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To the Graduate School:

This thesis entitled "Eastern Red Bat (*Lasiurus borealis*) and Eastern Pipistrelle (*Pipistrellus subflavus*) Maternal Roost Selection: Implications for Forest Management" and written by David Leput is presented to the Graduate School of Clemson University. I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Forest Resources.
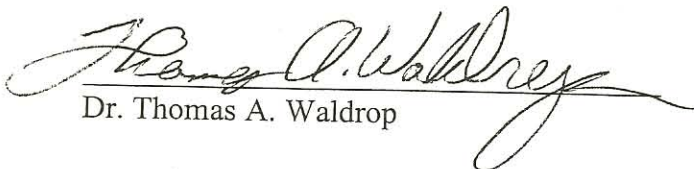
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Dr. Joseph D. Lanham, Thesis Advisor

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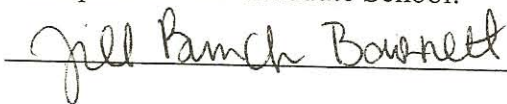
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Dr. Susan C. Loeb

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Dr. Thomas A. Waldrop

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Dr. David H. Van Lear

Accepted for the Graduate School:

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EASTERN RED BAT (*Lasiurus borealis*) AND EASTERN PIPISTRELLE (*Pipistrellus subflavus*) MATERNAL ROOST SELECTION: IMPLICATIONS FOR FOREST MANAGEMENT

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A Thesis

Presented to

the Graduate School of

Clemson University

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science

Forest Resources

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by

David Walter Leput

May 2004

Advisor: Dr. Joseph Drew Lanham

# ABSTRACT

Over the past century, suppression of natural fires and reduction in anthropogenic fires have resulted in the build up of unusually high fuel levels in the United States which has led to many destructive wildfires. The National Fire and Fire Surrogate Study (FFSS) is a nationwide study whose objective is to assess how forest ecosystem components and processes are affected by using fire and other treatments which may act as surrogates to natural fire to reduce fuel levels. However, there have been few studies determining how mid-rotation forest management practices, such as prescribed burning and thinning, affect forest bat communities. The objectives of this thesis were to determine eastern red bat (*Lasiurus boeralis*) and eastern pipistrelle (*Pipistrellus subflavus*) maternal roost use and selection at the tree, microhabitat, and macrohabitat scales. Additionally, used habitats were compared to those located in FFSS treatment plots to make inferences on how these fuel reduction treatments may affect roosting behavior. The study was conducted on and around the Clemson Experimental Forest, located in the upper Piedmont of South Carolina. During the summers of 2002 and 2003, reproductive female red bats (n = 11) and pipistelles (n = 4) were radiotracked to 32 and 7 roost trees, respectively. Red bats roosted within live foliage of a diversity of overstory hardwood tree species, however they roosted in hickories (*Carya* spp.), yellow-poplar (*Liriodendron tulipifera*), and oaks (*Quercus* spp.) most often. Hickories were used more than available as roost trees, indicating selection. The microhabitats surrounding red bat roost trees contained fewer trees than non-used habitat plots, which was the most important characteristic predicting their presence. Red bats primarily used mature,

undisturbed hardwood-dominated stands and had higher roost fidelity earlier in the maternity season than later. Pipistrelles roosted in live foliage and clusters of dead leaves, primarily in oaks. Microhabitats surrounding their roosts had a taller overstory and midstory and contained larger diameter trees than non-used areas. Pipistrelles used both hardwood-dominated and pine-dominated stands. These results suggest that conversion of hardwood stands to pine stands probably would not be beneficial to red bat maternal roosting. However, mid-rotation practices, such as thinning, and an uneven-aged forest management system, such as single tree selection, may reduce forest structure and provide maternal roosting habitat for red bats. In both instances, suitable roost trees should be retained. Forest management practices conducted during the early part of the maternity season, from May to mid-July, may negatively affect roosting behavior since red bats have higher roost fidelity during this period. Since both bats had small roosting range areas, shelterwood harvests that retain suitable roost trees may be beneficial to both bat species. FFSS treatments probably provide more habitat to pipistrelles than red bats, since pipistrelles used stands that were more comparable to those found in FFSS treatment sites. Also, more suitable roost trees for pipistrelles were located in the treatment sites than for red bats. Burn or thin treatments or no management may provide suitable pipistrelle roosting habitat in pine stands.

# ACKNOWLEDGMENTS

I am deeply indebted to my research advisor, Dr. Susan Loeb, for her guidance, friendship, and most importantly patience with me throughout my graduate experience. I would also like to thank my "other" advisor Dr. Drew Lanham for his friendship and guidance during difficult periods. And I will truly miss those pre-game fall mornings sitting on the tailgate of his truck discussing the day's games with him and his family and friends. Dr. Tom Waldrop and Dr. David Van Lear also served on my thesis committee and provided excellent guidance and suggestions. I would also like to thank Clemson University for providing me with an excellent graduate education.

This project would not have been half as succ[...] would like to thank Will Carlisle, Jennifer Hunnicutt[...] assistance. They deserve special recognition for sur[...] infested beaver ponds, and dealing with me every e[...] would also like to thank Corey Miller, Kasey Comp[...] for field assistance. Ross Philips and Helen Mohr[...] Forest Service also deserve recognition for provid[...]

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# CHAPTER 1

## INTRODUCTION AND LITERATURE REVIEW

Bats (Chiroptera) are unique organisms since they fly and use echolocation to navigate through their environment and locate potential prey. Thus, forest structure has been hypothesized as the primary factor determining insectivorous bat habitat use across a landscape (Bradshaw 1995). The first problem is a mechanical issue, where the amount of obstacles a bat has to fly through can limit the habitats used (Fenton 1990). Highly structured and cluttered stands may restrict usage for some species by inhibiting access and navigation within the stand, whereas stands with openings may provide easier access (Brigham et al. 1997). Secondly, more limbs and leaves can cause increased acoustical "clutter", which is defined as the echoes from background structures other than the target that can interfere with echolocation (Fenton 1990). Thus, bats not adapted to these highly cluttered environments would have more difficulty navigating and locating prey.

In contrast, insect densities are higher in more cluttered areas than in more open stands (Kalcounis and Brigham 1995). As a result, bat species have evolved wing morphologies and echolocation to forage and locate roosts within a diversity of environments. Wing morphologies have been used to predict foraging habitat (McKenzie and Rolfe 1986, Aldridge and Rautenbach 1987, Norberg and Rayner 1987, Crome and Richards 1988, Fenton 1990, Saunders and Barclay 1992, Kalcounis and Brigham 1995, Brigham et al. 1997). In general, highly maneuverable bats (i.e., smaller sized with low wing loading) are predicted to exploit structurally complex habitats for foraging (Fenton 1990). These slow moving bats use high-frequency calls which have higher resolution,

but shorter range (Barclay and Brigham 1991). Smaller bats, such as the eastern pipistrelle (*Pipistrellus subflavus*), would thus be able to more efficiently forage in highly cluttered areas. However, they can also use more open habitats.

Less maneuverable bats (i.e., larger sized with high wing loading) such as the eastern red bat (*Lasiurus borealis*), hoary bat (*L. cinereus*), and big brown bat (*Eptesicus fuscus*) are restricted to more open areas such as in forest gaps or above the canopy (Fenton 1990). These fast moving bats use low-frequency calls, which permit the detection of objects at a longer range but with less resolution (Barclay and Brigham 1991). Foraging efficiency for larger bat species has been predicted to decline in areas that are structurally cluttered since physical obstacles can affect their echolocation (Fenton 1990).

Forest structure is influenced by natural disturbances such as wind and fire. Humans also mimic these disturbances through various forest management practices. However, few studies have investigated the impacts of silvicultural practices on bats populations. Early studies determined the impacts clearcuts on foraging and activity. Some studies have found bats prefer foraging along forest edges, thus avoiding clearcuts and forest interiors (Crampton and Barclay 1996, Grindal 1996). In contrast, other studies have reported higher bat activity in clearcuts than undisturbed stands (Erickson and West 1996). However, many of these studies have been conducted in Pacific northwest forests, which are structurally different than southeastern U.S. forests. Also, these studies determined only the influence of even-aged management practices on bat activity and did not research the affects of mid-rotational treatments.

