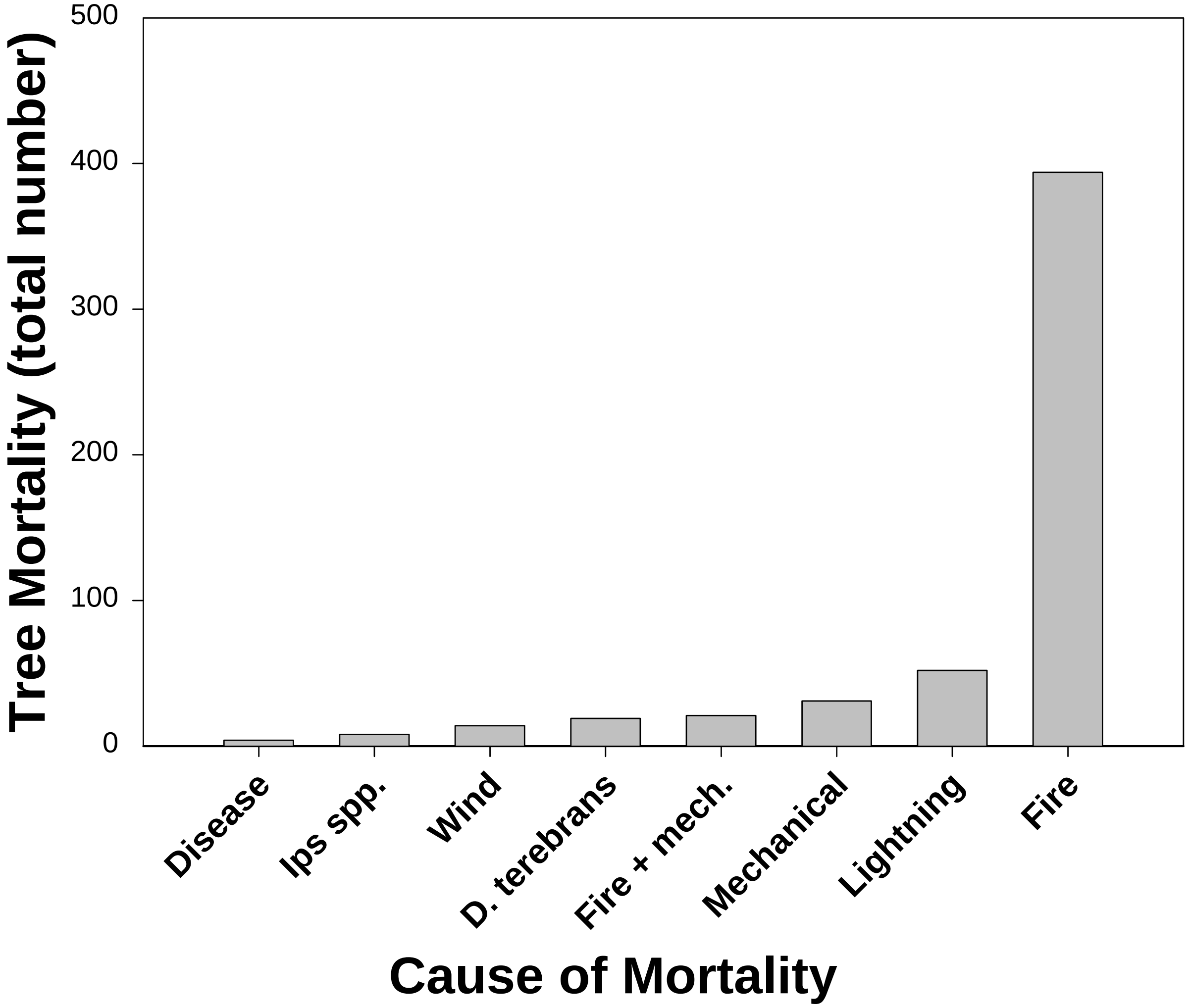

Fig. 6.6. Total tree mortality and cause of death on fire and fire surrogate plots from 2001-2004 on the Solon Dixon Experimental Forest, near Andalusia, AL.

