EFFECTS OF THINNING AT DIFFERENT INTENSITIES ON HABITAT USE BY BATS IN THE BANKHEAD NATIONAL FOREST, ALABAMA

By

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PREFACE

The first chapter of this work is an overview of the potential effects that thinning has on bats and their habitat use, followed by a literature review. The literature review covers habitat and diet preferences of bat species specific to the area, and effects of thinning on wildlife species. It also reviews sampling methods used for similar studies. The second chapter is written to be submitted to *The Southeastern Naturalist*, a publication of the Southeastern Association of Naturalists and follows the format required for that journal.

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INTRODUCTION

Bats (Chiroptera: Microchiroptera) are the primary predators of nocturnal, flying insects (Altringham 1996), including major pests to agricultural crops. For mammals of their size, bats are long lived, have low reproductive rates, and relatively long periods of parental dependence, which may place them at greater risk from impacts to their environment (Erickson and West 2003). Many of the world's bat species are in decline due to habitat loss (Gellman and Zielinski 1996) and pesticide exposure (Clark 1988; Mispagel et al. 2004). In the U.S. and its territories many species and subspecies are currently listed or proposed for listing under the Endangered Species Act (O'Shea and Bogan 2003). As the second largest order of mammals in the world, conservation of this highly diverse group of mammals is critical for maintaining biodiversity and ecological viability.

Bat species are an important component of forest ecosystems (Agosta 2002). Many bats species are forest dwelling and rely on forests for foraging and roosting habitat (Patriquin and Barclay 2003). Structural characteristics of forests are important to bats because they directly influence flight maneuverability (Aldridge and Rautenbach 1987) and indirectly affect prey abundance (Krusic et al. 1996, Kunz 1973). Wing morphology and body size affect flight maneuverability through structurally complex habitats such as forests; therefore, foraging bats tend to avoid areas with high tree densities (Erickson and West 2003, Meyer et al. 2004), despite higher densities of insects (Grindal 1996, Kalcounis and Brigham 1995).

Another important component of forests for bat species is presence of roosting sites in live and dead trees (Erickson and West 2003, Gellman and Zielinski 1996).

Suitable roosting trees for bats tend to be larger in diameter than surrounding trees, in areas with less canopy cover, and with fewer trees surrounding the roost (Campbell et al. 1996, Menzel et al. 1998, Trousdale and Beckett 2005). These characteristics are important for maintaining stable microclimates and providing protection from predators (Altringham 1996, Kunz 1982). Both foraging and roosting habitats are important for maintaining stable chiropteran communities; therefore any management activities affecting forest habitats have the potential to impact chiropteran activity and community structure.

A common practice in managing forests is thinning, the reduction in density of overstory trees through removal of only selected trees (Smith 1986). Intensity of thinning as well as types of trees retained depends on management objectives. Many managers use thinning as a means of maintaining forest habitat while allowing timber extraction (Perdue and Steventon 1996). Thinning also may mimic old growth characteristics in a forest stand and allow for regeneration of native tree species (Bailey and Tappeiner 1998, McComb et al. 1993). Humes et al. (1999) found that compared to unthinned stands, thinned stands had fewer trees per hectare, larger diameters of trees, less canopy cover, larger snags, and more canopy gaps. These characteristics suggest that thinned stands should provide more favorable habitat for forest dwelling bats than stands with high tree densities. The use of thinning is widespread in public, private, and industrial land management and is expected to continue to increase as demand for wood products increases (Allen et al. 1996) and forest habitat restorations continue.

The purpose of this study was to determine the effect that thinning at different intensities has on diversity and abundance of bats in a forested landscape, and to determine whether structural characteristics or food availability play a role in bats' preference among treatment types.

The study area is located in the Bankhead National Forest (BNF), in northwestern Alabama in Winston, Lawrence, and Franklin counties. It consists of ca. 73,653 ha of public land managed by the U.S. Forest Service. The Forest Service is under a multiple use mandate for managing national forests, meaning management objectives must include consideration of wildlife, water, recreation, and timber. In the BNF, management is focused on restoring and maintaining native forest community types, maintaining rare plant communities, and providing wildlife habitat. It is an important area for many wildlife species, including a diverse avifauna, endangered freshwater mussels, important game species including white-tailed deer (*Odocoileus virginianus*) and wild turkey (*Meleagris gallopavo*), and several species of bats.

Within BNF, the Forest Service has recently begun implementing a Forest Health and Restoration Project aimed at improving overall forest health, restoring native forest communities, and providing plant and animal communities that are uncommon throughout much of the Southern Cumberland Plateau physiographic region. In order to reach desired conditions for each area of the forest, thinning, prescribed burning, and reforestation regimes are being implemented. This project has allowed studies such as the vertebrate study reported here, to determine effects of forest management on the forest community including plants, animals, soils, and invertebrates.

LITERATURE REVIEW

I have focused this review of habitat requirements and diet on species that have been documented to occur in the BNF or could potentially occur, but have not been captured with current sampling efforts. Although roosting habitat was not directly addressed in this study, a review of roosting preferences is included in order to draw conclusions about required roosting habitat. I reviewed effects of thinning on wildlife species in general and specific effects on bat communities. A review of sampling methods is also included.

Bats in the BNF--Nine species of bats have been documented in the forest: big brown bat (*Eptesicus fuscus*), eastern red bat (*Lasiurus borealis*), silver-haired bat (*Lasionycteris noctivagans*), eastern pipestrelle (*Pipestrellus subflavus*), evening bat (*Nycticeus humeralis*), northern long-eared bat (*Myotis septentrionalis*), little brown bat (*M. lucifugus*), and two endangered species, Indiana bat (*M. sodalis*), and gray bat (*M. grisescens*; pers. com., T.U.Counts, District Wildlife Biologist, Bankhead National Forest). Other species that have ranges within the BNF are the seminole bat (*Lasiurus seminolus*), hoary bat (*Lasiurus cinereus*), southeastern myotis (*Myotis austroriparius*), and Rafinesque's big eared bat (*Corynorhinus rafinesquii*; Choate et al. 1994). Other studies on the forest have looked at habitat use by the Indiana bat (Battle 2003), but no research has been conducted on the use of habitat by other bat species.

Habitat Preferences--Summer roosts are important to bats because they reduce energetic costs of thermoregulation by providing a thermally stable environment (Kurta 1985). They also may provide protection from predators (Fenton 1983) and environmental elements (Vaughan 1987). In forest habitats bats utilize tree foliage, cavities, bark, and other crevices of both live and dead trees for roosting (Agosta 2002; Barclay et al. 1988, Britzke et al. 2003, Carter et al. 2003a, Gooding and Langford 2004, Kalcounis and Bringham 1998, Menzel et al. 2002b, Veilleux et al. 2003). Some species, such as the eastern red bat, also will roost in leaf litter on the forest floor (Mager and Nelson 2001).

Kalcounis-Ruppell et al. (2005) did a meta-analysis of roost site characteristics from studies on tree roosting bats. Their analyses included separating cavity roosting species from foliage roosting species because of differences in roosting behavior. For cavity roosting species they found preferences for larger diameter trees, taller trees, and trees in more open canopy stands. Foliage roosting species also preferred larger diameter and taller trees, but were in more closed canopy stands. Most species show preferences for trees with diameters >30 cm (Barclay et al.1988, Broders and Forbes 2004, Campbell et al. 1996, Mager and Nelson 2001, Menzel et al. 2001). Trousdale and Beckett (2005) found a mean diameter of 79.4 cm for roost trees of Rafinesque's big-eared bats in southeastern Mississippi. In a bottomland hardwood forest in northeastern Louisiana, roost trees used by Rafinesque's big-eared bats had a mean diameter of 120.12 cm and a mean tree height of 25.06 m (Gooding and Langford 2004). A review of mean tree heights showed a range of 6.1 m for silver-haired bats in the Pacific Northwest (Campbell et al. 1996) to 27.8 m for Seminole bats in the southeast (Menzel et al. 1998). Canopy closure ranged from 92.3% for red bats, a foliage roosting species, in Georgia and South Carolina (Menzel et al. 1998), to 27.9% in sub-adult evening bats in South Carolina (Menzel et al. 2001).

Use of forests by foraging bats varies based on a number of characteristics including insect abundance (Krusic et al. 1996, Kunz 1973), wing aspect ratio, wing loading, and call frequency (Barclay 1985, Menzel et al. 2002a, Owen et al. 2004). Bat echolocation calls are composed of frequency-modulated signals (FM) or constant frequency signals (CF) or combinations of both (Jones and Rydell 2003). Most bats species in the southeastern U.S. use FM calls which are short (1-5 ms) pulses of sound sweeping from high to low frequencies (Simmons et al. 1979) that may be useful for determining texture in the environment (Schmidt 1988). Frequency of calls affects the degree of resolution with which a bat can detect prey or obstacles in its environment. Higher frequency calls have shorter wavelengths than lower frequency calls and provide better target detail. However, high frequency calls are more directional (Fenton 1982), whereas lower frequency calls give bats a wider view of their surroundings. Low frequency calls are generally associated with open area foraging and high frequency calls are associated with more cluttered environments (Norberg and Rayner 1987).

Wing shape, as it pertains to maneuverability, is characterized mainly by wing-aspect ratios and wing-loading. Species with lower wing loading (weight of bat / wing area) have a sharper turning radius, therefore greater maneuverability (Aldridge 1986). Bats with higher wing-aspect ratios (wing span^2 / wing area) will have a harder time making sharp turns, and will be less maneuverable (Norberg and Rayner 1987).