Two mid-rotation silvicultural practices common to the South which alter forest structure are prescribed burning and thinning. Prescribed burning is defined as "the practice of using regulated fires to reduce unincorporated organic matter on the forest floor or low, undesirable vegetation", whereas thinning is the reduction of overstory tree density through removal of selected trees (Smith et al. 1997). However, few studies have determined how thinning influences bat activity (Humes et al. 1999, Owen 2000, Adams and Golten 2003, Patriquin and Barclay 2003, Tibbels and Kurta 2003). In Douglas-fir (*Pseudotsuga menziesii*)/western hemlock (*Tsuga heterophylla*) dominated forests of the Pacific northwest, bat activity of mainly *Myotis* spp. was greater in old-growth and thinned stands than nonthinned stands (Humes et al. 1999). In northwestern British Columbia bat use of heavy and lightly thinned ceder-hemlock stands was just as high as in unthinned or clearcut forests (Perdue and Stevenson 1996). A recent study in Colorado found the highest bat activity in thinned forests and least in unthinned forests (Adams and Golten 2003). In contrast, bat activity did not differ between thinned and nonthinned red pine (*Pinus resinosa*) plantations in Michigan (Tibbels and Kurta 2003). However, bat activity was higher in small openings within thinned and nonthinned stands than within the stands themselves. In West Virginia, the red bat/pipistrelle group had more calls located in deferment harvested forests than intact or complex canopied forests (Owen 2000).

In coastal South Carolina, bat activity was greater in gaps created by group selection harvest in bottomland hardwoods and Carolina bays than unharvested bottomland stands and upland stands (hardwood and pine) (Menzel et al. 2002). Foraging activity for most bat species (including bats of the genus *Lasiurus*) except

pipistrelles was concentrated in the created gaps and associated skidder trails. The study concluded that group selection harvests do not increase total levels of bat activity. However, they do influence foraging activity levels for individual bat species, such as *Lasiurus* spp., and that differences between species may be the result of partitioning of foraging micro-habitats to reduce inter-specific competition (Menzel et al. 2002). A study in the boreal mixed wood forest of Alberta, Canada found smaller more maneuverable bat species were less affected by tree density than larger less maneuverable species and also concluded that silvicultural methods affect each bat species differently (Patriquin and Barclay 2003).

Prescribed burning can influence bat use of forests by altering the structure of understory vegetation within a forest. However, only 1 study has determined potential impacts. This study concluded that northern long-eared myotis (*Myotis septentrionalis*) were not negatively impacted by prescribed burning, and continued or began to use areas that were recently burned (J. Jackson, pers. comm.).

The National Fire and Fire Surrogate Study (FFSS) was designed, in part, to determine how prescribed burning and thinning can affect various wildlife taxa. This study was developed in response to the catastrophic wildfires that had occurred primarily in the western states due to a build up of forest fuels from years of fire suppression. An objective of the FFSS is to determine how components and processes of forest ecosystems are affected by fuel reduction treatments, such as prescribed burning, thinning, and combinations of prescribed burning and thinning treatments. One objective for the FFSS at the South Carolina Piedmont site was to determine the effects of fuel reduction treatments on bat activity. An ongoing project is investigating bat activity and

foraging in the fuel reduction treatment plots on the Clemson Experimental Forest (CEF). It is believed that these intermediate treatments create openings within the overstory canopy and lower shrub layers and may make areas more accessible to bats.

While few studies have determined the influence of mid-rotational silvicultural practices on bat foraging, there is a paucity of studies on how these practices can alter their roosting habitat. Roosting is a critical component of bat ecology since they spend half of their lives at these sites (Kunz and Fenton 2003); however, few studies have determined roost selection at multiple habitat levels. The eastern red bat and eastern pipistrelle are common inhabitants of eastern forests. Little is known about their roosting ecology at multiple spatial scales or how forest management practices may affect their roosting ecology.

The eastern red bat is a common, medium-sized bat that mainly occurs in forested regions of the eastern and central U.S. (Shump and Shump 1982). It weighs 9.5 - 16 g and has an average total length of 112.3 mm (Whitaker and Hamilton 1998). Of the three eastern red bat subspecies, *L. borealis borealis* is the only one that occurs in South Carolina (Shump and Shump 1982). Eastern red bats are sexually dimorphic, with males having bright red fur and females having brownish-red fur with white frosting (Menzel et al. 2003). During winter months, red bats migrate to the eastern and southern portions of the U.S. (Cryan 2003) and roost on branches, leaf clusters (Barbour and Davis 1969), and within deciduous leaf litter (Saugey et al. 1989, Moorman et al. 1999). Summer roosts are important to red bats, particularly females, which raise their young at these sites. Further, Southern forests may serve as maternal roosting areas for red bats, since higher

female to male sex ratios in red bats are correlated with higher maximum summer temperatures (Ford et al. 2002).

Early anecdotal observations of eastern red bat diurnal roosting were primarily in hardwood trees (McClure 1942, Constantine 1966), although conifers were also occasionally used (McClure 1942). Roosts were often found in small trees and shrubs located close to the ground though some were also found within the canopy of overstory trees (McClure 1942). Early observations on their roosting behavior noted red bats used the same roost tree or limb for several consecutive days, especially females with young (McClure 1942). Conversely, recent studies have found red bats switch roosts frequently during summer months (Menzel et al. 1998, Hutchinson and Lacki 2000a, Mager and Nelson 2001). However, no studies have investigated if roost fidelity varies between sexes or over the course of the maternity season.

With the advent of miniature radiotransmitters, information on bat roosting ecology has increased (Kunz and Lumsden 2003). Radiotelemetry reduces personal observer bias and allows spatial and temporal variation of individual animals to be studied. Recent radiotracking studies have confirmed early observations of hardwood tree roosts (Menzel et al. 1998, Hutchinson and Lacki 2000a, Menzel et al. 2000, Mager and Nelson 2001, Limpert and Birch 2003, Thill and Perry 2003, Welch 2003, Durkee and Fink 2004) with occasional usage of pines (Menzel et al. 1998, Menzel et al. 2000). However, approximately 30% of red bat (both sexes and ages) roost trees in Mississippi were pines (Welch 2003). All radio-telemetry studies found roosts to be located higher in the canopy of trees than the early anecdotal observations.

Hutchinson and Lacki (2001) suggested that red bats use roost structures that reduce extreme and variable temperatures. Thus, a wide variety of summer diurnal roost structures have been reported including leaf petioles and small branches (Barbour and Davis 1969), woodpecker holes (Fassler 1975), leaf litter and dense grass (Mager and Nelson 2001), and clumps of Spanish moss (*Tillandsia usneoides*, Constantine 1958).

Red bats appear to select roost trees based on species and size. Red bat roost trees were taller (Menzel et al. 1998) and larger at breast height than other trees in the stand (Menzel et al. 1998, Mager and Nelson 2001, Thill and Perry 2003) and random trees (Limpert and Birch 2003). In eastern Kentucky, smooth-bark hickories (*Carya* spp.) and yellow-poplar (*Liriodendron tulipifera*) were used most often (Hutchinson and Lacki 2000*a*), whereas red bats in Arkansas preferred mockernut hickory (*C. tomentosa*) (Thill and Perry 2003).

Microhabitat characteristics surrounding roost trees may also influence red bat roost selection. Using logistic regression, Hutchinson and Lacki (2000*a*) determined that lower stand density (trees/ha) was the most important variable in predicting adult red bat roost tree presence in eastern Kentucky. Other important variables were a larger mean tree dbh and higher basal area of trees $\geq$ 25 cm dbh. They concluded that adult red bats used more mature tracts of hardwoods. In the coastal plain of South Carolina and Georgia, adult and juvenile red bat roost trees are located in areas that have a higher average overstory tree height and higher basal area (Menzel et al. 1998). Additionaly, stands used by red bats are mainly undisturbed (Menzel et al. 1998).

Stand type also appears to be important to red bat roost selection. In an unmanaged hardwood-dominated landscape in eastern Kentucky, all red bat roost trees

were located in mature upland hardwood stands (Hutchinson and Lacki 2000*a*). In an urban environment in Illinois red bats used stands dominated by hardwoods (Mager and Nelson 2001). In coastal South Carolina and Georgia landscapes dominated by pine, red bats used mature hardwood-dominated stands (Menzel et al. 1998, 2000). However, most adult red bat roost trees in a managed Arkansas landscape were in either unharvested hardwood stands or managed pine stands (Thill and Perry 2003). Further, 83% of red bats roosts were in thinned pine stands and 17% were in pine-hardwood stands > 80 years old in a pine-dominated landscape in Mississippi (Welch 2003).

The eastern pipistrelle is a common, small-sized bat that inhabits the eastern and central U.S. (Barbour and Davis 1969). It weighs 3.3 - 8 g and has an average total length of 85.1 mm (Whitaker and Hamilton 1998). There are 4 recognized subspecies, however only *P. subflavus subflavus* occurs in South Carolina (Fujita and Kunz 1984).

