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Bat activity in relation to fire and fire surrogate treatments in southern pine stands

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Abstract

Forest managers often use thinning and prescribed burning to reduce the risk of wildfire and insect outbreaks. Because thinning and burning alter the structure of forest stands and may affect insect prey abundance, they may change the suitability of stands for bats. Our objective was to test the effects of thinning and burning on bat foraging and commuting activity in pine stands in the Clemson Experimental Forest in the Piedmont of South Carolina. We also tested whether vertical use of stands varied with treatment and whether activity of three common species varied among treatments. Twelve stands in the Clemson Experimental Forest dominated by loblolly (*Pinus taeda*) and shortleaf (*P. echinata*) pine and at least 14 ha in size were selected and three replicates of four treatments were installed. The treatments were: (1) prescribed burning (Burn), (2) thinning to 18 m^2/ha (Thin), (3) thinning to 18 m^2/ha followed by prescribed burning (Thin&Burn) and (4) no treatment (Control). Bat activity was sampled with AnabatII bat detectors May–August 2001 and 2002. Big brown bats (*Eptesicus fuscus*), eastern red bats (*Lasiurus borealis*), and eastern pipistrelles (*Perimyotis subflavus*) were the most frequently recorded species and activity was significantly greater in 2001 than in 2002. In 2001, overall activity was significantly greater in the Thin stands than in the Control stands; activity in the Burn and Thin&Burn stands was intermediate. Activity was also greater in treated stands than in the Control stands in 2002, but the difference was not statistically significant ($P = 0.08$). In both years we recorded significantly more calls at 9 m than at 0.5 m above ground but the treatments did not affect vertical use of the stands. Activity of big brown bats and red bats was significantly higher in Thin stands than in Control or Burn stands, whereas activity of pipistrelles did not vary among treatments. Our results suggest that treatments that reduce clutter, particularly thinning, increase the suitability of pine stands for bats' foraging and commuting activity in the Piedmont region. Thus, use of these practices may help to preserve the biodiversity of managed pine forests in the South.
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Keywords: Bats; Fuel reduction; *Eptesicus fuscus*; *Lasiurus borealis*; *Perimyotis subflavus*; *Pinus* spp; Prescribed burning; Thinning

1. Introduction

Many forests in North America have greater fuel loads, more small trees, and fewer large trees than in the past. Consequently, these forests are highly susceptible to wildfire and insect outbreaks (McCullough et al., 1998; Van Lear et al., 2004; Fettig et al., 2007). These conditions have resulted from fire exclusion, timber harvesting, livestock grazing, farm abandonment and other land use histories (Youngblood et al., 2005). Although thinning and prescribed burning are often used to reduce the risks of wildfire and insect outbreaks, the ecological consequences of these management practices, particularly at an operational scale, are relatively unknown (Allen et al., 2002).

Bats are important components of forested ecosystems, but until recently few studies have examined the effects of forest management on their populations and behavior. Most studies conducted to date have examined the effects of various forest regeneration methods on bat habitat use, although a few studies have examined the response of bats to thinning of mature forests (Humes et al., 1999; Patriquin and Barclay, 2003; Tibbels and Kurta, 2003) or the effects of various harvest levels (Jung et al., 1999; Owen et al., 2004). In contrast, very little is known about the effects of wildfire or prescribed burning on bat populations or habitat use (Carter et al., 2002; Boyles and Aubrey, 2006).

Thinning and prescribed burning may have direct and indirect effects on bats. Both practices reduce the amount of

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clutter in the environment-physical obstacles such as branches, stems, and foliage. Clutter affects the ability of bats to fly and echolocate effectively (Fenton, 1990). Smaller bats with low wing loading and higher frequency echolocation calls are more clutter tolerant than larger bats with high wing loading and low frequency echolocation calls (Aldridge and Rautenbach, 1987; Norberg and Rayner, 1987; Crome and Richards, 1988). Therefore, reducing clutter through thinning or burning may increase overall bat activity and the number of bat species that use forest stands. For example, thinning increased use of 50–100-year-old Douglas fir (*Pseudotsuga menziesii*) forests in Oregon (Humes et al., 1999). However, it did not increase use of 50-year-old red pine (*Pinus resinoa*) stands in Michigan (Tibbels and Kurta, 2003) or mature boreal-mixed forest stands in Alberta, Canada (Patriquin and Barclay, 2003). Thus, the effects of thinning on bat habitat use are still not clear. Further, because thinning and burning are often used to reduce the midstory, they result in a change in stand vertical structure. Therefore, bats may respond to these practices through a change in their vertical use of space. However, change in vertical use of space in response to forest management practices has received little study.

Insect prey availability for bats may also be affected by forest management practices (Swengel, 2001). Both thinning and burning open the canopy, allowing more light to reach the forest floor. Increased light stimulates herbaceous growth which in turn increases the abundance and diversity of some insect taxa (Swengel, 2001; Campbell et al., 2007). In Michigan, however, nocturnal flying insect abundance in thinned red pine stands does not differ from nocturnal flying insect abundance in unthinned red pine stands (Tibbels and Kurta, 2003). Further, the effect of burning on insect diversity and abundance varies considerably depending on taxa, life history stage, exposure to flames, burn frequency, season of burn, and habitat (Swengel, 2001).