Hoary bats and silver-haired bats, which have lower wing-aspect ratios, higher wing-loadings, and lower call frequencies (Barclay 1985), generally prefer foraging in open habitats more than closed forests (Owen et al. 2004). *Myotis* spp., which are smaller in size, have higher echolocation call frequencies, and lower wing loading, use closed canopy forests more than other bat species (Ford et al. 2005, Owen et al. 2004). The northern long-eared bat (*Myotis septentrionalis*) shows a preference for foraging on hillsides and ridges and is one of the few species that will utilize dense timber (Ford et al. 2005). Ford et al. (2005) found that detection of northern Myotis and Indiana bats was related to increased canopy cover. However morphological and echolocation traits are not the only determinants of habitat use. For example big brown bats have a low frequency call and use both open and closed forest habitat (Owen et al. 2004). Bats such as the big brown bat and eastern red bat are generalists and will utilize a wide variety of habitats (Ford et al. 2005)

Diet-- Morphological characteristics, as well as habitat, may determine types of prey consumed by different species of bats. Most bat species will consume a variety of insects in the orders Lepidoptera, Coleoptera, Hemiptera, Homoptera, Hymenoptera, Neuroptera, Diptera, Orthoptera, Trichoptera, and Odonata, but some may show preferences for certain groups (Agosta 2002, Best et al. 1997, Carter et al. 2003b, Carter et al. 2004, Rosenthal et al. 1994, and Ross 1967). Kunz (1973) suggested that the northern long-eared bat is an opportunistic forager that is only limited by the size of insect it can capture. Silver-haired bats are also regarded as opportunistic foragers but may show different preferences throughout their range (Black 1974, Carter et al. 2003b, Whitaker 1972, and Whitaker et al. 1977). Eastern red bats also consume a variety of insects probably selected according to size instead of limiting their choice to certain orders (Ross 1967). However, some studies have documented a preference by eastern red bats for moths (Whitaker 1972) and beetles (Carter et al. 2003b). They also will feed on ground dwelling insects and spiders (Jackson 1961). Hoary bats focus on large insects, likely due to their low-frequency echolocation calls that make it difficult to detect and catch small prey (Barclay 1986). In South Carolina, Seminole bats consumed lower volumes of Coleoptera, Hemiptera, Diptera, and Trichoptera than were available, but Hymenoptera were taken in greater proportional to their availability (Carter et al. 2004). In the same study, evening bats consumed lower volumes of Coleoptera, Lepidoptera, Diptera, and Trichoptera than were proportional to availability, but Hemiptera and Homoptera were consumed in proportionally greater volumes (Carter et al. 2004). Carter et al. (2003b) found no preference in insect selection by eastern pipistrelles and little brown bats. Big brown bats are typically classified as beetle-strategists (Black 1974), but also consume moths in great numbers (Warner 1985, Whitaker et al. 1977). A captive female gray bat preferred members of the order Coleoptera and rejected Lepidopterans (Brack and Mumford 1983); however, in northeastern Alabama, Best et al. (1997) found the orders Lepidoptera, Diptera, and Coleoptera to represent over 48% of the total volume of prey consumed by gray bats.

Effects of thinning-- Thinning is a common timber management practice defined as the reduction in density of overstory trees through removal of selected trees (Smith 1986). Results of thinning vary depending on intensity and tree selection. Klenner and Sullivan (2003) found that thinning can help maintain mature forest habitat.

Effects of thinning on different species of mammals are influenced by the life history of the particular species. The southern red-backed vole (*Clethrionomys gapperi*) inhabits late successional forests and may be an important indicator of "old-forest conditions" (Merritt 1981), but Klenner and Sullivan (2003) found no difference in abundance of red-backed voles between uncut subalpine fir/ Engelmann spruce forest and thinned forest. Simard and Fryxell (2003) found that abundance of deer mice (*Peromyscus maniculatus*) in the Precambian Uplands of Canada was lower in stands that had been thinned compared to unthinned stands, but abundance of chipmunks (*Tamias striatus*) increased in thinned stands.

In chiropteran communities, thinning can affect important structural characteristics, roost site availability, and prey abundance. In northwestern British Columbia, Perdue and Steventon (1996) conducted a preliminary study of bat presence and activity in two intensities of thinning compared to clearcuts and uncut forests. Based on the length of time bats were present foraging in each habitat, they concluded that thinned forests were at least as suitable as unthinned forests. Tibbels and Kurta (2003) used acoustic sampling and mist netting to study bat activity in thinned and unthinned stands of red pine in Michigan. They found no difference in bat activity in thinned and unthinned stands, although they found a significantly higher amount of activity in adjacent openings. Thinning results in a decrease in tree density in a stand. Erickson and West (2003) found a negative correlation between bat activity and tree density in the northwestern U.S. Humes et al. (1999) looked at the difference in bat activity by means of acoustic sampling in thinned, unthinned, and old growth stands in western Oregon. Total bat activity differed among the three sites over two years. It was 1.9 times higher in old-growth than in unthinned stands and 1.6 times higher in thinned than in unthinned stands. Owen et al. (2003) suggest that partial timber harvests (thinning) in the Allegheny Mountains that left a relatively closed canopy could be beneficial to northern long-eared bats. Menzel et al. (2002a) found greater bat activity in stands with group selection timber harvest particularly along skidder trails and gap edges than in the intact canopy of mature forest in South Carolina. Relatively little is known about effects of thinning on chiropteran communities of the southern U.S., despite a large timber production industry in southern states.

Sampling Methods-- Use of ultrasonic detectors is becoming widespread for studying activity of bats in different habitats (Kunz and Brock 1975, Thomas and West 1988, Erickson and West 1996, Lance et al. 1996, Humes et al. 1999). Ultrasonic detectors are relatively low-cost and can be easily transported and set up. They also may provide information on use of an area by species that are hard to capture with traditional collecting methods. It is important to remember, however, that ultrasonic detectors can only provide estimates of bat activity, not actual population estimates because there is no one-to-one correlation between bat passes and the number of individuals present. Species identification also may be difficult when species have overlapping call structures, making them impossible to distinguish with certainty (Hart et al. 1993, Lance et al. 1996, Menzel et al. 2005, Thomas and LaVal 1988). This is especially true for species in the genus *Myotis*, therefore they are often lumped together for data analyses (Humes et al. 1999, Kalcounis et al. 1999, Patriquin and Barclay 2003). Some species, such as Rafinesque's big-eared bat, may be undetectable in acoustic monitoring due to the frequency of their calls (Menzel et al. 2001). This should be considered when analyzing data from an area that may have these species present. Other important considerations when comparing data from acoustic sampling is placement of detectors and temporal variation in bat activity. Lance et al. (1996) found that detectors placed at ground level detected more calls than detectors placed in the canopy. Many species of insectivorous bats exhibit a bimodal distribution of activity within a night (Kunz 1973, Erkert 1982, Taylor and

O'Neill 1988). With mean activity peaking shortly after sunset with a second, smaller peak just before sunrise (Hayes 1997).

Mist nets are the most commonly used method for capturing bats in flight (Kunz and Kurta 1988). They are relatively inexpensive, lightweight, and easily transported and set up in the field. There is a variety of ways in which to deploy mist nets in a forest setting. The most common way is to suspend the net between two poles across an area used as a flyway by bats (Kunz and Kurta 1988). Many studies have shown highest success rates when nets are placed across riparian areas or in edge habitat (Carroll et al. 2002, Menzel et al. 2005); however, in this study all sites are in upland forest. Other studies have evaluated netting within the forest interior (Bradshaw 1996, Carroll et al. 2002, Menzel et al. 2005). Due to the difficulty of mistnetting interior forests, sites must be selected based on accessibility and ability to set up nets (Bradshaw 1996). Another consideration when netting interior forests is the height at which nets are placed. Activity of insectivorous bats varies vertically in temperate forests. Vertical distribution depends on maneuverability of bats and vegetation structure of the habitat (Bradshaw 1996, Henry et al. 2004, Kalcounis et al. 1999, Menzel et al. 2005). Henry et al. (2004) documented greater capture rates in the canopy of a West African rain forest than in the understory. Alternately, Menzel et al. (2005) documented lower activity in the canopy of a coastal plain forest in South Carolina than in the understory. These differences are likely due to the vegetative structure of the two habitat types. In a West African rain forest the understory is more dense (Henry et al. 2004), whereas in a temperate forest the opposite applies.

As with acoustic monitoring, temporal variation in bat activity also affects the design of studies using mist nets. Considerations must be made for the time of emergence of particular species in the study area. In Mississippi Miller (2003) captured 78% of all bats in his study within 120 min. of sunset. Additionally, at least one specimen of each species, except the hoary bat, was captured within 45 min. of sunset. The hoary bat was captured within 2 h of sunset. Although mist netting is a more reliable method of positively identifying species present in an area, there are limitations to its use. It is difficult to determine area sampled by a mist net, therefore analysis must be limited to indices of bat abundance. Additionally, some species of insectivorous bats are able to detect mist nets better than others, which may result in biased sampling (Bergallo et al. 2003).