Most studies on pipistrelle summer roosting ecology have been of colonies in man-made structures (Allen 1921, Cope et al. 1961, Jones and Pagels 1968, Whitaker 1998). There has only been 1 thorough study on their roosting ecology in a forested environment (Vielleux et al. 2003). Occasional records of their roosting behavior in forested areas were in a clump of dead leaves (Findley 1954) and a hollow tree stump (Davis and Mumford 1962). Two females (1 juvenile and 1 lactating adult) were collected in a pitfall trap in front of a basal cavity of a sweetgum (*Liquidambar styraciflua*), which may have served as a maternity colony (Menzel 1996). Due to their small body size, gathering detailed information on pipistrelle roosting ecology in forested landscapes has been difficult. However, with the reduction in radio-transmitter size, studies of pipistrelle roosting ecology are now possible.

Pipistrelles roost within various structures in live trees located below the forest canopy. Menzel et al. (1999) in the Georgia coast radiotracked 1 pipistrelle to clumps of Spanish moss in understory trees. In the Upper Coastal Plain of South Carolina, Carter et al. (1999) tracked a pipistrelle to the upper canopy of hardwood trees, primarily oaks. In Michigan, a single juvenile female pipistrelle was tracked to large oak trees, where it was believed to roost within the foliage near the top of the trees (Kurta et al. 1999). These early radiotracking studies found pipistrelles using primarily oak species (Carter et al. 1999, Kurta et al. 1999, Menzel et al. 1999), though pines were also occasionally used (Menzel et al. 1999).

In their intensive radiotracking study of eastern pipistrelles in Indiana from 1998 to 2000, Veilleux et al. (2003) found that reproductive adult female pipistrelles prefer oaks and roost exclusively in foliage, mainly clusters of dead leaves (65%). Occasionally live foliage (30%) or squirrel nests (5%) were used. Roosts were primarily in live trees located well below the forest canopy. Roost fidelity was higher for these radiotracked pipistrelles (mean: 3.9 days) than for the eastern red bat (Menzel et al. 1998, Hutchinson and Lacki 2000a, Mager and Nelson 2001). In Nova Scotia, all pipistrelles roosted within old man's beard (*Usnea* spp.) in both hardwood and softwood (conifers) species (Quinn and Broders 2003). Site fidelity was high but roost tree fidelity was low (Quinn and Broders 2003).

The microhabitats surrounding roost trees were described for 3 studies (Carter et al. 1999, Kurta et al. 1999, Veilleux et al. 2003). However, Kurta et al. (1999) was the only study to report structural characteristics of the surrounding stand. The single

pipistrelle roosted in a five-year-old shelterwood cut with a basal area of 4.6 m²/ha and a mixed hardwood stand with a basal area of 23 m²/ha.

Stand types documented for roosting are a live oak community on a high-marsh hammock in coastal Georgia (Menzel et al. 1999) and bottomland hardwoods in the Upper Coastal Plain of South Carolina (Carter et al. 1999). However, Vielleux et al. (2003) found pipistrelles in Indiana roosted more often than expected in upland and riparian hardwoods and less often in bottomland hardwoods. They concluded this was due to the preference for white oaks, which dominated upland habitats.

Overall, there have been few studies on bat roosting ecology in the U.S., with none being conducted on red bats or pipistrelles in the southern Piedmont. Also, there have been few studies on how forest management practices other than clearcutting can affect bat activity (Humes et al. 1999, Owen 2000, Menzel et al. 2002, Adams and Golten 2003, Patriquin and Barclay 2003, Tibbels and Kurta 2003). While most studies have determined that thinning is beneficial for bat activity and foraging use, there have been no studies determining the effects of thinning on roosting. There has only been 1 study determining the effects of prescribed burning on bat foraging (J. Jackson, pers. comm.). However, no studies have determined the potential effects on their roosting or have been conducted in the southeastern Piedmont.

I determined maternal roost site selection at multiple habitat levels of the eastern pipistrelle and eastern red bat on the CEF in Chapter 2. In Chapter 3, I compare the roosting habitats used by each bat species to the habitats within FFSS treatment plots.

The objectives of this study were:

1) to determine maternal roost use and selection at the tree, microhabitat, and macrohabitat levels for eastern red bats and eastern pipistrelles on the CEF;

2) and to compare the habitats used by each bat species during the maternity season to habitats within FFSS treatment plots (control, burn, thin, thin/burn).

CHAPTER 2

ROOST SITE SELECTION FOR EASTERN RED BATS AND EASTERN

PIPISTRELLES: A HIERARICAL APPROACH

## Introduction

Due to their unusual combination of natural history traits (e.g., nocturnal behavior, ability to fly, and small body size), bats have been very difficult to study. Consequently, studies usually have inadequate sample sizes and true experiments that assess relationships between their behavior and environmental conditions are rarely conducted (Miller et al. 2003). As a result, it has been very difficult to determine critical habitats used by bats or behavioral mechanisms that drive habitat selection.

Johnson (1980) described a method for delineating suitable habitats for animals by assessing habitat selection from multiple hierarchical levels. Using this framework for forest bats' roosts, the highest level of selection is at the landscape (first-order selection), while the second-order selection would be the macrohabitat or forest stand(s) used. Third-order selection would be the microhabitats (structure and composition) immediately surrounding the roost tree, and forth-order selection would be the tree used as a diurnal roost. Selection is "a process in which an animal actually chooses that component" (Johnson 1980). Usage is "said to be selective if components are used disproportionately to their availability" (Johnson 1980).

There have been several in-depth roosting ecology studies involving habitat selection of eastern red bats (*Lasiurus borealis*) (Menzel et al. 1998, Hutchinson and Lacki 2000a, Menzel et al. 2000, Mager and Nelson 2001, Limpert and Birch 2003, Thill

and Perry 2003; Welch 2003, Durkee et al. 2004). However, there has only been 1 thorough study on eastern pipistrelles (*Pipistrellus subflavus*) (Vielleux et al. 2003). All of these studies have been conducted in different forest types with none in the southeastern Piedmont. Also, no studies have been conducted in a forested landscape that contains approximately 50% hardwood dominated stands and 50% pine dominated stands in an actively managed forest.

The objective of this research was to determine maternity roost selection at multiple habitat levels for reproductively active female red bats and pipistrelles and compare habitats used between bat species. Determining the characteristics of maternity roosts is particularly vital to conservation efforts since females raise their young at these sites (Hutchinson and Lacki 2000$b$). This paper will address second- thru forth-order habitat selection levels described by Johnson (1980).

The null hypotheses tested in this chapter are:

- $Ho_1$: Diurnal roost tree characteristics do not differ between bat species during the maternity season.

- $Ho_2$: Diurnal roost tree species and dbh size classes used by both bat species during the maternity season do not differ from the proportion available at the stand or landscape scales.

- $Ho_3$: Microhabitats surrounding diurnal roost trees during the maternity season do not differ between used and non-used plots in a stand and between bat species.

- $Ho_4$: Macrohabitats, containing verified diurnal roost trees, used by each bat species during the maternity season do not differ from their proportion available on the CEF and between bat species.

## Methods

### Study Area

The study was conducted on the Clemson Experimental Forest (CEF), a 7,024 hectare (ha) tract located in Anderson, Oconee, and Pickens counties in the upper Piedmont physiographic region of South Carolina (Figure 2.1). The CEF, initially 12,000 ha of eroded agricultural old-fields, was purchased by Clemson College during the 1930's under the provisions of the Bankhead-Jones Tenant Act to restore, protect, and develop its natural resources (Sorrells 1984). Most of the forests currently located on the CEF are in second- or third-growth timber resulting from reforestation programs when acquired (Waldrop 2000). From 1955 to 1963 the Lake Hartwell reservoir was created by damming the Savannah River and impounding the Seneca, Keowee, and Twelve Mile Rivers which reduced a portion of the CEF land base to its current size (Sorrells 1984). Currently, the CEF is managed by the Clemson University Forest Management Office (FMO) for multiple uses, such as forest products, wildlife habitat, research, water, and recreation.