Our objective was to test the effects of thinning and burning on bat activity in pine stands located in the Clemson Experimental Forest in the Piedmont of South Carolina. We also tested whether vertical use of the stands varied with treatment. Finally, we tested whether activity of three common species varied among treatment stands. We predicted that overall bat activity would be higher in thinned, burned, and thinned and burned stands than in control stands and that vertical distribution of activity would be more equal in the thinned, burned, and thinned and burned stands than in the control stands. We also predicted that among the three most common species, the large bodied big brown bat (*Eptesicus fuscus*) and medium sized red bat (*Lasiurus borealis*) would show a stronger response to treatments than the small bodied eastern pipistrelle (*Perimyotis subflavus*).

2. Methods

2.1. Study area and design

This study is a component of the National Fire and Fire Surrogate Study, which uses an interdisciplinary approach at multiple sites across the United States to examine ecological consequences of fuel reduction (http://www.srs.fs.usda.gov/ffs/). Thus, study site selection, treatments, and vegetation and fuels measurements followed the national protocol (Youngblood et al., 2005).

We conducted the study in the Clemson Experimental Forest (CEF) in the Piedmont physiographic province of South Carolina. The CEF surrounds Hartwell Lake, a reservoir constructed in the 1950's. Most of the 7082 ha CEF consists of managed loblolly (*Pinus taeda*) and shortleaf (*P. echinata*) pine stands. However, stands of pine-hardwood, upland hardwood, bottomland hardwood and cove hardwood forests are widespread throughout. Common hardwood species include white oak (*Quercus alba*), southern red oak (*Q. falcata*), black oak (*Q. velutina*), post oak (*Q. stellata*), water oak (*Q. nigra*), yellow-poplar (*Liriodendron tulipifera*), sweetgum (*Liquidambar styraciflua*), sourwood (*Oxydendrum arboreum*), and flowering dogwood (*Cornus florida*). The area is characterized by rolling hills and elevation ranges from 200 to 300 m. Climate is moderate with average summer minimum and maximum temperatures ranging from 13.4 and 27.1 °C in May to 19.8 and 32.2 °C in July, respectively.

We selected 12 stands dominated by loblolly and shortleaf pine and at least 14 ha in size. A minimum stand size of 14 ha provided an area that was sufficiently large to measure the responses of mobile wildlife such as bats, while being small enough to reduce within stand variability. Stands were scattered across the CEF, but were blocked by stand age: stands in Block 1 contained pulpwood sized trees (15–25 cm dbh), stands in Block 2 contained a mixture of pulpwood and sawtimber trees, and stands in Block 3 contained sawtimber sized trees (>25 cm dbh). For all stands, time since last thinning was >10 years and time since last burning was >5 years. Within each block, we randomly assigned the stands to one of four treatments: (1) thinned to 18 m^2/ha basal area (Thin), (2) thinned to 18 m^2/ha and burned the following spring (Thin&Burn), (3) prescribed burned (Burn) and (4) control (Control). Thinning occurred in winter 2000–2001. Burning in the Burn stands occurred in April 2001 and the prescription was for a moderate intensity fire resulting in some overstory mortality to open the canopy. Strip head fires and flanking fires were used and flame heights ranged from approximately 0.3–3.5 m. The burn prescription for the Thin&Burn stands was a low intensity fire that would reduce midstory cover. Strip head fires were used and flame heights ranged from approximately 0.3–1.3 m. Due to heavy fuel loads from the 2001 thinning, burning in the Thin&Burn stands did not occur until spring 2002. Thus, even though all stands were sampled in 2001, there were essentially only three treatments in that year (Control, Burn, and Thin).

2.2. Bat activity sampling

AnabatII bat detectors connected to laptop computers were used to sample bat activity in each stand for two nights each month from May through August, 2001 and 2002 (Note: The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S.

Department of Agriculture of any product or service). Detectors were calibrated prior to each field season and the sensitivity of each detector was set to reduce the amount of variability among detectors (Larson and Hayes, 2000). Two detectors were placed at randomly selected grid points during the first night and moved to two other randomly selected points for the second night. Each night, one detector was placed at approximately 0.5 m above ground at one point and the other was placed on a pole at approximately 9 m above ground at the other point. All four stands within a block were sampled simultaneously and then detectors were moved to the next block. Thus, in most months, four points per stand were sampled each month. However, because of inclement weather or equipment malfunction, stands were occasionally sampled only for one night or <8 points were sampled in a night. Both detectors were oriented with the microphones pointing straight up. Detectors were turned on by sunset and turned off after sunrise, but were not deployed during rain.