Vegetation characteristics play an important role in habitat selection by bat species. Numerous studies have looked at affects of different vegetation characteristics on both foraging and roosting habitat of bats (Ford et al. 2005, Kalcounis-Ruppell et al. 2005, Menzel et al. 1998, Owen et al. 2004). Due to their unique method of locomotion, bats are sensitive to habitat complexity within a forest (McKenzie and Rolfe 1986). Methods used to assess vegetative characteristics important to bats depend on habitat type, species likely present, and objectives of the study. In forested habitats, complexity is an important vegetative component (Bradshaw 1996, Broders et al. 2004, Veilleux et al. 2003). Density of vegetation can be measured in various ways. Bradshaw (1996) constructed vertical profiles of foliage density following methods set by MacArthur and Horn (1969) to measure habitat along transects. Stand basal area and stems/ha can also be used to determine amount of vegetation density within the forest. Both measurements are relatively easy to obtain. Stand basal area is the cross sectional area of all trees at breast height (1.3 m above ground) per hectare of forest, measured in m^2/ha.

For roosting habitat studies, canopy closure is measured at the roost tree either by visual estimation (Vonhof 1996), or by averaging readings taken with a spherical densiometer in each of the four cardinal directions (Menzel et al. 2002b). To assess potential roosting sites, snag density can be estimated to determine the quantity of available roost trees. Quality of snags can be assessed by assigning a decay class based on characteristics such as presence of limbs, soundness of bole, and tightness of bark (Clark 2003, Menzel et al. 2002b, Spetich et al. 1999). Because bats generally forage above and below the forest canopy in temperate forests (Menzel et al. 2005), the midstory layer may play an important role in determining use by bats. Tibbels and Kurta (2003) estimated percent coverage of the midstory by plants in 1 m^2 plots at 10 m intervals along a transect. As with the overstory, midstory also can be assessed in terms of number of stems/ha.

Bats also use areas based on food availability, therefore measuring differences in insect diversity and abundance can help interpret results from habitat use studies. A common method of collecting insect samples for bat studies is by use of a light trap (Hayes 1997, Meyer et al. 2004, Tibbels and Kurta 2003). Flying insects are attracted to a light source and become trapped in a holding container. Another method of collecting flying insects is by use of a Malaise trap (Ouin et al. 2006, Tangmitcharoen et al. 2006). Malaise traps are composed of nylon mesh walls and roof (Ouin et al. 2006). Malaise traps are relatively easy to use and can be left open for up to a month before being checked. Foliage insects and spiders can be collected using a collecting cloth, spread out beneath vegetation while branches and stems are shaken with a pole. Collected insects are preserved and later identified to order (Meyer et al. 2004). Once all insects are collected and identified, dry weight is obtained to determine biomass of each order (Tibbels and Kurta 2003).

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EFFECTS OF THINNING AT DIFFERENT INTENSITIES ON HABITAT USE BY BATS IN THE BANKHEAD NATIONAL FOREST, ALABAMA

ABSTRACT

Many bat species in the southeastern U.S. utilize forests for summer habitat. Understanding how forest management practices affect bat populations is critical to making informed management decisions. The purpose of this study was to determine the effects of forest thinning on diversity and abundance of foraging bats in Bankhead National Forest. Mist-netting and echolocation call recordings were used to assess habitat use by bats in three treatments: light thinned, heavy thinned, and unthinned. Vegetative characteristics and insect abundance were evaluated within each treatment to determine effects of thinning on vegetative characteristics and prey abundance as they relate to habitat use by bats. No differences in habitat use, structural complexity, or prey abundance were determined between the two thinning intensities. However, when both thinning treatments were combined there was significantly greater bat activity and diversity, less midstory and overstory density, and greater prey abundance in thinned sites compared to unthinned sites. This suggests that thinning improves habitat for forest dwelling bats by decreasing structural complexity and increasing prey abundance, but that the two intensities used in this study were not different enough to influence habitat use or prey abundance.

INTRODUCTION

Bats are an important part of ecosystems worldwide. As the second largest order of mammals, they make up a large part of global biodiversity. Agriculturally, bats are important because they consume large quantities of pest insects and aid in pollination. For mammals of their size, bats are long lived, have low reproductive rates, and relatively long periods of infancy dependence. This places them at a greater risk from impacts to their environment (Erickson and West 2003), making them indicators of disturbance as well as an assessment of the conservation value of an area (Medellin 2000). Many of the world's bat populations are in decline and some are threatened or endangered (Altringham 1996, Tuttle 1979) due to human impacts such as habitat alteration (Adam et al. 1994, Altringham 1996, Parker et al. 1995) and pesticide exposure (Clark 1988, Mispagel et al. 2004).

Forests provide important habitat for both foraging and roosting for bat species throughout the world (Medellin 2000, Perry et al. 2007, Patriquin and Barclay 2003, Struebig et al. 2006). Microchiropteran bats are nocturnal, volant mammals that use echolocation to navigate, making the structural characteristics within a forest important. Characteristics such as amount of midstory and tree density can directly affect bats by limiting maneuverability (Aldridge and Rautenbach, 1987) and indirectly by influencing prey abundance (Krusic et al. 1996, Kunz 1973). Availability of roosting sites is also an important characteristic (Kurta 1985, Fenton 1983, Perry et al. 2007, Vaughan 1987). Bat species in North America use both live and dead trees for roosting (Agosta 2002, Britzke et al. 2003, Menzel et al. 2002b). Some species utilize natural cavities and crevices within the tree (Barclay et al. 1988, Gooding and Langford 2004, Kalcounis and Bringham 1998) whereas others roost within the foliage (Carter et al. 2003b, Veilleux et al. 2003). Any alterations to forests have the potential to affect habitat characteristics important to bats.

Over 60% of the southeastern United States is dominated by forest cover (Sharitz et al. 1992). Most of the forests in this region undergo intensive forest management (Conner and Hartsell 2002). A common practice in forest management is thinning. Thinning is a selective harvest in which single trees are removed, leaving the remaining trees with more room and resources to grow. Intensity of thinning as well as types of trees retained depends on management objectives. Many managers use thinning as a means of maintaining forest habitat while allowing timber extraction (Perdue and Steventon 1996). Thinning may also mimic old growth characteristics in a forest stand and allow for regeneration of native tree species (Bailey and Tappeiner 1998, McComb et al. 1993). In Alaska's temperate rainforest, Parker et al. (1995) found more bat activity in old-growth than in clearcuts and more in clearcuts than in second growth forests. Patraquin and Barclay (2003) found that in boreal forests of Alberta, more maneuverable species (*Myotis* spp.) preferred intact forests and edges of clearcuts while larger species (*Lasionycteris noctivagans*) preferred clearcuts. This indicates that effects of forest management on bats vary based on morphological characteristics, which in turn affects foraging behavior. Menzel et al. (2003) recorded more bat activity in bottomland stands of South Carolina in which group selection harvest had occurred compared to unharvested stands. Some studies have looked specifically at effects of thinning on bats. Tibbels and Kurta (2003) found no differences in thinned and unthinned stands of red pine in Michigan, however, activity was low in both treatments. Humes et al. (1999) recorded bat activity in western Oregon and found more activity in old-growth and thinned stands than in unthinned stands, but no difference in old-growth and thinned stands. Perdue and Steventon (1995) compared two intensities of thinning to unharvested stands and clearcuts in northwestern British Colombia. They found the greatest use in heavy removal followed by light removal and unharvested and the least amount of use in clearcuts. Few studies have been done in the southeastern U.S. despite a growing timber industry in this area. Miller (2003) studied species diversity in managed pine forests of Mississippi; however, his study did not look specifically at the effects of thinning on bat species. These studies illustrate how the effects of forest management vary depending on geographic location, species composition, and forest type. With the demand for timber expected to increase, understanding how forest management affects bat populations specifically in the southeastern U.S. is key to preventing further declines in microchiroperan communities and providing better quality habitat for those species already in decline.

STUDY AREA

The study area is located in the Bankhead National Forest (BNF), in northwestern Alabama in Winston, Lawrence, and Franklin counties. BNF comprises ca. 73,653 ha of public land managed by the U.S. Forest Service of which ca. 71,225 ha are currently forested. The forested land can be broadly classified as about 51% southern pines and 49% hardwoods (USDA Forest Service 2003). BNF is located in the uplands of the Cumberland Plateau. Habitat in the forest varies greatly. The southern area reaches the northernmost extent of the longleaf pine (*Pinus paulustris*) range and is made up of coastal pine and pine/hardwood stands. The northern area, in which this study occured, lies in the Warrior Mountains, the westernmost terminus of the Appalachian Mountains. Forest cover is generally mid- to late successional and is composed of a mixture of pine and hardwoods from 40 to 100 years in age (USDA Forest Service 2003).

The BNF is an important area for many wildlife species, including a diverse avifauna, endangered freshwater mussels, important game species including white-tailed deer (*Odocoileus virginianus*) and wild turkey (*Meleagris gallopavo*), and several species of bats. There are nine documented species occurring in BNF: big brown bat (*Eptesicus fuscus*), eastern red bat (*Lasiurus borealis*), silver-haired bat (*Lasionycteris noctivagans*), eastern pipistrelle (*Pipestrellus subflavus*), evening bat (*Nycticeus humeralis*), northern long-eared bat (*Myotis septentrionalis*), little brown bat (*Myotis lucifugus*), and two endangered species, Indiana bat (*Myotis sodalis*) and gray bat (*Myotis grisescens*; pers. comm., T.U. Counts, District Wildlife Biologist, Bankhead National Forest). Other species whose range is within the BNF are the hoary bat (*Lasiurus cinereus*), Seminole bat (*Lasiurus seminolus*), and Rafinesque's big-eared bat (*Corynorhinus rafinesquii*), but currently these species have not been documented within the forest (Choate et al. 1994).