The CEF is currently dominated by regenerated forests common to the Southeast, including loblolly pine (*Pinus taeda*) stands, mixed pine-hardwood, upland hardwood, bottomland hardwood, and cove hardwood forests. Shortleaf (*P. echinata*) and Virginia (*P. virginia*) pines are the dominant pines in mixed pine-hardwood stands. Common hardwood tree 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*).
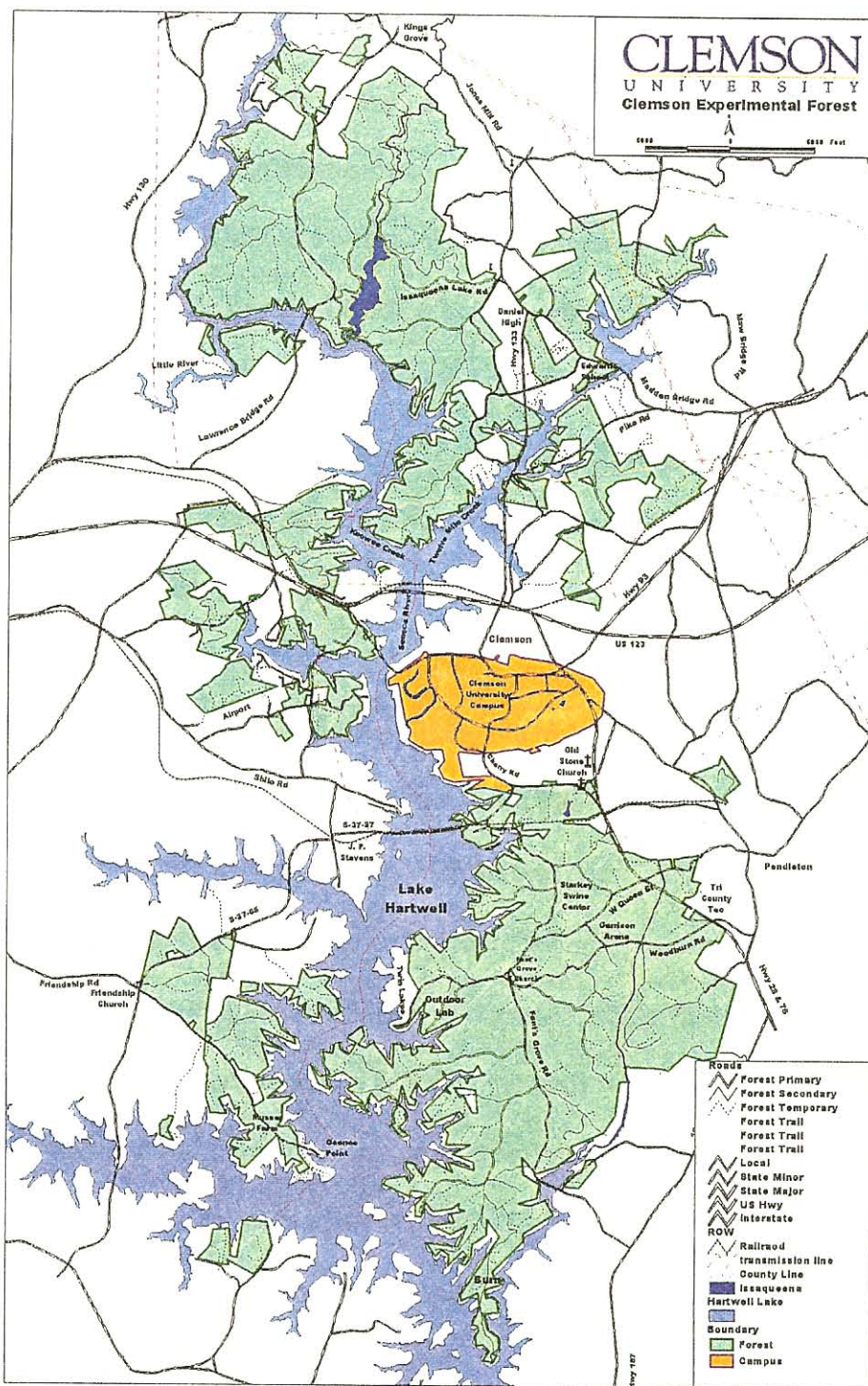
Figure 2.1  Boundary of the Clemson Experimental Forest.

## Bat Capture and Radio-tracking

Bats were captured using 2.6 m, 6 m, or 9 m wide by 2.6 m tall mist-nets (Avinet, Inc., Dryden, New York, USA) placed over forest roads, logging roads, hiking trails, streams, and beaver ponds (Kunz and Kurta 1988). Single or double nets (5.2 m high) were set depending on overhanging vegetation height. Mist-nets, usually 4-5 per night, were opened just before dusk and remained open for approximately 5 hours. Nets were opened for 836 net hours (both years combined). Species, mass (g), forearm length (mm), sex, age (juvenile or adult), and reproductive condition were recorded for each bat caught. Age-class (juvenile or adult) was determined by the degree of epiphyseal-diaphyseal ossification (Anthony 1988). Reproductive condition was determined by palpating the abdomen for embryos and examining the mammae for evidence of lactation or post-lactation (Racey 1988). Each bat captured was fitted with an aluminum lipped wing band used for mark/recapture information (Lambournes, LTD.). Males were banded on the right forearm, and females on the left. Trapping was conducted during the maternity period from approximately mid-May (pregnancy) to the first week of August (end of post-lactation). All capturing and handling methods were approved by the Clemson University Animal Care and Use Committee (protocol # 20033).

Reproductive adult female red bats were fitted with either a 0.52 g or 0.33 g radio-transmitters (Blackburn Transmitters, Nagodoches, Texas, USA) between the scapulae using Skin Bond® surgical cement (Pfizer, Largo, Florida, USA). Due to their smaller size, adult female pipistrelles were fitted with only 0.33 g radio-transmitters by the same attachment technique. No transmitter attached weighed more than 5% of an individual bat's body weight (Aldridge and Brigham 1988). Bats were tracked to day

roosting locations using TR-5 receivers (Telonics, Mesa, Arizona, USA) with hand-held 3-element Yagi antennas or vehicle mounted antennas. Tracking started the morning after release and continued each day throughout the life of the transmitter battery or until the transmitter detached from the bat. The transmitter batteries were designed to last 10-12 days; however, a few transmitters lasted shorter or longer than this time period.

Emergence observations were conducted each evening at dusk to verify the roost tree and roost structure (live foliage, clump of dead foliage, under bark, etc.). Usually 2 or 3 people surrounded the possible roost tree during an emergence observation. Confirmed roosts were flagged with colored surveyors tape and marked with a numbered metal tag for future identification. Each roost tree was mapped using a Trimble XR-Pro Global Positioning System (GPS). Roosting range area (ha) was calculated using the Home Range and Animal Movements Extensions in ArcView. Roosting ranges were only calculated for bats with $\geq 3$ roost trees (polygon). The Minimum Convex Polygon (MCP) was used to estimate roosting area.

## Habitat Description Methods

Verified roost trees were identified to species and characteristics of the tree were recorded. Diameter at breast height (dbh) was measured using a dbh tape. Tree height and crown height were measured using a clinometer. Crown height was estimated by measuring from the bottom of the tree crown's foliage to the top. Crown diameter was determined by measuring the crown's outermost foliage on 2 transects, 1 running north-south and 1 running east-west, from the ground. The 2 diameters were averaged to get the mean crown diameter. Distance to nearest water and road were measured with a steel measuring tape, and larger distances were either paced or calculated by overlaying roost

GPS locations and CEF roads/water source layers in ArcMap Geographical Information System (GIS). Roads were considered edges only when overstory tree canopy was broken by the road.

The composition and structure of the microhabitat surrounding the roost tree was sampled by establishing a 0.05 ha (12.6 m radius) circular plot centered on all verified roost trees. All live trees and snags ($\geq$ 10.2 cm dbh) within the plot were identified to species and their dbh was measured. Snags were defined as dead woody vegetation greater than 10.2 cm dbh and taller than 3.05 m. The percent slope of the plot was estimated using a clinometer. Woody stems < 10.2 cm dbh were counted in 2 perpendicular 2 m wide transects centered on the roost tree, 1 in a north –south direction and 1 in an east-west direction. Overstory and midstory heights were measured at points 0 m, 6 m, and 12 m from the roost tree in the four cardinal directions (9 total measurements). An estimate of canopy closure was taken using a densitometer at 3m, 6m, 9m, and 12m intervals on each of the four cardinal directions from the center tree. Understory densities were taken by counting the number of times understory vegetation touched a 2 m tall vegetation pole from 0-1 m and 1-2 m above ground at 3 m, 6 m, 9 m and 12 m at each of the four cardinal directions from the roost tree.

Microhabitat selection was determined by comparing microhabitat variables surrounding the roost tree to those surrounding a comparable, non-used tree. A comparable tree was used to determine which microhabitat variables might influence bat roost sites within a stand. The tree was located by pacing 50 m from the roost tree in a random compass direction. The first tree found from that random location that was comparable to the verified roost tree was used as the non-used tree. The comparable tree

had to be within 5 cm dbh of the used roost tree; have similar bole structure (broken or intact); be located on a similar slope direction; and be located within the same stand. Also, this comparable tree was not used as a roost for any bats radiotracked, however, it is unknown if an untracked reproductive female red bat or pipistrelle roosted in this non-used tree. A 0.05 ha circular plot was established around the non-used tree and all tree and surrounding microhabitat measurements listed above for the roost tree were recorded. The non-used tree was > 30 m from the roost tree to avoid overlap of microhabitat plots. The non-used trees for 1 red bat were not located due to unusual roosting behavior (i.e. roosting in an open field and in the yard of a private residence). In these instances, non-used trees could not be located since a comparable tree of the same species and similar size could not be found in the surrounding area.