Analook (Version 4.9j, 2004) was used to filter and analyze bat calls. Two filters were used to select calls for analysis: an activity filter and an identification filter. The activity filter required that each bat pass have ≥1 bat call and selected lower quality calls than the identification filter, including non-search phase calls (Britzke, 2003). A bat pass is a series of echolocation calls recorded without an interruption of >5 s. The activity filter was run first and files were checked to ensure that they contained bat calls. All files that did not contain bat calls were eliminated. Activity files were used as an index of overall bat activity including foraging and commuting activity. The identification filter was run on the files that passed the activity filter. Because search phase calls contain the most useful characteristics for species identification (Fenton and Bell, 1981), the identification filter selected bat passes that contained ≥5 calls and generally represented search phase calls (Britzke and Murray, 2000). Each pass that made it through the identification filter was also visually examined in Analook to ensure that it contained search phase calls. The filtered passes were identified to species using a combination of quantitative and qualitative methods. First, a discriminant function model based on >23,000 known search phase calls was used to identify calls (Brizke, 2003). Each identified pass was also visually inspected in Analook (total x-axis = 150 ms, compressed time) to confirm or correct the species designation obtained from the discriminant function model. We only used data from systems that ran the entire night.

2.3. Vegetation sampling

Trees (≥10 cm dbh) and saplings (<10 cm dbh and >1.4 m tall) were sampled at each of 10 20 m × 50 m plots within each treatment stand. Vegetation plots were subdivided into 10 10 m × 10 m subplots; trees and saplings were sampled on half the subplots. Species, diameter at breast height (dbh), and status (live or dead) of each tree were recorded. Saplings were tallied based on size class (<3 cm dbh, 3–6 cm dbh, and >6 cm dbh) and status (live or dead). Data were collected in the Thin, Burn, and Control plots in 2001 and in the Thin&Burn plots in 2002.

2.4. Statistical analyses

We averaged the number of passes at each detector height for each stand and month. Because the data were not normally distributed, they were transformed [ln(x + 0.5)] for analysis. A t-test was used to determine whether activity (number of passes per night) differed between years. Because the Thin&Burn treatment was not fully implemented in 2001 and the additional burning in 2002 might have affected between year comparisons, we did not include data from the Thin&Burn plots in this analysis. A repeated measures mixed-model ANOVA was used to test the effects of block, treatment, detector height, month, and all interactions on bat activity (PROC MIXED; Littell et al., 1996). An autoregressive order one covariance structure for the repeated factor (month) was used. Because the Thin&Burn treatment was not applied until 2002, the data were analyzed separately for each year. Least squares means were calculated and a Tukey's multiple comparisons test was run among main effect means. Back-transformed means ± S.E. are presented.

Sample sizes for several combinations of species and year were low and thus, we were not able to analyze individual species data by year or with the repeated measures model used for overall activity. Therefore, we pooled individual species data for each treatment over the 2 years. Because the Thin&Burn treatment was not applied in 2001, we did not include this treatment in our analysis. We used a Kruskal–Wallis One-Way Analysis of Variance by Ranks test to compare activity of big brown bats, red bats, and eastern pipistrelles among Control, Thin, and Burn treatments. A multiple comparison test was run to determine how activity differed among individual treatments (Conover, 1999).

Tree and sapling density and basal area data were pooled across the five subplots at each vegetation plot. We used a one-way ANOVA for a completely randomized block design with subsampling to test for differences in tree and sapling density and basal area among treatments (PROC GLM; SAS, 2002). Least squares means were calculated and a Tukey's test was run to separate means. A significance level of 0.05 was used for all tests.

3. Results

3.1. Stand structure

Due to the small number of replications and high variability in stand structure, few of the structural characteristics differed significantly among treatments (Table 1). However, treatments appeared to have considerable effects on stand structure. For example, live tree density in the treated stands was 58.2%–76.3% as great as that in the Control stands, and live tree basal area in the treated stands was 56.2%–71.4% as great as that in the Control stands (Table 1). These reductions were due largely to reductions in the midstory. Overstory density in the treatment stands was 71.8%–97.7% as great as that in Control stands whereas midstory density in treatment stands was 47.8%–64.6% as great as that in the Control stands. Snag density was significantly higher in Burn stands than in the other treatment

Table 1
Least squares means and standard errors of vegetation characteristics in fuel reduction treatment stands 1 year after treatment (2001 for Burn and Thin stands and 2002 for Thin&Burn stands) in the Clemson Experimental Forest, South Carolina

Characteristic	Control	Burn	Thin	Thin&Burn
Live tree density (#/ha)	754.7 ± 81.9^{a}	532.0 ± 81.9^{a}	576 ± 81.9^{a}	439.3 ± 81.9^{a}
Live tree basal area (m^2/ha)	29.7 ± 2.3^{a}	18.6 ± 2.3^{ab}	21.2 ± 2.3^{ab}	16.7 ± 2.3^{b}
Snag density (#/ha)	84.0 ± 40.9^{a}	280 ± 40.9^{b}	14.0 ± 40.9^{a}	81.3 ± 40.9^{a}
Snag basal area (m^2/ha)	2.8 ± 1.0^{ab}	7.0 ± 1.0^{b}	0.4 ± 1.0^{a}	2.5 ± 1.0^{ab}
Overstory live tree density (#/ha)	302.0 ± 44.9^{a}	238.0 ± 44.9^{a}	295.3 ± 44.9^{a}	220.7 ± 44.9^{a}
Overstory live tree basal area (m^2/ha)	18.2 ± 2.2^{a}	12.8 ± 2.2^{a}	15.8 ± 2.2^{a}	11.6 ± 2.2^{a}
Midstory live tree density (#/ha)	452.7 ± 64.4^{a}	292.0 ± 64.4^{a}	280.7 ± 64.4^{a}	216.0 ± 64.4^{a}
Midstory live tree basal area (m^2/ha)	11.4 ± 1.5^{a}	5.7 ± 1.5^{a}	5.5 ± 1.5^{a}	5.0 ± 1.5^{a}
Live saplings (#/ha)	2370.7 ± 683.5^{a}	754.7 ± 683.5^{a}	2493.3 ± 683.5^{a}	1247.3 ± 683.5^{a}
Dead saplings (#/ha)	0.0 ± 487.7^{a}	1525.3 ± 487.7^{a}	8.7 ± 487.7^{a}	1602.7 ± 487.7^{a}