The BNF is undergoing implementation of its Forest Health and Restoration Project. Beginning in the 1960's, in an effort to improve forest economic yields, the U.S. Forest Service began replacing upland hardwood forests with faster growing loblolly pine (*Pinus taeda*). Although loblolly pine is a native species, the dominance of pure stands is not typical in native landscapes that occur in the BNF (USDA Forest Service 2003). Once the management objectives for the Forest Service changed from timber production to overall resource management, many of these stands became overstocked. In addition to causing un-natural conditions in the forest, these stands facilitated an infestation of Southern Pine Beetle that killed ca. 7,527 ha of pine forest in both native and reforested areas. The Forest Health and Restoration project is aimed at improving overall forest health, restoring native forest communities, and providing plant and animal communities that are uncommon throughout much of the Southern Cumberland Plateau physiographic region. In order to reach desired conditions for each area of the forest, thinning, prescribed burning, and reforestation regimes are being implemented. This study is in cooperation with a large scale forest ecosystem study being conducted by Alabama A&M University in which a multi-disciplinary team is looking at the effects of thinning and burning on a variety of forest ecosystem elements including vertebrate communities.

The study sites are all located in upland loblolly pine stands. Three treatments were selected to determine effects of thinning: unthinned, light thin, and heavy thin. Unthinned treatment sites had no trees removed. In the thinned treatment sites (light and heavy thin) standard timber harvest practices were followed, retaining hardwoods to meet target basal area of 75 ft^2/ac in light thin sites and 50 ft^2/ac in heavy thin sites. This study involved the initial harvest of these sites, meaning that the majority of remaining trees are still loblolly pine. All sites were harvested within 14 months prior to the study.

I hypothesized that bats would be most abundant in heavy thinned sites and least abundant in unthinned sites and that insects would be most abundant in unthinned sites and least abundant in heavy thinned sites.

METHODS

Bats- Mist netting and acoustic sampling were used to determine bat diversity and abundance. Data were collected at three sites for each treatment type: light thin, heavy thin, and unthinned. Each site was sampled 4 nights in 2006 from June to September. In order to standardize sampling across the treatment sites, nets were placed at each end of two perpendicular transects measuring 60 m each (Fig. 1) for a total of 4 nets per night at each site. When site characteristics allowed, one transect was placed on a road or trail so that two nets were across a potential flyway, and two nets were in interior forest. Nets were opened at 2000h (CST), checked every 20 min., and closed by 2300h (CST). Acoustic sampling was done using Anabat II detectors (Titley Electronics, Ballina, Australia) interfaced with a laptop computer with a zero-crossing analysis interface module (ZCAIM). Files were automatically saved to the laptop for later analysis. Anabat detectors were placed at the intersection of the two transects and turned on for the total duration of netting.

All bats were handled following methods approved by the Alabama A&M IACUC. Each bat was identified to species and sex was determined. Ear, tragus, and forearm length, as well as body mass were recorded for each individual. Age class was categorized by the degree of ossification of the finger bones and length of forearms (Anthony 1988). Each individual was marked using a small dab of nail polish on the dorsal side and then released at the site of capture.

Echolocation call analysis- Echolocation calls were analyzed using the software program Analook (version 4.9j, Titley Electronics, Ballina, Australia). Files not containing bat activity (i.e., insects) were discarded. Activity was assessed in two ways.

First by counting the number of files recorded each night. The Anabat software automatically saves files based on two primary criteria: completion of a 5-s pause in detection of sound or after 15 s of continuous recording. Because this method can produce a disproportionately large number of files in an area of intermittent activity and a comparatively small number of files in an area of continuous activity (Britzke et al. 1999), activity also was assessed by counting the number of pulses each night. Both number of files and pulses were quantified as an average per night for each treatment type.

Species identification using echolocation calls is becoming widespread in chiropteran studies (Humes et al. 1999, Tibbels and Kurta 2003). Calls can be identified either quantitatively or qualitatively. A quantitative approach involves carrying out a multivariate discriminant analysis on a database of known calls to develop a model for classification of unknown calls (Parsons and Jones 2000, Vaughan et al. 1997). Qualitative identification is accomplished by visual comparison of an unknown call to a known call. This method can be quick and generally accurate when dealing with small numbers of echolocation call files; however, qualitative identification requires an experienced researcher to accurately identify species (O’Farrell et al. 1999). Because of geographic variation in echolocation calls among species (Barclay et al. 1999, Murray et al. 2001, Parsons 1997) both approaches require an extensive library of known calls from the specific area of study. Due to inexperience in identifying echolocation calls and a lack of known calls from my study area, species identification could not be performed with a reliable degree of accuracy. However, call sequences could be differentiated as different unknown species, so that a number of different species within each treatment type could be estimated.

Vegetation- To assess vegetative structure in each treatment type, 10 circular plots, 10 m^2 each (r = 5.6 m) were set up in each site for a total of 100 m^2 per site. Plots were set up in a grid across the netting transects with 20 m between each plot center. Within each plot, number of stems in the overstory and midstory were counted and recorded as hardwood, pine, or snag. Overstory was defined as all trees over 30 ft tall and midstory was defined as all vegetation between 8-30 ft in height. Height and diameter at breast height (DBH) of all snags was measured and a decay class from 1 (least decayed) to 3 (heavy decay) was assigned based on methods of Clark (2003; Table 1). At the center point of each plot, basal area (BA) was estimated using a 10 BA prism, litter depth taken using a metric ruler, and a visual ocular estimate of percent canopy cover was recorded. Height of lowest limbs present and total height of trees in the overstory was measured on both a pine and a hardwood within each plot. These measurements give an estimate of overstory canopy height as well as canopy depth, which is calculated as the distance from the lowest limb to the top of the tree. Presence or absence of standing water was noted in each plot. Mean and standard deviation were determined for vegetative variables across the ten plots for each site before analysis. Because searching for roost sites is out of the scope of this project, vegetative characteristics were used to draw conclusions about roost site availability in the study area.

Insects- Insects were collected using Malaise traps. Malaise traps capture flying insects, the primary prey item of the bat community in the BNF. Traps were set up at the intersection of the two netting transects. Collection bottles were approximately half full with a mixture of 50% ethyl alcohol and 50% low-tox anti-freeze. In order to sample insects active during bat foraging, collection bottles were attached only during the duration of bat netting each night. Samples for each night were stored in collection bottle liquid until processed in the lab. The majority of studies on insectivorous bats involving prey abundance or fecal content identify insects to order (Meyer et al. 2004). To allow for comparison with these studies, I identified insects to order as well. Insects from each site were combined to assess the total abundance and biomass at each site from four nights of trapping. Abundance was determined by counting the number of individuals captured in each site. Total biomass of each order was obtained through a dry weight measure. Once identified, insects were transferred to 90% Ethanol until being counted and dried at 60º C for approximately 24 h. Although storing the samples in anti-freeze and alcohol may affect dry weight (Gaston et al. 1996, Cressa 1999), all samples were subjected to the same conditions to allow for a relative measure of biomass among treatments, but my measures of insect biomass across the treatments cannot be directly compared with other studies. Diversity at each site was calculated using Simpson's index.

Statistical analysis- Because of low sample size, Chi-square tests were used to test for significant differences in abundance of bats from mist netting data. Analysis of variance (ANOVA) was used to test for significant differences in vegetative characteristics. If significant variations were found, Bonferroni corrected *t*- tests were used to assess differences. Because echolocation call and insect abundance data were not normally distributed, Kruskal-Wallis tests were used to compare data among treatments. All statistical tests were run in SAS 9.1 (©SAS Institute Inc., Cary, NC, USA).

RESULTS

Mist-netting was conducted between 12 June and 1 September 2006. A total of 18 bats were captured in 174 net nights. Because of low capture rates, abundance from mist netting was calculated as total number of bats per treatment type. Also, because more than one species was captured only in light thin sites, diversity indices were not calculated for mist net data. Abundance was significantly higher in the light thin treatment sites then in the unthinned ($\chi^2 = 13.539$, $p < 0.005$) and the heavy thin treatment sites ($\chi^2 = 238.25$, $p < 0.005$). Heavy thin and unthinned treatment sites did not differ ($\chi^2 = 1$, $p = 0.05$). In the light thin treatment a total of 14 bats were captured, 3 *Myotis septentrionalis* (all male), 4 *Eptesicus fuscus* (2 males, 1 female, 1 unknown), and 7 *Lasiurus borealis* (5 adult males, 2 juvenile females). In the heavy thin sites 1 adult male *Myotis septentrionalis* was captured and in the unthinned sites 2 adult males and 1 juvenile male *Myotis septentrionalis* were captured (Fig. 2).

Due to technical difficulties with one of the laptops used, Anabat data from 16 nights were unavailable. However, echolocation calls were recorded at least one night in each treatment type (Table 2). Highest activity was recorded in the heavy thin treatment (24.66 files/night and 778.33 pulses/night) and lowest activity was in the unthinned treatment (0.375 files/night and 3.625 pulses/night). Light thin treatment sites had 15.8 files/night and 314.5 pulses/night. Bat activity differed significantly among the three treatment types (files/night: $\chi^2 = 6.148$, $p = 0.036$; pulses/night: $\chi^2 = 6.143$, $p = 0.036$). Since average number of files/night yielded the same results as average number of pulses/night (Fig. 3), pairwise comparisons using Kruskal-Wallis tests were run on pulses/night. No differences were significant between the unthinned and heavy thin sites ($\chi^2 = 0.0497$, $p = 0.824$) or between light thin and heavy thin ($\chi^2 = 0.907$, $p = 0.341$), however, activity was significantly greater in light thin than unthinned sites ($\chi^2 = 6.978$, $p = 0.0083$; Table 2). The lack of significant differences in the heavy thinned sites and both unthinned and light thinned is likely due to small sample size. When thinned sites were combined there was significantly more activity in the thinned sites compared to the unthinned sites ($\chi^2 =5.328$, $p = 0.021$). Total number of species, as determined by different call patterns, differed among the treatments and from mist-netting data (Fig. 4). Two species were present in the unthinned sites, seven in the light thin, and five in the heavy thin. All species present in the unthinned sites were present in both thinned sites and all species present in the heavy thin sites were present in the light thin sites.