A third 0.05 ha circular plot was established 50 m from the roost tree in a random compass direction within the same stand. This plot was used to gain additional information on tree composition for roost tree selection at the stand spatial scale. This plot's center was located > 30 m from the non-used tree, but did not have to be centered on a tree. Only trees and snags > 10.2 cm dbh were identified, and only dbh was recorded in this plot.

Roost tree selection at the landscape scale was conducted by comparing the verified roost tree species and dbh sizes to available trees found across the CEF landscape. Available tree information on the CEF was gathered as part of the Continuous Forest Inventory (CFI) during the summer of 2002 by FMO personnel. They established 236 randomly located points across the CEF landscape and tallied trees around each point

using a 10 factor prism ($ft^2$/acre). All trees included were identified to species and dbh measured.

Stand (macrohabitat) use was determined using ArcView GIS (Version 3.3). Locations of verified roost trees were overlaid on the CEF stand database layer to determine the forest stand type used. FMO personnel classified and delineated stands based on dominate tree species composition in 2001. Stand use was determined by dividing the number of stands used for each stand type by the total number of stands used. Each stand type's availability was determined by summing the total area (ha) of each stand type. Only stands classified by FMO personnel were used as available stands.

## Statistical Analysis

### Roost Fidelity

A "bat day" was defined as each day an individual bat was radiotracked to a verified roost tree. Roost fidelity was defined as the number of consecutive days a bat spent at a roost before it switched to a new roost or tree. The roosting date for roost fidelity was determined by using the median date a bat spent in a particular roost. For example, if a bat was tracked to a roost for 3 days from 26 May to 28 May, the median date would be 27 May. Regression (PROC REG, SAS Institute 1999) was used to develop a relationship between roost fidelity and the roosting date for red bats. Because the variance in days per switch was not equal across the summer, the data were log-transformed. Only red bats tracked for > 1 day (n = 9) were used in this analysis (two bats omitted due to transmitter detachment after 1 day). Pipistrelles were not analyzed due to small sample size.

## Tree Selection

Selection of roost tree species and dbh size class for each bat species was determined at the stand and landscape scale by utilization-availability analysis (Neu et al. 1974, Byers et al. 1984). The overall premise is that a resource is either used more, less, or in proportion to availability (Johnson 1980). Available trees at the stand spatial scale were trees within the 3 circular plots (0.05 ha each) described above, whereas available trees at the landscape scale were trees tallied in the CEF CFI data. A chi-square goodness-of-fit test (PROC FREQ; SAS Institute 1999) was used to determine whether there was a significant difference between the available frequency of tree species and dbh size classes and the observed frequency. If a difference was detected, selection of tree species and size classes was determined by comparing Bonferroni 90% "family"confidence intervals on the proportions used and the proportions available. An alpha level of 0.10 was used to reduce the probability of committing a Type II error when determining the confidence intervals for each category. A continuity correction factor was used for categories with small sample sizes (Blyth and Still 1983). Similar trees species were combined to reduce the number of classifications. All verified roost trees located were used including those outside the CEF boundaries for the landscape scale analysis; only verified roost trees that had all 3 0.05 ha circular plots measured were used for the stand scale analysis.

## Microhabitat Selection

Microhabitat selection was determined by comparing the 27 vegetation characteristics (Table 2.1) surrounding the used and non-used roost trees. Only verified

Table 2.1  Variables analyzed in the microhabitat surrounding roost trees.

| Microhabitat variables |
| --- |
| Tree density (trees per plot) |
| Snags per plot |
| Overstory tree spp. per plot |
| Woody stem density (0-5 cm dbh) (stems per plot) |
| Woody stem density (5-10 cm dbh) (stems per plot) |
| Percent slope (%) |
| Mean overstory height (m) |
| Mean midstory height (m) |
| Landscape aspect (°) |
| Distance to nearest edge (m) |
| Distance to nearest water (m) |
| Canopy closure – 3 m (%) |
| Canopy closure – 6 m (%) |
| Canopy closure – 9 m (%) |
| Canopy closure – 12 m (%) |
| Total canopy closure (%) |
| Distance to nearest tree (m) |
| Nearest tree dbh (cm) |
| Nearest tree height (m) |
| Distance to nearest taller tree (m) |
| Nearest taller tree dbh (cm) |
| Nearest taller tree height (m) |
| Mean tree dbh (cm) |
| Basal area (m$^2$/ha) |
| Understory density (0-1 m) (number per plot) |
| Understory density (1-2 m) (number per plot) |
| Total understory density (0-2 m) (number per plot) |

ining

ed means $\pm$ 1

roost trees that had both a used plot and non-used plot were used for this analysis.

Assumptions of normality for means were tested using the Shapiro-Wilk W statistic

(PROC UNIVARIATE, SAS Institute 1999). For normal data, paired two-sample t-tests

(PROC TTEST; SAS Institute 1999) were used to detect differences between the means

of the vegetation characteristics for the used and non-used plots of each bat species. Data

with non-normal distributions were transformed first by logarithm and square root

transformations. If data were normal after transformations, then paired t-tests were used.

If the data were not considered normal after transformations then they were compared

using the Wilcoxon Signed-Rank test (PROC UNIVARIATE, SAS Institute 1999). An

alpha level of 0.10 was used to reduce the probability of committing a Type II error when

determining significant differences between means. All data are reported as

untransformed means $\pm$ 1 standard error.

The 27 microhabitat variables surrounding each species' roost trees (Table 2.1)

were also compared to those surrounding the non-used trees using stepwise logistic

regression (PROC LOGISTIC; SAS Institute 1999). This analysis determined which

variables were most important in predicting bat roosting presence. A level of

significance of alpha $\leq 0.10$ was used to determine entry and retention of a variable into

the model and reduce the probability of committing a Type II error.

Macrohabitat Selection

Macrohabitat (stand type) selection was determined by comparing used to

available stand classifications by the same utilization/availability analysis described

above (Neu et al. 1974; Byers et al. 1984). However, a Fisher's exact goodness-of-fit test

was used since there was a small sample size of stands located. Bonferroni 90%

confidence intervals were used to determine selection for each classification. An alpha level of 0.10 was used to reduce the probability of committing a Type II error when determining the confidence intervals for each category. Only roost trees located within the CEF boundaries were used for this analysis. Similar stand types (i.e., natural shortleaf pine stands and loblolly pine stands) were combined to reduce the number of classifications. Stand types classified by FMO were bottomland hardwood, cove hardwood, pine-hardwood, upland hardwood, pine-dominated, agriculture, and other. Pine-dominated stands included primarily pine stands (mostly loblolly pine with some naturally regenerated shortleaf and Virginia pine). Agriculture stands included farms, fields, and old fields, whereas other stands included old home sites, non-productive forest sites, and emergent wetland areas created by beavers (*Castor canadensis*).

Comparison of Habitats Between Bat Species

Assumptions of normality for means were tested using the Shapiro-Wilk W statistic (PROC UNIVARIATE, SAS Institute 1999). Two-sample t-tests (PROC TTEST; SAS Institute 1999) were conducted to compare the characteristics of roost trees and microhabitat variables between bat species for normally distributed data. Data with non-normal distributions were transformed first by logarithm and square root transformations. If data were normal after transformations, t-tests were used. If the data were not considered normal after transformations, then they were compared using the Wilcoxon Rank Sum test (PROC UNIVARIATE, SAS Institute 1999). An alpha level of 0.10 was used to reduce the probability of committing a Type II error when determining significant differences between means. All data are reported as untransformed means $\pm$ 1 standard error.

<u>Outliers</u>

One red bat (n = 4 roost trees) was removed from roost tree microhabitat selection analysis (t-test comparison and logistic regression) and roost tree species/dbh size selection within the stand spatial scale. It was considered to be an outlier. One roost tree was located in a horse pasture and 3 were located in a private landowner's yard. Thus, no comparable trees could be located within the stand. However, these 4 trees were included in roost tree selection at the landscape spatial scale since these trees could be compared to the available trees across the landscape. Pipistrelle roost data were not analyzed at the stand or landscape scales due to a small sample size.

## Results

Bat Captures and Roosting Behavior

During the summers of 2002 and 2003, 115 bats were captured and processed in 836 net hours. Captures included 54 red bats, 29 big brown bats (*Eptesicus fuscus*), 15 pipistrelles, 14 evening bats (*Nycticeius humeralis*), 2 adult male silver-haired bats (*Lasionycteris noctivigans*), and an adult female Seminole bat (*Lasiurus seminolus*) (Table 2.2).