Means within a row followed by the same letter are not significantly different ($P \geq 0.05$).

stands. Density of live saplings was lowest in stands that had been burned, and density of dead saplings was highest in these stands.

3.2. Bat activity

We sampled bat activity on 20 nights in 2001 and 23 nights in 2002 and recorded 1661 bat passes in 2001 and 921 bat passes in 2002. Activity was significantly greater ($t = 2.64$, df = 41, $P = 0.012$) in 2001 (36.2 ± 0.78 passes/night) than in 2002 (12.6 ± 0.83 passes/night). We were only able to identify 198 passes to species in 2001 and 172 passes to species in 2002. We recorded big brown bats, red bats, eastern pipistrelles, evening bats (*Nycticeius humeralis*), and hoary bats (*L. cinereus*). Hoary bats were only recorded during May and August and were probably migrating individuals. Evening bats were recorded throughout both summers but were uncommon.

In 2001 bat activity varied significantly with treatment and height (Table 2). Activity was significantly greater in the Thin stands than in the Control stands ($P = 0.014$) and significantly greater at 9 m than at 0.5 m ($P = 0.0007$; Table 3). Activity in the Burn and Thin&Burn stands did not differ significantly from activity in the Control or Thin stands. In 2002, activity did not vary significantly with treatment (Table 2). However, the pattern of activity among treatment stands was similar to that in 2001, with activity being higher in the treated stands than in the Control stands (Table 3). As in 2001, activity was significantly greater at 9 m than at 0.5 m (Tables 2 and 3). The treatment × height interaction was not significant in either year, which indicates that the treatments did not affect vertical use of space. The number of passes recorded at 9 m was greater than the number of passes recorded at 0.5 m in all treatments.

Big brown bat and red bat activity varied significantly among treatments (Kruskal–Wallis $\chi^2 = 6.87$, df = 2, $P = 0.03$ and $\chi^2 = 6.86$, df = 2, $P = 0.03$, respectively). Activity of big brown bats and red bats was significantly greater in Thin stands than in Control and Burn stands ($P < 0.05$) but there was no difference in activity between Control and Burn stands for either species (Table 4). Although activity tended to be higher in Thin stands (Table 4), there was no significant difference in activity of eastern pipistrelles among treatments ($\chi^2 = 3.10$, df = 2, $P = 0.21$).

4. Discussion

There are several inherent assumptions made when studying bat activity and habitat use with bat detectors (Hayes, 2000). One of the most important assumptions when comparing across habitat types is that the number of echolocation calls at a site is a good indication of the amount of use at that site. This assumption can be violated if five sources of variation are not taken into account. These are: (1) variation among detectors, (2) temporal variability, (3) variation in detectability of bats among habitats due characteristics of the habitat (e.g., clutter), (4) horizontal variation, and (5) vertical variation. Because we calibrated our detectors so that they had equal sensitivity and randomly placed the detectors within stands, variation among detectors should not have biased our results. Further, we

Table 2
Degrees of freedom (d.f.), *F*-values (*F*), and probability of a greater *F*-value (*P*) for repeated measures analysis of variance on overall bat activity among 4 fuel reduction treatments in the Clemson Experimental Forest, South Carolina during May through August 2001 and 2002

Source of variation	2001			2002		
	d.f.	*F*	*P*	d.f.	*F*	*P*
Treatment	3	4.68	0.0171	3	3.64	0.0844
Height	1	17.94	0.0007	1	13.79	0.0018
Treatment × height	3	0.24	0.8637	3	0.88	0.4733
Month	3	0.52	0.6718	3	2.50	0.0721
Treatment × month	9	1.68	0.1316	9	0.70	0.7033
Height × month	3	2.40	0.0850	3	0.28	0.8389
Treatment × height × month	9	1.44	0.2112	9	1.34	0.2440

Table 3
Least square means and standard errors (S.E.) of number of bat passes per night in each of four fuel reduction treatments and at two detector heights during May through August 2001 and 2002. Means within a column followed by the same letter do not differ significantly ($P > 0.05$)

Variable	2001		2002	
	Mean	S.E.	Mean	S.E.
Treatment				
Control	1.33[a]	0.86	0.41[a]	0.80
Burn	2.10[ab]	0.86	1.99[a]	0.81
Thin	8.23[b]	0.86	2.10[a]	0.80
Thin & Burn[a]	3.44[ab]	0.86	1.87[a]	0.81
Height				
0.5 m	1.35[a]	0.74	0.72[a]	0.70
9.0 m	6.41[b]	0.74	2.57[b]	0.70

[a] The burn portion of the Thin&Burn treatment was not applied in 2001. Thus, these stands received only the equivalent of the Thin treatment in 2001.

randomly placed detectors at four points within the stand each month and at two different heights, thus accounting for horizontal and vertical variation. We also sampled each stand several times over the season to account for temporal variation.