Vegetative variables did not differ among the two thinned treatment types. However, compared to the unthinned treatment type, the thinned sites contained fewer stems/ha in both canopy and midstory, lower basal area of pine, and less canopy cover as would be expected due to objectives of thinning (Table 4). Although not significantly different, the light thin treatment contained fewer stems/ha in both the midstory and overstory than the heavy thin, suggesting that the number of trees removed in my study sites did not match the treatment targets.

Heavy thinned sites had the greatest amount of total insects collected (375.66/ site) as well as the greatest biomass (0.618g/site.), followed by the light thinned sites (121.33/site and 0.495g/site) and unthinned sites (87.33/site and 0.292g/site) (Fig.5 and Fig.6). Total insect abundance (total number of insects in each treatment site) did not differ among the treatments (χ^2 = 4.356, p = 0.132), however abundance of the orders Lepidoptera and Neuroptera were significantly different among treatments (χ^2 = 5.6, p = 0.05; χ^2 = 5.631, p = 0.036; respectively). Lepidoptera was significantly more abundant in light thin sites compared to the unthinned (χ^2 = 3.857, p = 0.049) and in the heavy thinned compared to the unthinned (χ^2 = 3.857, p = 0.049). Neuroptera was significantly more abundant in heavy thin sites compared to unthinned sites (χ^2 = 4.09, p = 0.0431). When both thinned treatments were combined, there was significantly more total insects collected (χ^2 = 4.267, p = 0.039) in thinned sites compared to unthinned sites, as well as insects in the orders Lepidoptera and Neuroptera (χ^2 = 5.40, p = 0.020; χ^2 = 4.94, p = 0.026; respectively)

The only significant differences in total biomass collected at each site was in the order Neuroptera (χ^2 = 5.793, p = 0.046) in which dry weight was significantly greater in light thin (χ^2 = 4.354, p = 0.037) and heavy thin sites (χ^2 = 4.355, p = 0.037) compared to unthinned sites. When thinned treatments were combined, dry weight of Neuroptera was greater in thinned sites compared to unthinned sites (χ^2 = 5.586, p = 0.018).

Simpson’s diversity index for insects was greatest in unthinned sites (0.788), followed by heavy thin sites (0.485), and least in light thin sites (0.438).

DISCUSSION

Mist-netting data yielded low diversity and abundance in all sites. Mist-netting in upland forests is extremely difficult due to vertical stratification of foraging bats (Henry et al. 2004). Some species of bats (e.g., *Lasiurus cinereus* and *Tadarida brasiliensis*) tend to forage above the forest canopy, while others forage within or under (*Myotis septentrionalis*, *Myotis lucifugus*, and *Lasionycteris noctivagans*) the canopy (Adams 2003, Harvey et al., 1999, Kalcounis et al. 1999, Schmidly 1991). Studies have shown significantly higher capture rates in areas over water, especially riparian zones where bats are either coming to drink, forage, or traveling (Ford et al. 2005, Parker et al. 1995). All sites within this study were along ridges, therefore there were no riparian areas or bodies of water. The open canopy and minimal midstory in the thinned treatments offered limited vegetative characteristics to funnel bats into nets. This may have played a role in the low number of captures in the heavy thin, but comparatively high number of captures in the light thin. Although not significantly different, the light thin sites had greater midstory than the heavy thin sites which may have been enough to force the bats down to net level. Further complicating the matter, the sampling area of mist-nets is extremely small, relative to what is used by bats and many bats are able to detect and avoid nets while foraging (Carroll et al. 2002).

When both thinned treatments were combined there were more individuals captured as well as greater activity than in the unthinned stands. There was also more species present in thinned sites than in unthinned sites, however, unequal sampling effort does not allow for accurate comparisons. Humes et al. (1999) found similar results in Oregon. Their study found greatest activity in old-growth and thinned stands compared to unthinned stands of Douglas-fir (*Pseudotsuga menziesii*). As with this study, both thinned and unthinned stands were similar in age with few snags present. Alternately, Tibbels and Kurta (2003) did not find a difference in bat activity between thinned and unthinned stands of red pine; however, both unthinned and thinned sites yielded a significantly low number of files than adjacent openings.

Bats vary in their ability to utilize habitats, therefore, effects of thinning may yield different results when analyzed at the species level. In my study *M. septentrionalis* was captured in all treatment types in similar numbers (2 in unthinned, 2 in light thin, and 1 in heavy thin). This suggests that this species is less affected by tree density than *E. fuscus* and *L. borealis*, which were only captured in the light thin sites. Patriquin and Barclay (2003) reported similar findings. In their study examining differences in habitat use by two species of *Myotis* (*M. lucifugus* and *M. septentrionalis*) and *Lasionycteris noctivagans*, the smaller, more maneuverable *Myotis* species were less affected by tree density than the larger, less maneuverable *L. noctivagans*. Ford et al. (2005) found that detection of *M. septentrionalis* was related to greater canopy cover. This species is a gleaner that often takes prey from low branches and the ground (Adams 2003). Its maneuverability allows it to utilize dense timber. All sites in this study were also located on ridges and hillsides, which are preferred foraging areas for *M. septentrionalis* (Adams 2003, Harvey et al. 1999). The height at which *M. septentrionalis* forages (among branches and the ground) also may make this species more susceptible to mist nets placed in forested upland sites, at or near ground level.

The other two species captured (*E. fuscus* and *L. borealis*) are both larger, less maneuverable species than *M. septentrionalis*. These are two of the most common and widely distributed species in North America. (Agosta 2002, Elmore et al. 2004, Harvey et al. 1999, LaVal and LaVal 1979). *L. borealis* has an average wing aspect ratio and high wing loading allowing for rapid, straight flight, usually above or along the tree canopy, but with poor maneuverability (Elmore et al. 2004; Norberg and Rayner 1987). The echolocation call structure of *L. borealis* is variable, but consistent with species that feed in more open areas in that it can target prey from relatively large distances. As with *L. borealis*, *E. fuscus* also has a variable call allowing it to exploit a large range of habitat types (Krusic and Neefus 1995). *E. fuscus* has low wing loading and long wings making it fly slowly, away from clutter such as tree canopies (Norberg and Rayner 1987). These morphological characteristics may explain the absence of these two species in the unthinned sites, but greater abundance in thinned sites. This relationship has been seen in other studies of these two species. Krusic and Neefus (1995) recorded the most activity of both species in clearcuts. Menzel et al. (2002) recorded greater activity of *L. borealis* and *E. fuscus* in gaps than interior forest. Ford et al. (2005) found that in habitat where both species were detected there was greater minimum canopy gap width and lower canopy cover. Lack of captures of both species in the heavily thinned sights within my study is most likely due to problems associated with mist netting upland forest areas, instead of actual absence of the species based on data from echolocation calls recorded.

With seven total species recorded, a greater number of species was detected from echolocation call data than mist-netting. As with the mist-netting data, the greatest number of species was recorded in the light thin sites, however this may have been a result of a low number of echolocation samples available in the heavy thinned sites. All species detected in the unthinned sites were also detected in the heavy thinned sites, and all species in heavy thinned sites were detected in light thinned sites. This suggests that thinning makes the forest available to a greater number of bat species. It also illustrates the importance of conducting mist-net surveys along with echolocation call recordings when conducting bat habitat use studies. The additional species recorded by Anabat were most likely some of the species that have been previously documented in the BNF (*Lasionycteris noctivagans*, *Pipestrellus subflavus*, *Nycticeus humeralis*, *Myotis lucifugus*, *Myotis sodalist, Myotis grisescens*) or those whose range is within BNF (*Lasiurus cinereus*, *Lasiurus seminolus*, *Corynorhinus rafinesquii*).

I found that thinning effects vegetative characteristics by decreasing percent canopy cover, basal area of the overstory, and number of stems in the midstory and overstory. This is similar to results in other studies (Humes et al. 1999, Tibbels and Kurta 2003). Differences in vegetative characteristics between thinned and unthinned treatments did not yield any unexpected results. Because all sites were even aged stands similar in age class before thinning was applied, the remaining trees were not significantly different in canopy height or canopy depth. More stems in the midstory in the unthinned treatment compared to both thinned treatments is due to machinery used in timber extraction. When overstory trees are harvested, midstory plants are incidentally taken as well. Because thinning increases amount of light penetrating the canopy, midstory plants will begin to reestablish relatively quickly altering the vertical stratification of vegetation within the stands.

Within my study sites, the target thinning intensities for the light thin and heavy thin treatments did not match the vegetative data I collected. Unfortunately, the two intensities were very similar and should probably be considered the same treatment. Few studies have looked at the effects of thinning at different intensities. Perdue and Steventon (1995) looked at the influence of two intensities of partial cutting on use of forest stands by bats compared to unharvested stands and clearcuts. Similar to my study the partial cutting intensities were heavy removal (60% of stand volume removed) and light removal (30% of stand volume removed), and they found that heavy removal had greatest activity as assessed from echolocation call data, followed by light removal, uncut, and clearcut.