Wing-bands were attached to 105 bats (91% of captures). Three bats, 1 red bat and 2 evening bats, were recaptured in 2003. The female red bat was initially caught on 24 July 2002 as a juvenile. She was recaptured on 25 May 2003 in the same net setup, and was pregnant and had gained 5 g. Both adult male evening bats were captured on 29 May 2003 in the same net, but were recaptured on different days (9 and 11 June 2003) in the same net setup.

Table 2.2  Bat captures on the CEF during summers of 2002 & 2003.

| Bat species | Adult Female | Adult Male | Juvenile Female | Juvenile Male |
|---|---|---|---|---|
| Eastern red bat | 16 | 21 | 6 | 11 |
| Big brown bat | 19 | 8 | 2 | 0 |
| Eastern pipistrelle | 7 | 7 | 0 | 1 |
| Evening bat | 1 | 11 | 1 | 1 |
| Silver-haired bat | 0 | 2 | 0 | 0 |
| Seminole bat | 1 | 0 | 0 | 0 |

Radio-transmitters were attached to 14 female red bats and 5 female pipistrelles. However only 11 female red bats (2 pregnant, 5 lactating, 4 post-lactating) and 4 pipistrelles (2 pregnant, 2 lactating) were located. The 11 red bats were tracked to 32 roost trees (2.9 roosts per bat) for 107 "bat days" and 4 pipistrelles were tracked to 7 roost trees (1.75 roosts per bat) for 23 "bat days." Tracking length was from 1 to 32 days.

Mean roosting fidelity for red bats and pipistrelles was 3.3 days per roost. Red bats spent more days at a roost at the beginning of the reproductive period (pregnancy) than later in the season (post-lactation) ($R^2 = 0.3991$, $P < 0.001$) (Figure 2.2).
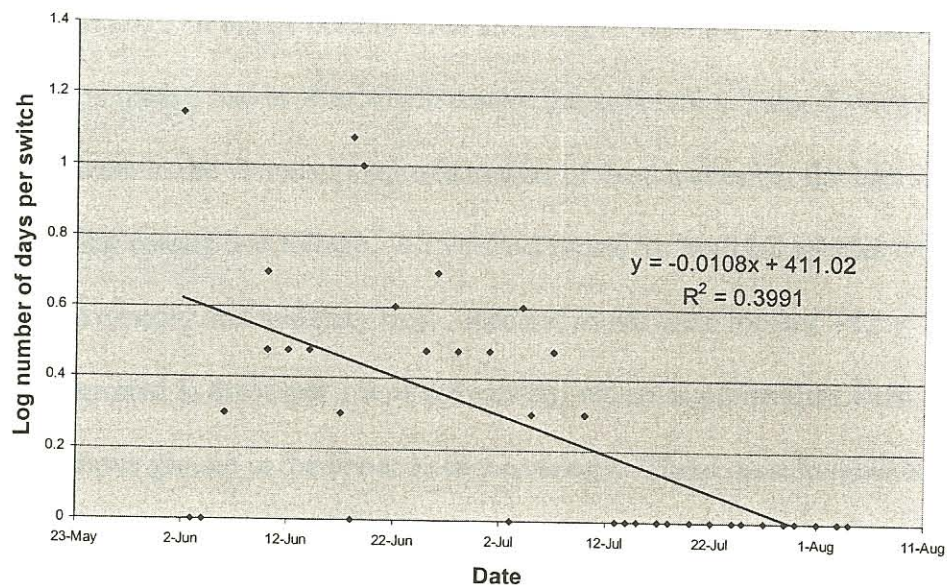


Figure 2.2 Female red bat (n = 9) roost tree fidelity (n = 40 tree switches) on the CEF during the summers 2002 & 2003.

All roost trees were located on CEF property except 5 red bat roost trees (2 individuals) and 1 pipistrelle roost tree which were located on private properties adjacent to the CEF. Mean distance from capture site to roost tree was $806.1 \pm 145.42$ m $(42.7 - 2870.0)$ for red bats $(n = 32)$ and $824.6 \pm 190.52$ m $(499.9 - 1945.0)$ for pipistrelles $(n = 7)$. These distances were not significantly different $(t = -0.06, df = 37, P = 0.955)$.

All verified roost trees were live hardwood trees, with red bats using 12 tree species (Table 2.3) and pipistrelles using 4 species (Table 2.4). Most commonly used trees for red bats were yellow-poplar, hickories, and oaks, whereas pipistrelles primarily used oaks (86%). Verified roosting structures for pipistrelles were live foliage (57%, $n = 4$) and clumps of dead leaves (43%, $n = 3$), whereas red bats used only live foliage (100%, $n = 17$). The dead leaf clusters pipistrelles roosted within were located at the outer canopy of the tree where there was less vegetation clutter. The clusters were approximately 0.5 m tall by 0.25 m wide and hung downward. In both instances, it appeared the branch had broken which caused the structure to hang downward. Two red bat roosts were in the vicinity (1 m) of a cluster of dead leaves but the bats were observed to be roosting among live foliage. All verified roosts for both bat species were within the foliage of overstory and midstory trees. Red bat roosts were located $14.3 \pm 1.21$ m $(n = 15)$ above ground in the upper 1/3 of the canopy, where as pipistrelles were located $10.9 \pm 2.97$ m above ground in the upper ½ of the canopy. These roost heights were not significantly different $(t = 1.23, df = 21, P = 0.233)$.

Table 2.3  Tree species used by red bats for day roosts on the CEF and surrounding areas during summer 2002 & 2003 (n = 32 trees).

| Tree Species | % of roost trees | Number of Roost Trees |
|---|---|---|
| *Liriodendron tulipifera* | 28.1 | 9 |
| *Quercus alba* | 15.7 | 5 |
| *Carya glabra* | 15.7 | 5 |
| *C. tomentosa* | 12.5 | 4 |
| *Q. falcata* | 6.2 | 2 |
| *Q. stellata* | 3.1 | 1 |
| *Q. velutina* | 3.1 | 1 |
| *Q. coccinea* | 3.1 | 1 |
| *Liquidambar styraciflua* | 3.1 | 1 |
| *Oxydendrum arboreum* | 3.1 | 1 |
| *Juglans nigra* | 3.1 | 1 |
| *Amelanchier arborea* | 3.1 | 1 |

Table 2.4  Tree species used by pipistrelles for day roosts on the CEF and surrounding areas during summer 2002 & 2003 (n = 7 trees).

| Tree Species | % of roost trees | Number of Roost Trees |
|---|---|---|
| *Q. alba* | 42.9 | 3 |
| *Q. rubra* | 28.5 | 2 |
| *Q. stellata* | 14.3 | 1 |
| *Liriodendron tulipifera* | 14.3 | 1 |

Only 1 red bat roost tree contained more bats than the radiotracked bat. On 20 July 2002, I observed 2 additional bats (which appeared to be reddish in color and assumed to be red bats) emerge from a black walnut (*Juglans nigra*) tree located on private property adjacent to the southern portion of the CEF. The radiotagged bat and another bat roosted near a clump of live leaves approximately 10 m from the ground, where as the third bat roosted about 3 m from the ground on a lower limb. On 22 July 2002, I observed 4 bats, including the radiotracked red bat, fly from the same black walnut tree. They were all roosting near the middle of the crown but no exact locations could be determined. When captured on 18 July 2002, the female bat was post-lactating. These other bats appeared to be smaller than the radio-tagged adult and may have been the offspring of the adult female red bat, although there was no way to determine this.

On 2 occasions more bats than the radio-tagged pipistrelle emerged from a cluster of dead leaves. On 17 June 2002, 4 bats were observed flying out from a dead leaf cluster 17.8 m high in a 73.5 cm dbh post oak including the radio-tagged pipistrelle. At the time of capture 5 days prior, she was lactating and had recently nursed young. The radio-tagged pipistrelle emerged with the 3 other bats for 6 continuous days before the transmitter detached. The second observation of a pipistrelle roosting in a cluster of dead leaves was on 7 July 2003. At the time of capture 5 days prior, the pipistrelle was pregnant and had a very swollen abdomen. Initially, the bat roosted for 3 consecutive days within live foliage of a large white oak. Next, the pipistrelle roosted for a single day within the foliage of another white oak located 20 m from the first. The third roost observed was a cluster of dead leaves where 3 bats, including the radio-tagged pipistrelle, emerged for 2 consecutive days. The cluster of dead leaves was 18.3 m high in a 23.5 cm

dbh white oak located approximately 25 m and 40 m from the first and second roost trees respectively. Finally, she moved back to the first white oak foliage roost for 1 day until the transmitter detached. The other 2 bats that emerged could not have been her young since she was pregnant when captured; thus this cluster may have been serving as a maternity colony.

Mean bat roosting range for both bat species combined was $0.30 \pm 0.13$ ha (Table 2.5). Red bat roosting range was $0.35 \pm 0.14$ ha (n = 5). There was no relationship between number of roost trees and roosting range size.