While the effect of structural differences between treatments may have affected some of our results, we believe these effects were minimal. Few studies have examined the effects of forest structure on detectability of bat calls by detectors although it is assumed to be an important factor. We were not able to test the effects of the treatments on detectability of individual species due to low sample sizes. However, using Program PRESENCE (MacKenzie et al., 2002) we found that our ability to detect at least some bat activity in a stand was not affected by treatment. Further, by sampling many points within each stand, we increased the likelihood that we sampled in both dense and open areas (e.g., gaps, near roads) in all the stands, including Controls. Patriquin et al. (2003) found that detection of 40 kHz sounds (those characteristic of red bats and eastern pipistrelles as well as many *Myotis* spp.) does not differ between thinned, unthinned and clear-cut stands. However, higher intensity sounds were required for 25 kHz pulses (those characteristic of the big brown bat) to be detected in clearcut and intact forests than in thinned stands. In hardwood forests of Missouri, the understory ($\leq$3 m) density did not affect the detectability of five species of bats including eastern pipistrelles and red bats (Yates and Muzika, 2006).

Although bat activity in our study was relatively low, it was comparable to activity levels in the Upper Piedmont and Mountains of South Carolina (Loeb and O'Keefe, 2006). Further, bat activity was significantly lower in 2002 than in 2001. Lower activity in 2002 may have been the result of short-term treatment effects, i.e., bat activity increased in the first year after treatment and then returned to pre-treatment levels. However, activity in Control plots also decreased in 2002, suggesting that the decrease in activity may have been due to other factors. Although prey availability was not measured as part of this study, arthropods were sampled as part of a concurrent study in the Control, Burn, and Thin plots and were significantly more abundant in 2001 than in 2002 (Zebehazy, 2002). Thus, lower bat activity levels in 2002 may have been a response to decreased arthropod availability.

Despite overall low activity levels, we found higher total bat activity as well as higher activity levels of big brown bats and red bats in stands where silvicultural treatments had reduced clutter, particularly those stands which had been thinned. The structure of treatment stands differed considerably from that of the Control stands, and this suggests that increased bat activity in the treatment stands was a response to reduced clutter in these stands. Differences in structure among the treatments were primarily in the midstory. Several studies have suggested that bats, especially the larger bodied species, avoid areas with dense clutter (Brigham et al., 1997; Erickson and West, 2003; Sleep and Brigham, 2003, Ellison et al., 2005). Our results are similar to those of Humes et al. (1999), who found that bat activity was higher in thinned stands than in unthinned stands. However, reducing clutter alone may not be sufficient to improve the suitability of forest stands for bats. For example, bat activity in thinned and unthinned red pine stands in Michigan does not differ (Tibbels and Kurta, 2003). Even after thinning, these stands are monocultures with little understory vegetation and receive little use by other mammals and birds. Further, thinning does not affect bat use of conifer stands in Alberta, Canada (Patriquin and Barclay, 2003). Thus, reducing forest stand clutter by thinning may be beneficial in some forest types and situations, but may not be sufficient to increase habitat use in other areas and forest types.

Prey availability was probably not an important factor contributing to differences in use among study stands. Arthropod abundance was significantly greater in the Burn than in the Control or Thin plots in both years of the study (Zebehazy, 2002), whereas bat activity was highest in the Thin plots in 2001 and similar among the treated plots in 2002. However, Zebehazy (2002) used sticky traps placed on tree boles to sample arthropods which is not an appropriate method

Table 4
Comparison of activity (number of passes per night) by big brown bats, eastern red bats, and eastern pipistrelles in the Control, Burn, and Thin treatment stands during 2001 and 2002 combined. Means, medians, and standard errors are presented

	Big brown bat			Red bat			Eastern pipistrelle		
	Mean	S.E.	Median	Mean	S.E.	Median	Mean	S.E.	Median
Treatment									
Control	0.09	0.06	0[a]	0.49	0.49	0[a]	0.07	0.03	0[a]
Burn	0.28	0.23	0[a]	0.27	0.16	0[a]	0.07	0.04	0[a]
Thin	1.20	0.56	0.38[b]	0.70	0.38	0.14[b]	0.35	0.18	0.13[a]

Medians within a column followed by the same letter are not significantly different ($P \geq 0.05$).

for sampling bat prey availability. Although sticky traps can be used to sample bat prey availability, cylindrical traps should be used and they should be suspended away from the tree bole (Kunz, 1988). Thus, future studies of bat response to thinning and burning operations should also test the effects of these treatments on insect prey availability using appropriate methods.