Thinning did not have an effect on the number of snags available for roosting sites. Overall these stands contain a relatively low number and quality of snags. Other studies have shown that species of bats that use snags for roosting typically prefer larger diameter trees in intermediate stages of decay (Barclay et al. 1988, Kalcounis-Ruppell et al. 2005, Vonhof 1996). Menzel et al. (2001) reported a mean dbh for roost trees of subadult and adult female *Nycticeius humeralis* of 30.9 cm and 31.3 cm respectively. Broders and Forbes (2004) found that *M. septentrionalis* prefers roost trees in a decay class 2, and although not significantly different, dbh of roost trees (female-43.8cm, male-32.0cm) was greater than what was available in the surrounding area (female-38.3, male-27.2). Alternately, Boyles and Robbins (2006) found that *N. humeralis* selected trees in late stages of decay. Average decay class of snags in my study range from 1.0 - 2.1 suggesting that decay class is not a limiting factor in availability of roosting sites. However, average dbh of snags for all treatments in this study ranged from 4.6 cm to 6.7 cm, which is much lower than that documented to be preferred by bats.

Other characteristics affected by thinning may play a role in future establishment of roosting sites. Thinned sites have been shown to have larger diameter trees (Humes et al. 1999), which will result in larger diameter snags. Thinning in these stands has already improved characteristics preferred by most bats for roosting habitat. The thinned stands have more open canopies and less overstory density, both of which have been shown as preferred characteristics of roosting sites (Kalcounis-Ruppell et al. 2005)

Depth of the leaf litter may be an important characteristic for *L. borealis*. It has been found to roost in leaf litter (Mager and Nelson 2001), especially in the winter when temperatures drop (Carter et al. 2002b). During winter burning in the BNF, *L. borealis* has been seen emerging from leaf litter (pers.com., J.A. Cochran, Biological Scientist, Bankhead National Forest). Accumulation of leaf litter on the forest floor may affect the ability of *L.borealis* to thermoregulate during extreme temperatures in the winter. It is unknown whether *L.borealis* selects for a certain litter depth and how that plays a role in thermoregulation, predator avoidance, and energy reserves in the winter. *L. borealis* is a medium sized bat with a forearm length of 35-45 mm and average total length of 106 mm (Schmidly 1991). It is assumed that litter depth must at least be great enough to conceal its body completely. In my study sites average litter depth was not significantly different across treatments and ranged from 43.9 mm in light thinned sites, 47.5 mm in unthinned sites, and 58.7 mm in heavy thinned sites. These results suggest that thinning does not affect litter depth except in areas directly impacted by harvesting machinery, which can compact the litter initially.

Although no significant differences were found in total insect abundance among the three treatments, when thinned sites were combined they contained significantly more total insects than unthinned sites. Other studies on insect abundance in forested habitats yield conflicting results. Lunde and Harestad (1986) and Tibbels and Kurta (2003) reported higher insect abundance in open habitats compared to forest stands. However, similar to my study, Kalcounis and Brigham (1995) and Grindal (1995) captured more insects in cluttered habitats than more open sites. Significant differences found in total insect abundance as well as for Lepidoptera from total number counted, but not from dry weight are likely due to the large number of small (<2 mm) moths collected in the two thinned sites. Some species such as *M. septentrionalis* are limited by the size of prey available (Kunz 1973), meaning that an abundance of smaller moths is more important than greater overall insect biomass. Neuroptera was the only other order collected with significant differences between the treatments; however, studies do not mention this order as an important component of the diet of insectivorous bats.

There are both interspecific and intraspecific variations in the dietary preferences of insectivorous bats. Interspecific variations are due to size, morphology, and echolocation call structure of individual species (Barclay 1991, Barclay and Brigham 1991, Bogdanowitz 1999, Saunders and Barclay 1992). Intraspecific variation is generally due to geographic location (Black 1974, Carter et al. 2003a, Whitaker 1972) and seasonal changes in energy demands (Barclay 1991). Overall bats consume a variety of insects within the orders Lepidoptera, Coleoptera, Hemiptera, Homoptera, Hymenoptera, Neuroptera, Diptera, Orthoptera, Trichoptera, and Odonata (Agosta 2002, Best et al. 1997, Carter et al. 2003a, Carter et al. 2004, Rosenthal et al. 1994, and Ross 1967). Some species may select insects based on their ability to utilize habitats. Less maneuverable species are limited to open habitats whereas more maneuverable species are able to utilize both closed and open habitats giving them more flexibility in prey selection (Fenton 1990). Insect abundance is not the same as insect availability for some species. *M. lucifugus*, a less maneuverable species, may be less efficient at capturing prey with unpredictable flight patterns or those that can detect and evade echolocating bats such as some Lepidopterans (Fullard 1987, Saunders and Barclay 1992). Likewise, species that glean insects from vegetation (e.g., *M. septentrionalis*) have a wider range of prey available because they can capture both flying and stationary insects (Barclay 1991). Species, such as *L. cinereus*, that use low-frequency echolocation have difficulty detecting and consuming small prey, therefore they must focus on large insects (Barclay 1986). Likewise, *M. septentrionalis* may be limited to small insects because of their small body size (Barclay and Brigham 1994).

Although bats will consume a variety of insects, when available, *M. septentrionalis* and *L. borealis* primarily consume beetles and moths, *E. fuscus* consumes beetles, *L. cinereus* and *Lasionycteris noctivagans* consume primarily moths, and *Pipistrellus subflavus* and *M. lucifugus* show no preferences (Anthony and Kunz 1977, Black 1972 and 1974, Brack and Whitaker 2001, Carter et al. 2003a, Freeman 1981, Hamilton 1933, Hickey et al. 1996, Ross 1961, Whitaker 1972).

All of the sites in this study have a desired future condition of an upland hardwood forest under the Forest Health and Restoration Project. The unthinned sites had significantly more pine trees in the overstory than the two thinning treatments, but did not have significant differences in the number of hardwoods in the overstory. This transition from a predominately loblolly pine to hardwood forest takes many years. Studies have shown habitat use preferences between hardwood and conifer forest. Menzel et al. (1998) found *L. seminolus* roosting only in forest stands dominated by pines, but *L. borealis* in both pine-mixed hardwood stands. Jung et al. (1999) suggested that *L.borealis* prefers foraging in open, conifer dominated stands. Menzel et al. (2002) found *M. septentrionalis* roosting exclusively in hardwood trees. An ongoing study in these areas would be useful in determining how this gradual change affects bat communities.

All sites were thinned within two years prior to this study. There is a paucity of information on the length of time required for bat species to begin moving into an area after management. It may depend on factors such as proximity to other suitable habitat, abundance of bats within the surrounding areas, and competition among individuals and species. Affects of thinning should be seen more as a continuum across years rather than a single point in time, and my study represents a starting point for such a long-range analysis of effects of management regimes.

I hypothesized that bats would be most abundant in heavy thinned sites and least abundant in unthinned sites in response to vegetative variables and that insects would be most abundant in unthinned sites and least abundant in light thinned sites. Mist net captures did not support this hypothesis. However, when echolocation call data were analyzed, the hypothesis was partially supported, in that the least activity was recorded in unthinned sites. My hypothesis on insect abundance was not supported. Insect abundance was significantly lower in unthinned sites when both thinning intensities were combined. No significant differences were found between heavy and light thinning in bat activity, vegetative characteristics, or insect abundance, but when combined, thinned sites had lower midstory and overstory pine density, greater insect abundance, and greater bat activity than unthinned sites. This suggests that thinning improves habitat for forest dwelling bats by decreasing structural complexity and increasing prey abundance, but that the two intensities used in this study were not different enough to influence bat habitat use or prey abundance after 14 months.

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Table 1. Criteria for determining decay class of snags modified from Clark (2003) as adapted from Spetich et al. (1999)

	Decay Class		
Characteristic	1	2	3
Branches/Crown	Twigs present	Large branches present	Absent
Bark	Tight	Loose or absent	Absent
Bole	Recently dead	Standing decayed	Heavy decay

Table 2. Mean bat activity (mean ± SD) per night in each treatment from available echolocation call data.

Treatment	Number of Sites	Total nights	Files/night	Pulses/night
Unthinned	2	8	0.38 ± 0.75	3.63 ± 8.12
Light Thin	3	9	16.11 ± 15.52	314.50 ± 455.33
Heavy Thin	1	1	24.67 ± 23.88	778.33 ± 1348.11

Table 3. Mean (±SD) of vegetation variables measured in unthinned, light thin, and heavy thin treatment sites in Bankhead National Forest, Alabama. Letters denote variables that did not significantly differ using Bonforoni's tests.