Table 2.5  Bat roosting range size (ha) on the CEF and adjacent properties during summer 2002 & 2003 (n = 6 bats).

| Bat Species & Frequency (khz) | Number of Roosts | Number of Days Tracked | Roost Range (ha) ** |
|---|---|---|---|
| Red bat 150.060 | 7 | 24 | 0.85 |
| Red bat 150.859 | 3 | 3 | 0.30 |
| Red bat 150.300 | 4 | 7 | 0.08 |
| Red bat 151.480 | 4 | 4 | 0.07 |
| Red bat 150.594 | 4 | 6 | 0.45 |
| Pipistrelle 150.060 | 3 | 6 | 0.02 |
| | | Mean: | 0.30 |

* Only bats with $\geq$ 3 roost trees were used.
** MCP estimate

## Roost Tree Selection

Red bats roosted in 30 overstory trees and only 2 midstory trees, whereas pipistrelles roosted in 4 overstory trees and 3 midstory trees. Red bats primarily used trees > 20 cm dbh (n = 30, 94%). Pipistrelles used both smaller and larger diameter trees; all trees were > 10 cm dbh (n = 7, 100%, range = 10.2 – 73.5 cm, Table 2.6). Red bat and pipistrelle roost trees were similar in tree characteristics (Table 2.6).

Red bat roost tree species were not used in the same proportion as available trees at the stand ($\chi2 = 34.42$, df = 2, P < 0.001) or landscape ($\chi2 = 62.60$, df = 2, P < 0.001) scales. Red bats used smooth-barked hickories (*Carya* spp.) as roost trees in greater proportion than availability and did not use pine species in proportion to their availability (Tables 2.7 & 2.8). Other hardwood tree species were used less than available at the stand scale (Table 2.7), but were used in proportion at the landscape scale (Table 2.8).

Roost tree dbh size classes were used disproportionately to availability at the stand scale ($\chi2 = 39.27$, df = 2, P < 0.001), but not at the landscape scale ($\chi2 = 1.92$, df = 2, P = 0.383). Red bats used trees in the 10.2-19.9 size class less than available but used trees > 30 cm size class more than the proportion available at the stand scale (Table 2.9). All tree size classes were used in proportion to availability at the landscape scale (Table 2.10).

Table 2.6  Characteristics of red bat roost trees (n = 28) and pipistrelle roost trees (n = 7) during summers 2002 & 2003 and results of two-sample t-tests.

| Variable | Red bat roost trees | | Pipistrelle roost trees | | |
| --- | --- | --- | --- | --- | --- |
| | Mean | Std. Err. | Mean | Std. Err. | P-value |
| Roost tree dbh (cm) | 37.2 | 3.30 | 31.9 | 8.45 | 0.498 |
| Roost tree height (m) | 19.7 | 1.23 | 19.4 | 3.87 | 0.943 |
| Roost tree crown height (m) | 11.2 | 0.86 | 11.9 | 2.38 | 0.743 |
| Roost tree crown diameter (m) | 9.4 | 0.58 | 9.5 | 2.10 | 0.949 |

Table 2.7  Red bat roost tree species selection at the stand spatial scale during summer 2002 & 2003.

| Tree Type | Total Trees | Proportion of Total Trees ($p_{io}$) | Number of Trees observed | Expected Number of Trees observed | Proportion observed in each type ($p_i$) | Bonferroni 95% CI (CI $p_i$) |
|---|---|---|---|---|---|---|
| Conifers | 144 | 0.075 | 0 | 2.1 | 0 | $0 \leq p_1 \leq 0.018$ |
| Hickories | 147 | 0.076 | 9 | 2.1 | 0.321 | $0.098 \leq p_2 \leq 0.544$ |
| Yellow-poplar | 331 | 0.172 | 9 | 4.8 | 0.321 | $0.098 \leq p_3 \leq 0.544$ |
| Oak | 403 | 0.209 | 7 | 5.9 | 0.250 | $0.042 \leq p_4 \leq 0.458$ |
| Other hardwoods | 902 | 0.468 | 3 | 13.1 | 0.107 | $0 \leq p_5 \leq 0.261$ |
| Total | 1927 | | 28 | | | |

Table 2.8  Red bat roost tree species selection at the landscape spatial scale during the summer 2002 & 2003.

| Tree Type | Total Trees | Proportion of Total Trees ($p_{io}$) | Number of Trees observed | Expected Number of Trees observed | Proportion observed in each type ($p_i$) | Bonferroni 95% CI on (CI $p_i$) |
|---|---|---|---|---|---|---|
| Conifers | 533 | 0.385 | 0 | 12.3 | 0 | $0 \leq p_1 \leq 0.016$ |
| Hickories | 54 | 0.039 | 9 | 1.2 | 0.281 | $0.081 \leq p_2 \leq 0.482$ |
| Yellow-poplar | 151 | 0.109 | 9 | 3.5 | 0.281 | $0.081 \leq p_3 \leq 0.482$ |
| Oak | 387 | 0.279 | 10 | 8.9 | 0.313 | $0.106 \leq p_4 \leq 0.519$ |
| Other hardwoods | 260 | 0.188 | 4 | 6.0 | 0.125 | $0 \leq p_5 \leq 0.277$ |
| Total | 1385 | | 32 | | | |

Table 2.9  Red bat roost tree dbh size class selection at the stand spatial scale during the summer 2002 & 2003.

| Dbh size class (cm) | Total Trees | Proportion of Total Trees ($p_{io}$) | Number of Trees observed | Expected Number of Trees observed | Proportion observed in each type ($p_i$) | Bonferroni 95% CI on (CI $p_i$) |
|---|---|---|---|---|---|---|
| 10.2-19.9 | 1092 | 0.567 | 2 | 15.3 | 0.074 | $0 \le p_1 \le 0.200$ |
| 20-29.9 | 413 | 0.214 | 6 | 5.8 | 0.222 | $0.034 \le p_2 \le 0.411$ |
| >30 | 422 | 0.219 | 19 | 5.8 | 0.704 | $0.498 \le p_3 \le 0.909$ |
| Total | 1927 | | 27 | | | |

Table 2.10  Red bat roost tree dbh size class selection at the landscape spatial scale during the summer 2002 & 2003.

| Dbh size class (cm) | Total Trees | Proportion of Total Trees ($p_{io}$) | Number of Trees observed | Expected Number of Trees observed | Proportion observed in each ($p_i$) | Bonferroni 95% CI on (CI $p_i$) |
|---|---|---|---|---|---|---|
| <20 | 257 | 0.187 | 3 | 6.0 | 0.094 | $0 \le p_2 \le 0.219$ |
| 20-29.9 | 301 | 0.219 | 7 | 7.0 | 0.219 | $0.048 \le p_3 \le 0.390$ |
| >30 | 818 | 0.595 | 22 | 19.0 | 0.688 | $0.498 \le p_4 \le 0.877$ |
| Total | 1376 | | 32 | | | |

## Microhabitat Selection

Red bats used areas of the stand that had significantly fewer trees, more woody understory stems (0 – 5 cm dbh), and a taller overstory than non-used sites (Table 2.11). Also, red bat roost trees were significantly closer to the nearest forest edge than non-used trees (Table 2.11). Common forest edges encountered were 2-lane and single lane forest roads. Red bat roost sites were on a north-northwest aspect whereas non-used sites had a north aspect (Table 2.11). Also, the nearest taller tree dbh was significantly larger for red bat roost sites than non-used sites (Table 2.11).

Pipistrelles used areas that had a significantly taller overstory and midstory than non-used sites (Table 2.12). Pipistrelle roost trees were significantly closer to the nearest water source than non-used trees (Table 2.12). The nearest taller tree was significantly taller at the pipistrelle roost site than non-used site (Table 2.12). Also, trees surrounding pipistrelle roost sites had a larger mean dbh and a higher basal area than those surrounding non-used trees (Table 2.12).

Pipistrelles were located in habitats with a significantly taller midstory than red bats (Table 2.13). The distance to the nearest taller tree was significantly farther for red bats than pipistrelles (Table 2.13). The trees surrounding pipistrelle roosts had significantly larger mean dbh and higher basal area than those surrounding red bat roosts (Table 2.13).