We were unable to determine whether thinning, burning, or a combination of thinning and burning provided the best habitat for bat foraging and commuting activity. For example, in 2001 the Thin and Thin&Burn stands received the same treatment, but activity was considerably higher in the Thin stands than in the Thin&Burn stands, and in 2002, activity was similar among all the treated stands. Bat activity is highly variable in space and time (Hayes, 1997; Broders, 2003; Ellison et al., 2005) due to variation in prey availability, weather conditions, and proximity to roosts. Further, microhabitat variation can also affect bat habitat use. Small openings and gaps within forest stands usually receive higher use than more continuous portions of stands (Law and Chidel, 2002; Menzel et al., 2002; Tibbels and Kurta, 2003). Thus, differences in activity among the treated stands probably represented normal temporal and spatial variability in bat use.

Because our detectors were placed at the top of the midstory and at ground level and the primary effect of the treatments was a reduction in midstory, we expected the vertical distribution of bat activity to be more even in the treated stands than in the Controls. This did not occur. Activity in all stands was greater at the top of the midstory and lower canopy than in the lower midstory and understory. Vertical use of forest stands has received relatively little study. Some researchers have found that activity is greater above the canopy (Kalcounis et al., 1999) while others have found that it is greater in the lower canopy and at ground level (Hecker and Brigham, 1999; Hayes and Gruver, 2000) or does not vary significantly with height (Menzel et al., 2005). However, these studies have also found that vertical use of forest stands varies with forest type and structure (Bradshaw, 1996; Menzel et al., 2005), species (Kalcounis et al., 1999; Hayes and Gruver, 2000), time of night (Hayes and Gruver, 2000), and moonlight (Hecker and Brigham, 1999). Hypothesized factors driving this variation include variation in clutter, insect availability, and predation risk (Hecker and Brigham, 1999; Hayes and Gruver, 2000). Unfortunately, few studies have tested these hypotheses and greater understanding of vertical use of stands is needed to predict how forest management practices will affect bat habitat use.

We recorded big brown bats, eastern red bats, eastern pipistrelles, evening bats, and hoary bats during this study. Big brown bats, eastern red bats, and eastern pipistrelles were the most common species recorded and were also the species most frequently captured on the CEF during the summers of 2002 and 2003 (Leput, 2004). Additional species captured by Leput during the summer were evening bats and a Seminole bat (*L. seminolus*). Thus, our acoustic recordings were a good reflection of the bat community in the area.

As we predicted, activity of big brown bats and red bats was positively affected by the Thin treatment (but not the Burn treatments) whereas there was no significant variation in eastern pipistrelle activity among treatments. Species with high wing loading and aspect ratios, such as the big brown bat and red bat are strong, fast flyers but have less maneuverability (Fenton, 1990). Thus, they are expected to prefer areas with reduced clutter (Aldridge and Rautenbach, 1987; Crome and Richards, 1988). In the south, big brown bats are often found in early successional habitats and in mature forests (Ellis et al., 2002; Menzel et al., 2005; Loeb and O'Keefe, 2006), suggesting that they prefer open areas with little clutter. In contrast, red bats often do not show a strong response to forest structure (Ellis et al., 2002; Menzel et al., 2005; Loeb and O'Keefe, 2006). However, our data suggest that reducing clutter may be beneficial for red bats in pine forests in the Piedmont. While activity of big brown bats and red bats was higher in the Thin stands compared to Control stands, activity in the Burn stands was not. Burning decreased the density and basal area of live trees, but there were still many snags in the plots. Thus, overall physical clutter may have been considerably higher in these stands than in the Thin stands. Once the snags have fallen, activity of big brown bats and red bats in the Burn stands may increase.

Increased use of Thin stands by big brown bats and red bats may have also been due to treatment effects on insect prey availability. Coleoptera and Lepidotera are the main food items of both species (Agosta, 2002; Carter et al., 2003). However, thinning had no effect on the biomass of either Coleoptera or Lepidotera in red pine stands in Michigan (Tibbels and Kurta, 2003).

Due to their small size and low wing loading, eastern pipistrelles are thought to be more clutter-adapted than larger species such as big brown bats. Thus, we did not expect the treatments to have an effect on their activity levels. However, several studies have found that eastern pipistrelles use low clutter habitats such as early-successional areas more than mid- and late-succesional stands (e.g., Ellis et al., 2002; Menzel et al., 2005; Loeb and O'Keefe, 2006). Although activity of eastern pipistrelles did not vary significantly among treatments, activity was five times higher in Thin stands than in Control or Burn stands. Thus, thinning may benefit eastern pipistrelles as well as big brown bats and red bats, but the results are inconclusive.

5. Conclusions

Our results suggest that silvicultural treatments such as prescribed burning and thinning may be beneficial for bats inhabiting pine forests of the southern Piedmont. These treatments appear to increase the suitability of pine stands for foraging and commuting. The reduced clutter brought about by the treatments, particularly thinning, most likely increased the ease and efficiency of flight and echolocation in these stands, particularly by big brown bats and red bats. Thus, these treatments may be important tools for preserving biodiversity in managed stands in the southern Piedmont. However, the effects may be short-term and the long-term effects of these treatments need to be addressed. Although reduced clutter is the most likely cause of the increased use of the treated stands compared to the Controls, we cannot rule out the possibility that the insect prey base was also affected by the treatments. Future studies should examine the effects of the treatments on nocturnal flying insects.

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References

Agosta, S.J., 2002. Habitat use, diet and roost selection by the big brown bat (*Eptesicus fuscus*) in North America: a case for conserving an abundant species. Mamm. Rev. 32, 179–198.