Vegetative Variable	Unthinned	Light Thin	Heavy Thin	p-value
% Canopy Cover	70.367^{a} ± 5.15	18.167^{b} ± 2.08	21.033^{b} ± 9.59	<0.0001
Basal Area (ft^{2}/ac.)				
pine	127.00^{a} ± 30.5	39.33 ^{b} ± 16.4	37.33 ^{b} ± 5.1	0.0025
hardwood	47.00 ^{a} ± 22.1	13.50 ^{a} ± 11.0	18.00 ^{a} ± 2.6	0.0559
Litter Depth (mm)	47.50 ^{a} ± 6.9	43.93 ^{a} ± 30.7	58.70 ^{a} ± 58.5	0.8879
Midstory				
# of Stems/ha	15267 ^{a} ± 6208	3067 ^{b} ± 850	2467 ^{b} ± 1686	0.0095
canopy height (m)	8.026 ^{a} ± 2.1	6.724 ^{a} ± 0.2	5.812 ^{a} ± 1.5	0.2690
Overstory				
# of stems/ha-pine	8533 ^{a} ± 2060	1600 ^{b} ± 608	2011 ^{b} ± 253	0.0013
# of stems/ha-hardwood	4333 ^{a} ± 2888	792 ^{a} ± 200	996 ^{a} ± 177	0.0715
Canopy height/ pine (m)	19.023 ^{a} ± 1.4	17.745 ^{a} ± 2.2	18.179 ^{a} ± 1.0	0.6409
Canopy height/ hardwood (m)	16.620 ^{a} ± 3.2	16.840 ^{a} ± 3.3	17.150 ^{a} ± 3.0	0.9789
Canopy depth/ pine (m)	8.553 ^{a} ± 1.5	7.348 ^{a} ± 3.0	6.047 ^{a} ± 0.9	0.3750
Canopy depth/ hardwood (m)	10.207 ^{a} ± 1.1	9.660 ^{a} ± 2.1	10.526 ^{a} ± 1.0	0.7832
Snags				
Snags/ha	166.7 ^{a} ± 57.7	33.3 ^{a} ± 57.7	166.7 ^{a} ± 208.2	0.4015
Average DBH	6.7 ± 1.2	4.6 ± 4.5	5.1 ± 4.8	-----
Average decay class	2.1 ± 1.0	1.0 ± 1.4	1.4 ± 1.2	-----

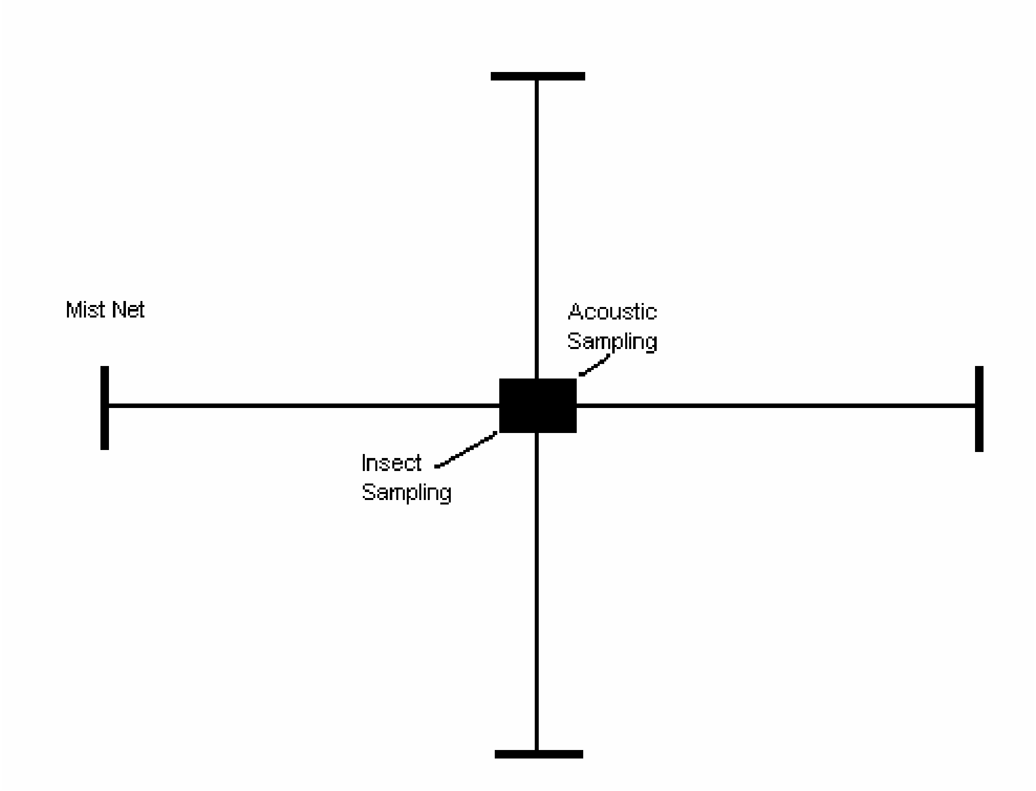

Figure 1. Schematic of sampling transect design showing position of nets, Anabat detector, malaise trap, and vegetation plots. Each perpendicular transect is 60m in length.

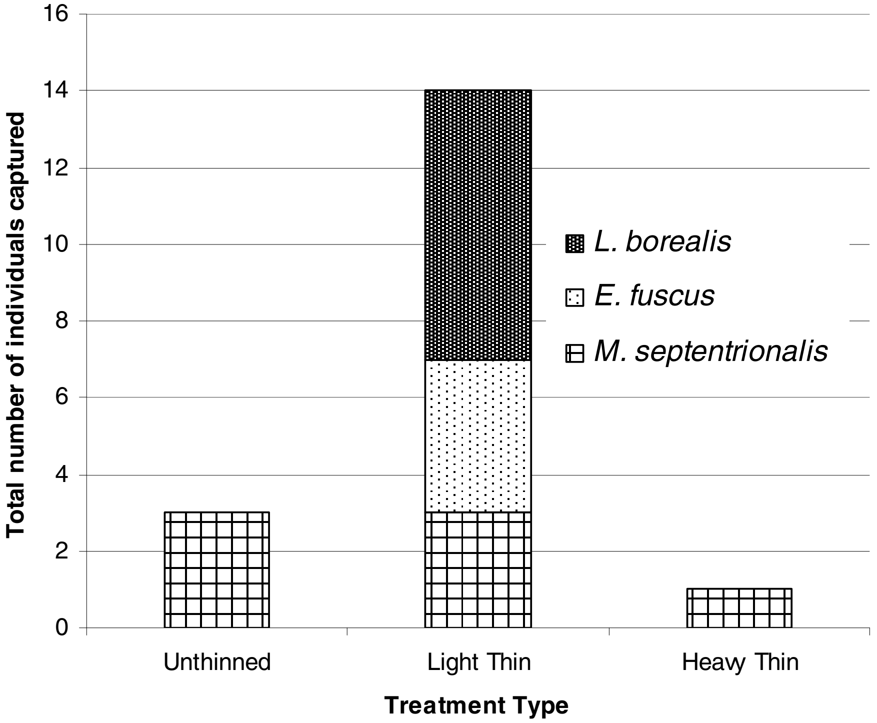

Figure 2. Total number and species of mist net captures in unthinned, light thin, and heavy thin treatment sites in Bankhead National Forest, Alabama.

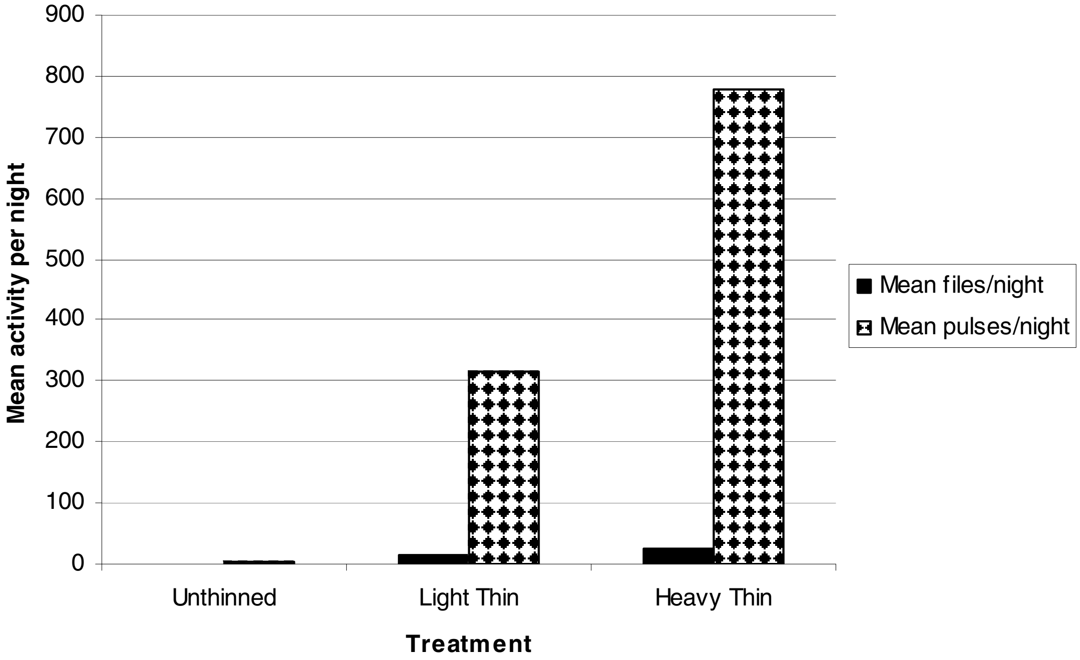

Figure 3. Bat activity in all three treatments, assessed by mean number of files/night and mean number of pulses/night from echolocation call data. Files were automatically saved by Anabat software after 15s of continual recording or after a 5s pause in detection of sound. Pulses refer to each individual call within a file. For standard deviation of the means see table 2