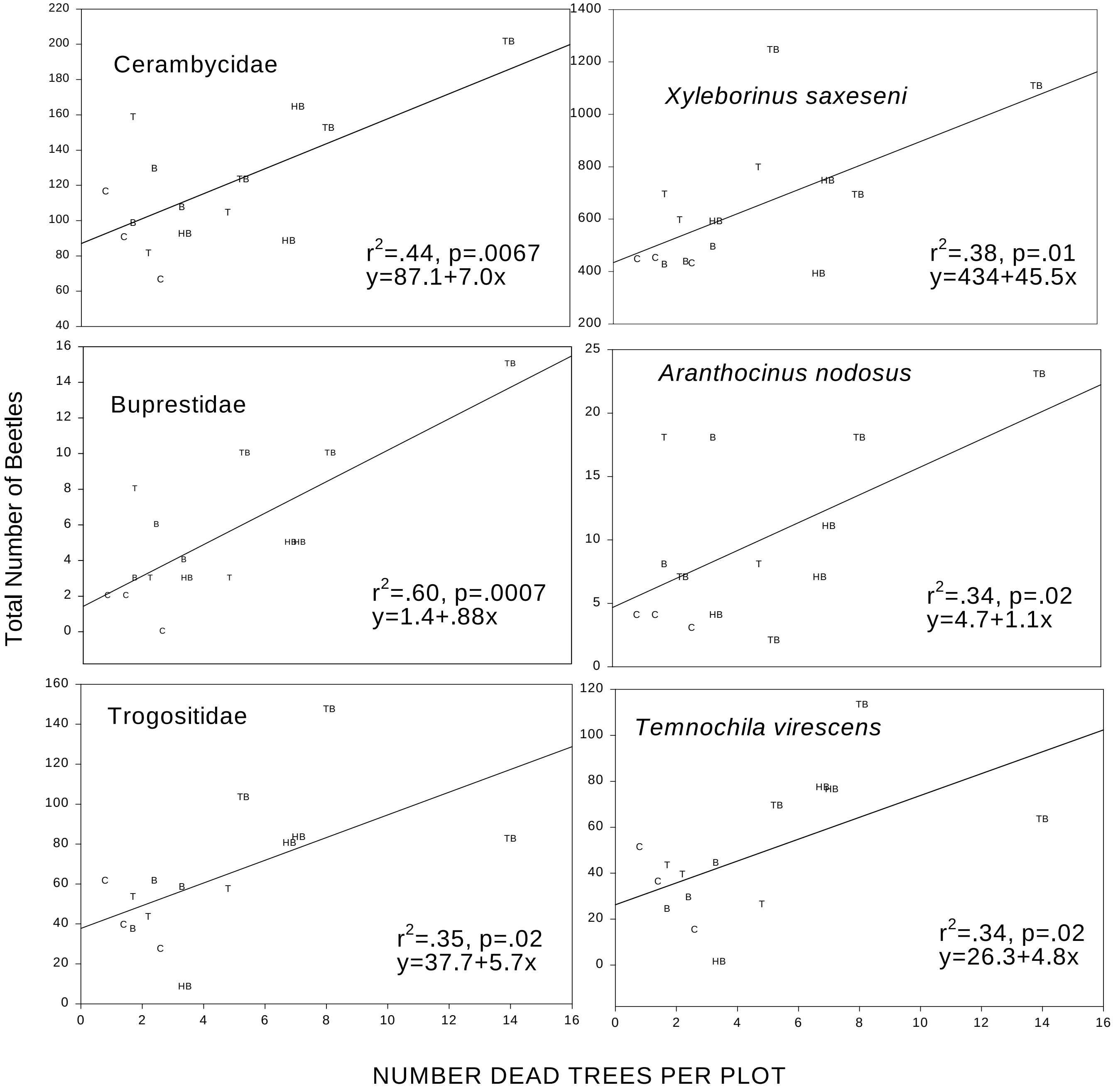

Fig. 6.7. Linear regression of the number of dead trees per hectare versus total numbers of various Coleoptera families and species captured in multiple funnel traps on plots receiving growing season prescribed burns or alternative to them on the Solon Dixon Experimental Forest. Treatments were: TB=thin plus burn, T=thin, B=burn, HB=herbicide plus burn, and C=control.

CHAPTER 7

CONCLUSIONS

Forest dwelling insects are considered vital parts of a forest ecosystem. Pollinating insects maintain and enhance plant diversity and saproxylic insects help recycle nutrients back into the soil by decomposing dead wood. Forest management practices such as prescribed burns, thinnings, mechanical brush removal, or herbicides are commonly used methods to limit fuel build up within forests. However, their effects on pollinating and saproxylic insects are poorly understood.

In the Blue Ridge Province of North Carolina, Hymenoptera was the most abundant and diverse order, with Halictidae being the most abundant family. The majority of floral visitors were captured in the mechanical plus burn treatments, while lower numbers were caught on the mechanical only treatments, burn only treatments and control treatments. Overall species richness was also higher on mechanical plus burn treatments compared to other treatments. Total pollinator abundance was correlated with decreased tree basal area (r^2=0.58) and increased percent herbaceous plant cover (r^2=0.71).

We captured 37,191 saproxylic Coleoptera in North Carolina, comprising 20 families and 122 species. Overall, species richness and total abundance of Coleoptera were not significantly different among treatments. However, total numbers of many key families, such as Scolytidae, Curculionidae, Cerambycidae, and Buprestidae, have higher total numbers in treated plots compared to untreated controls and several families

(Elateridae, Cleridae, Trogositidae, Scolytidae) showed significant differences ($p \leq 0.05$) in abundance.

In the Coastal Plain Plain Province of south Alabama, Hymenoptera was the most abundant and diverse order, with Halictidae being the most abundant family. Overall, our results indicated that none of the treatments we tested were better than others for enhancing general floral insect visitor abundance or diversity. However, all significant differences in abundance or diversity were higher on treated plots compared to controls.

We captured 75,598 saproxylic Coleoptera in south Alabama, comprising 17 families and 130 species. Coleoptera abundance was not significantly different among treatments, but all treated plots had higher numbers than untreated controls. Species richness was significantly higher on thin plus burn plots compared to thin only and control plots. Linear regression analysis of dead trees per plot versus various Coleoptera showed captures of Buprestidae, Cerambycidae, Trogositidae, *Aranthocinus nodosus*, *Temnochila virescens*, *Xyleborinus saxeseni* increased with increasing number of dead trees. Our results show that the treatments tested did not cause increased bark beetle related tree mortality and they did not have a negative effect on populations of early successional saproxylic beetle fauna.

Our findings indicate that forest disturbances such as prescribed burning, mechanical and chemical shrub reduction, and forest tree thinning can clearly influence pollinating and saproxylic insect abundance and diversity. However, in every case these practices increased pollinators or saproxylic beetles. I saw no evidence of detrimental impacts of the forest management practices on these groups of insects, but other management activities may negatively affect these or other insects. Therefore, land managers should consider the effects that various forest management practices could have on beneficial insect communities. Future research should focus on long-term changes that could arise as a result of the alterations of the communities initiated at our study site in North Carolina and Alabama.