Aldridge, H.D.J.N., Rautenbach, I.L., 1987. Morphology, echolocation and resource partitioning in insectivorous bats. J. Anim. Ecol. 56, 763–778.

Allen, C.D., Savage, M., Falk, D.A., Suckling, K.F., Swetnam, T.W., Schulke, T., Stacey, P.B., Morgan, P., Hoffman, M., Klingel, J.T., 2002. Ecological restoration of southwestern ponderosa pine ecosystems: a broad perspective. Ecol. Appl. 12, 1418–1433.

Boyles, J.G., Aubrey, D.P., 2006. Managing forests with prescribed fire: implications for a cavity-dwelling bat species. For. Ecol. Manage. 222, 108–115.

Bradshaw, P.A., 1996. The physical nature of vertical forest habitat and its importance in shaping bat species assemblages. In: Barclay, R.M.R., Brigham, R.M. (Eds.), Bats and Forests Symposium, Canada Research Branch, B. C. Ministry of Forestry, Victoria, B.C, pp. 199–212.

Brigham, R.M., Grindal, S.D., Firman, M.C., Morissette, J.L., 1997. The influence of structural clutter on activity patterns of insectivorous bats. Can. J. Zool. 75, 131–136.

Britzke, E.R. 2003. Use of ultrasonic detectors for acoustic identification and study of bat ecology in the eastern United States, Dissertation, Tennessee Technological University, Cookville, TN, USA.

Britzke, E.R., Murray, K.L., 2000. A quantitative method for selection of identifiable search-phase calls using the Anabat system. Bat Res. News 41, 33–36.

Broders, H.G., 2003. Another quantitative measure of bat species activity and sampling intensity considerations for the design of ultrasonic monitoring studies. Acta Chirop. 5, 235–241.

Campbell, J.W., Hanula, J.L., Waldrop, T.A., 2007. Effects of prescribed fire and fire surrogates on floral visiting insects of the Blue Ridge province of North Carolina. Biol. Cons. 134, 393–404.

Carter, T.C., Ford, W.M., Menzel, M.A., 2002. Fire and bats in the Southeast and mid-Atlantic: more questions than answers? In: Ford, W.M., Russell, K.R., Moorman, C.E. (Eds.), The Role of Fire in Nongame Wildlife Management and Community Restoration: Traditional Uses and New Directions. USDA Forest Service, Northeastern Research Station, General Technical Report, NE-288 Newtown Square, PA, pp 139-143.

Carter, T.C., Menzel, M.A., Owen, S.F., Edwards, J.W., Menzel, J.M., Ford, W.M., 2003. Food habits of seven species of bats in the Allegheny Plateau and Ridge and Valley of West Virginia. Northeast. Nat. 10, 83–88.

Conover, W.J., 1999. Practical Nonparametric Statistics. John Wiley & Sons, Inc, New York, NY.

Crome, F.H.J., Richards, G.C., 1988. Bats and gaps: microchiropteran community structure in a Queensland rain forest. Ecology 69, 1960–1969.

Ellis, A.M., Patton, L.L., Castleberry, S.B., 2002. Bat activity in upland and riparian habitats in the Georgia Piedmont. In: Proceeding of the Annual Conference Southeast. Assoc. Fish and Wildl. Agencies 56. pp. 210–218.

Ellison, L.E., Everette, A.L., Bogan, M.A., 2005. Examining patterns of bat activity in Bandelier National Monument, New Mexico, by using walking point transects. Southwest Nat. 50, 197–208.

Erickson, J.L., West, S.D., 2003. Associations of bats with local structure and landscape features of forested stands in western Oregon and Washington. Biol. Cons. 109, 95–102.

Fenton, M.B., 1990. The foraging behaviour and ecology of animal-eating bats. Can. J. Zool. 68, 411–422.

Fenton, M.B., Bell, G.P., 1981. Recognition of species of insectivorous bats by their echolocation calls. J. Mamm. 62, 233–243.

Fettig, C.J., Klepzig, K.D., Billings, R.F., Munson, A.S., Nebeker, T.E., Negrón, T.E., Nowak, J.T., 2007. The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States. For. Ecol. Manage. 238, 24–53.

Hayes, J.P., 1997. Temporal variation in activity of bats and the design of echolocation-monitoring studies. J. Mamm. 78, 514–524.

Hayes, J.P., 2000. Assumptions and practical considerations in the design and interpretation of echolocation-monitoring studies. Acta Chirop. 2, 225–236.

Hayes, J.P., Gruver, J.C., 2000. Vertical stratification of bat activity in an old-growth forest in western Washington. Northwest Sci. 74, 102–108.

Hecker, K.R., Brigham, R.M., 1999. Does moonlight change vertical stratification of activity of forest-dwelling insectivorous bats? J. Mamm. 80, 1196–1201.

Humes, M.L., Hayes, J.P., Collopy, M.W., 1999. Bat activity in thinned, unthinned, and old-growth forests in western Oregon. J. Wildl. Manage. 63, 553–561.