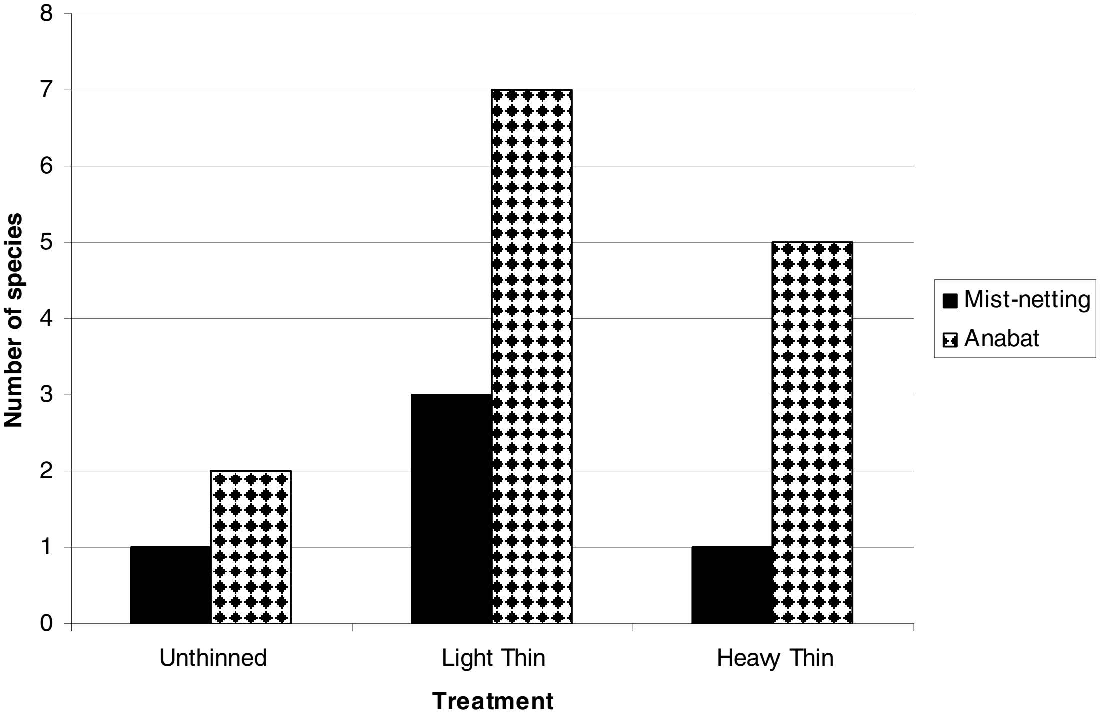

Figure 4. Number of species captured in mist nets and recorded with Anabat within each treatment.

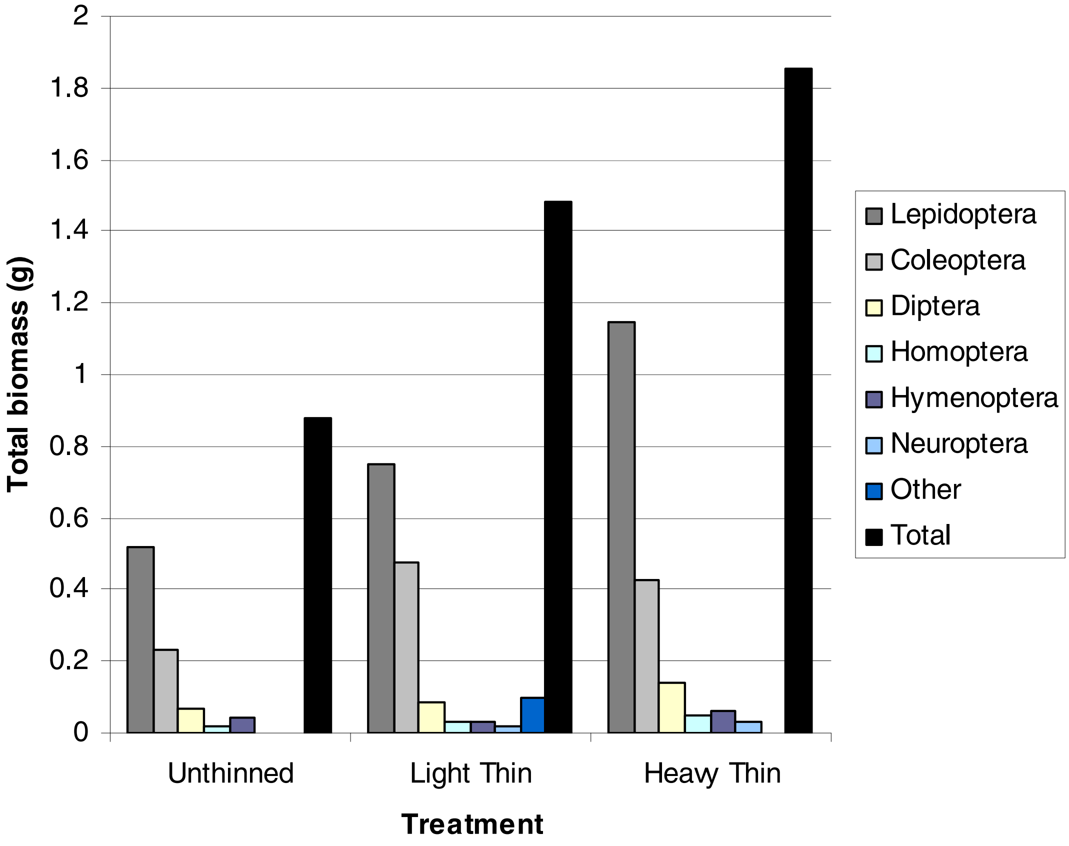

Figure 5. Total number of individuals of each order captured in each treatment type.

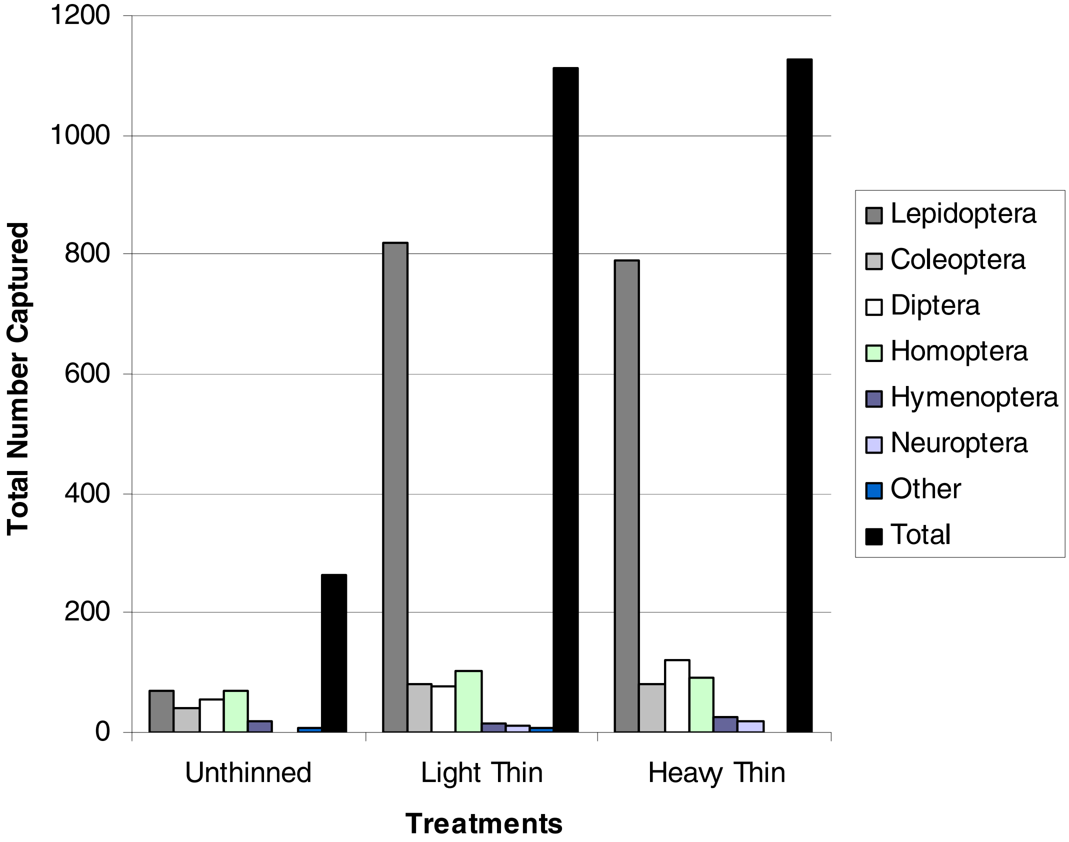

Figure 6. Total biomass, from dry weight measures (g), of each order of insect captured in each treatment type.

VITA

April Jenet' Hart

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF THINNING AT DIFFERENT INTENSITIES ON HABITAT USE BY BATS IN THE BANKHEAD NATIONAL FOREST, ALABAMA

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Title of Study: EFFECTS OF THINNING AT DIFFERENT INTENSITIES ON HABITAT USE BY BATS IN THE BANKHEAD NATIONAL FOREST, ALABAMA

Pages in Study: 71 Candidate for the Degree of Master of Science

Major Field: Wildlife and Fisheries Ecology

Scope and Method of Study: The objective of this study was to determine the effects of forest thinning on the diversity and abundance of foraging bats in Bankhead National Forest. Mist-netting and echolocation call recordings were used to assess habitat use by bats in three treatments: light thinned, heavy thinned, and unthinned. Vegetative characteristics and insect abundance were evaluated within each treatment to determine effects of thinning on structural complexity and prey abundance as they relate to bat habitat use.

Findings and Conclusions: No differences in habitat use, structural complexity, or prey abundance were determined between the two thinning intensities. However, when both thinning treatments were combined there was significantly greater bat activity and diversity, less midstory and overstory density, and greater prey abundance in thinned sites compared to unthinned sites. This suggests that thinning improves habitat for forest dwelling bats by decreasing structural complexity and increasing prey abundance, but that the two intensities used in this study were not different enough to influence bat habitat use or prey abundance.

ADVISER'S APPROVAL: Karen McBee