Jung, T.S., Thompson, I.D., Titman, R.D., Applejohn, A.P., 1999. Habitat selection by forest bats in relation to mixed-wood stand types and structure in central Ontario. J. Wildl. Manage. 63, 1306–1319.

Kalcounis, M.C., Hobson, K.A., Brigham, R.M., Hecker, K.R., 1999. Bat activity in the boreal forest: importance of stand type and vertical strata. J. Mamm. 80, 673–682.

Kunz, T.H., 1988. Methods of assessing the availability of prey to insectivorous bats. In: Kunz, T.H. (Ed.), Ecological and Behavioral Methods for the Study of Bats. Smithsonian Institution Press, Washington, DC, pp. 191–210.

Larson, D.J., Hayes, J.P., 2000. Variability in sensitivity of Anabat II bat detectors and a method of calibration. Acta Chirop. 2, 209–213.

Law, B., Chidel, M., 2002. Tracks and riparian zones facilitate the use of Australian regrowth forest by insectivorous bats. J. Appl. Ecol. 39, 605–617.

Leput, D.W., 2004. Eastern red bat (*Lasiurus borealis*) and eastern pipistrelle (*Pipistrellus subflavus*) maternal roost selection: implications for forest management, M.S. Thesis, Clemson University, Clemson, SC, USA.

Littell, R.C., Milliken, G.A., Stroup, W.W., Wolfinger, R.D., 1996. SAS System for Mixed Models. SAS Institute, Inc, Cary, NC.

Loeb, S.C., O'Keefe, J.M., 2006. Habitat use by forest bats in South Carolina in relation to local, stand, and landscape characteristics. J. Wildl. Manage. 70, 1210–1218.

MacKenzie, D.I., Nichols, J.D., Lachman, G.B., Droege, S., Royle, J.A., Langtimm, C.A., 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83, 2248–2255.

McCullough, D.G., Werner, R.A., Neumann, D., 1998. Fire and insects in northern boreal ecosystems of North America. Ann. Rev. Ent. 43, 107–127.

Menzel, J.M., Menzel, M.A., Kilgo, J.C., Ford, W.M., Edwards, J.W., McCracken, G.F., 2005. Effect of habitat and foraging height on bat activity in the coastal plain of South Carolina. J. Wildl. Manage. 69, 235–245.

Menzel, M.A., Carter, T.C., Menzel, J.M., Ford, W.M., Chapman, B.R., 2002. Effects of group selection silviculture in bottomland hardwoods on the spatial activity patterns of bats. For. Ecol. Manage. 162, 209–218.

Norberg, U.M., Rayner, J.M.V., 1987. Ecological morphology and flight in bats (Mammalia; Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. Phil. Trans. Royal Soc. London. B 316, 335–427.

Owen, S.F., Menzel, M.A., Edwards, J.W., Ford, W.M., Menzel, J.M., Chapman, B.R., Wood, P.B., et al., 2004. Bat activity in harvested and intact forest stands in the Allegheny Mountains. No. J. Appl. For. 21, 154–159.

Patriquin, K.J., Barclay, R.M.R., 2003. Foraging by bats in cleared, thinned and unharvested boreal forest. J. Appl. Ecol. 40, 646–657.

Patriquin, K.J., Hogberg, L.K., Chruszcz, B.J., Barclay, R.M.R., 2003. The influence of habitat structure on the ability to detect ultrasound using bat detectors. Wildl. Soc. Bull. 31, 475–481.

SAS Institute Inc., 2002. SAS/STAT User's Guide. Version 9. SAS Institute Inc., Cary, NC.

Sleep, D.J.H., Brigham, R.M., 2003. An experimental test of clutter tolerance in bats. J. Mamm. 84, 216–224.

Swengel, A.B., 2001. A literature review of insect responses to fire, compared to other conservation managements of open habitat. Biodivers. Cons. 10, 1141–1169.

Tibbels, A.E., Kurta, A., 2003. Bat activity is low in thinned and unthinned stands of red pine. Can. J. For. Res. 33, 2436–2442.

Van Lear, D.H., Harper, R.A., Kapeluck, P.R., Carroll,W.D., 2004. History of Piedmont forests: implications for current pine management. In: Connor, K.F. (Ed.), Proceedings of the 12th Biennial Southern Silvicultural Research Conference, USDA Forest Service, Southern Research Station, General Technical Report, SRS-71, Asheville, NC, pp. 139-143.

Yates, M.D., Muzika, R.M., 2006. Effect of forest structure and fragmentation on site occupancy of bat species in Missouri Ozark forests. J. Wildl. Manage. 70, 1238–1248.

Youngblood, A., Metlen, K.L., Knapp, E.E., Outcalt, K.W., Stephens, S.L., Waldrop, T.A., Yaussey, D., 2005. Implementation of the fire and fire surrogate study–a national research effort to evaluate the consequences of fuel reduction treatment. In: Peterson, C.E., Maguire, D.A. (Eds.), Balancing Ecosystem Values: Innovative Experiments for Sustainable Forestry. USDA Forest Service, Pacific Northwest Station, Portland, OR, pp. 315–321.

Zebehazy, L. A. 2002. Avian and arthropod responses to fuel reduction treatments in the upper Piedmont of South Carolina. M. S Thesis, Clemson University, Clemson, SC, USA.