Table 2.11 Characteristics of red bat roost plots (n = 28) and non-used plots (n = 28) during the summers 2002 & 2003 and results of paired two-sample t-tests.

| Variable | Used tree site | | Non-used tree site | | |
|---|---|---|---|---|---|
| | Mean | Std. Err. | Mean | Std. Err. | P-value |
| Tree density (trees per plot) | 20.7 | 1.25 | 23.5 | 1.37 | 0.079 |
| Snags per plot | 1.9 | 0.39 | 1.9 | 0.43 | 0.655 |
| Overstory tree spp. Per plot | 7.9 | 0.43 | 7.9 | 0.44 | 0.953 |
| Woody stem density (0-5 cm dbh) | 21.0 | 3.36 | 16.8 | 2.78 | 0.094 |
| Woody stem density (5-10 cm dbh) | 3.7 | 0.41 | 3.1 | 0.35 | 0.192 |
| Percent slope (%) | 20.3 | 3.08 | 15.4 | 2.69 | 0.123[a] |
| Mean overstory height (m) | 19.6 | 0.70 | 19.0 | 0.69 | 0.092[a] |
| Mean midstory height (m) | 7.1 | 0.29 | 6.3 | 0.43 | 0.436[a] |
| Landscape aspect (°) | 331.9 | 14.79 | 7.8 | 19.07 | 0.031 |
| Distance to nearest edge (m) | 69.1 | 7.47 | 89.5 | 13.34 | 0.071 |
| Distance to nearest water (m) | 75.7 | 13.78 | 70.5 | 12.66 | 0.758 |
| Canopy closure – 3 m (%) | 86.6 | 3.01 | 90.2 | 2.68 | 1.000 |
| Canopy closure – 6 m (%) | 78.6 | 3.80 | 79.5 | 3.87 | 0.820[a] |
| Canopy closure – 9 m (%) | 76.8 | 4.25 | 80.4 | 4.14 | 0.498[a] |
| Canopy closure – 12 m (%) | 77.7 | 3.71 | 75.0 | 4.07 | 0.612[a] |
| Total canopy closure (%) | 73.3 | 2.62 | 74.8 | 2.89 | 0.670 |
| Distance to nearest tree (m) | 2.3 | 0.27 | 2.6 | 0.21 | 0.419 |
| Nearest tree dbh (cm) | 19.5 | 1.79 | 20.2 | 2.05 | 0.808 |
| Nearest tree height (m) | 13.9 | 1.02 | 14.5 | 1.10 | 0.708 |
| Distance to nearest taller tree (m) | 14.3 | 2.96 | 13.0 | 3.03 | 0.356 |
| Nearest taller tree dbh (cm) | 39.5[b] | 2.96 | 36.0[b] | 2.05 | 0.083 |
| Nearest taller tree height (m) | 21.7[b] | 1.13 | 22.5[b] | 1.02 | 0.287 |
| Mean tree dbh (cm) | 23.2 | 0.82 | 22.3 | 0.65 | 0.372 |
| BA (m²/ha) | 18.8 | 0.99 | 20.0 | 1.23 | 0.512 |
| Understory density (0-1 m) [c] | 9.4 | 1.61 | 7.8 | 0.88 | 0.594 |
| Understory density (1-2 m) [c] | 6.1 | 1.11 | 5.0 | 0.98 | 0.179 |
| Total understory density [c] | 15.4 | 2.28 | 12.8 | 1.41 | 0.190 |

[a] Wilcoxon Signed-Rank Test was used.
[b] n = 24.
[c] (# per plot).

Table 2.12  Characteristics of pipistrelles roost plots (n = 7) and non-used plots (n = 7) during the summers 2002 & 2003 and results of paired two-sample t-tests.

| Variable | Used tree site | | Non-used tree site | | |
|---|---|---|---|---|---|
| | Mean | Std. Err. | Mean | Std. Err. | P-value |
| Tree density (trees per plot) | 17.3 | 1.55 | 16.3 | 2.82 | 0.631 |
| Snags per plot | 1.7 | 0.52 | 1.3 | 0.42 | 0.407 |
| Overstory tree spp. per plot | 6.9 | 1.0 | 5.7 | 0.92 | 0.406[a] |
| Woody stems (0-5 cm dbh) | 18.6 | 3.37 | 17.6 | 5.74 | 0.790 |
| Woody stems (5-10 cm dbh) | 5.0 | 1.75 | 3.7 | 1.19 | 0.587 |
| Percent slope (%) | 20.7 | 7.47 | 14.8 | 4.74 | 0.213 |
| Mean overstory height (m) | 20.1 | 2.07 | 16.6 | 2.50 | 0.099 |
| Mean midstory height (m) | 9.1 | 0.66 | 6.2 | 1.49 | 0.061 |
| Landscape aspect (°) | 24.0 | 39.96 | 1.4 | 46.57 | 0.749 |
| Distance to nearest edge (m) | 69.9 | 29.32 | 73.4 | 34.40 | 0.650 |
| Distance to nearest water (m) | 34.0 | 12.40 | 54.9 | 14.84 | 0.084 |
| Canopy closure – 3 m (%) | 92.9 | 4.61 | 85.7 | 4.43 | 0.457 |
| Canopy closure – 6 m (%) | 75.0 | 7.72 | 78.6 | 10.10 | 0.838 |
| Canopy closure – 9 m (%) | 67.9 | 13.04 | 75.0 | 7.72 | 0.631 |
| Canopy closure – 12 m (%) | 75.0 | 9.45 | 78.6 | 6.52 | 0.792 |
| Total canopy closure (%) | 70.1 | 4.73 | 72.7 | 6.76 | 0.798 |
| Distance to nearest tree (m) | 2.6 | 0.53 | 2.7 | 0.70 | 0.904 |
| Nearest tree dbh (cm) | 25.4 | 4.12 | 19.0 | 2.65 | 0.169 |
| Nearest tree height (m) | 14.2 | 1.79 | 11.2 | 1.47 | 0.279 |
| Distance to nearest taller tree (m) | 3.9 | 0.97 | 18.7 | 13.64 | 0.437 |
| Nearest taller tree dbh (cm) | 45.7 | 9.37 | 30.9[b] | 5.12 | 0.184 |
| Nearest taller tree height (m) | 22.0 | 3.68 | 17.0[b] | 2.96 | 0.089 |
| Mean tree dbh (cm) | 26.3 | 0.84 | 22.5 | 1.02 | 0.020 |
| BA (m²/ha) | 22.8 | 1.11 | 14.5 | 2.27 | 0.018 |
| Understory density (0-1 m) [c] | 15.7 | 5.50 | 12.3 | 2.52 | 0.388 |
| Understory density (1-2 m) [c] | 9.3 | 2.75 | 6.3 | 1.58 | 0.389 |
| Total understory density [c] | 25.0 | 7.81 | 18.6 | 3.78 | 0.347 |

[a] Wilcoxon Signed-Rank Test was used.
[b] n = 6.
[c] (# per plot).

Table 2.13  Characteristics of red bats roost plots (n = 28) and pipistrelles roost plots (n = 7) during the summers 2002 & 2003 and results of two-sample t-tests.

| | Red bat roost site | | Pipistrelle roost site | | |
|---|---|---|---|---|---|
| Variable | Mean | Std. Err. | Mean | Std. Err. | P-value |
| Tree density (trees per plot) | 20.7 | 1.25 | 17.3 | 1.55 | 0.208 |
| Snags per plot | 1.9 | 0.39 | 1.7 | 0.52 | 0.755[a] |
| Overstory tree spp. per plot | 7.9 | 0.43 | 6.9 | 1.0 | 0.294 |
| Woody stems (0-5 cm dbh) | 21.0 | 3.36 | 18.6 | 3.37 | 0.801[a] |
| Woody stems (5-10 cm dbh) | 3.7 | 0.41 | 5.0 | 1.75 | 0.498 |
| Percent slope (%) | 20.3 | 3.08 | 20.7 | 7.47 | 1.000[a] |
| Mean overstory height (m) | 19.6 | 0.70 | 20.1 | 2.07 | 0.749 |
| Mean midstory height (m) | 7.1 | 0.29 | 9.1 | 0.66 | 0.014[a] |
| Landscape aspect (°) | 331.9 | 14.79 | 24.0 | 39.96 | 0.151 |
| Distance to nearest edge (m) | 69.1 | 7.47 | 69.9 | 29.32 | 0.454[a] |
| Distance to nearest water (m) | 75.7 | 13.78 | 34.0 | 12.40 | 0.226[a] |
| Canopy closure – 3 m (%) | 86.6 | 3.01 | 92.9 | 4.61 | 0.489[a] |
| Canopy closure – 6 m (%) | 78.6 | 3.80 | 75.0 | 7.72 | 0.704[a] |
| Canopy closure – 9 m (%) | 76.8 | 4.25 | 67.9 | 13.04 | 0.639[a] |
| Canopy closure – 12 m (%) | 77.7 | 3.71 | 75.0 | 9.45 | 0.967[a] |
| Total canopy closure (%) | 73.3 | 2.62 | 70.1 | 4.73 | 0.603[a] |
| Distance to nearest tree (m) | 2.3 | 0.27 | 2.6 | 0.53 | 0.599 |
| Nearest tree dbh (cm) | 19.5 | 1.79 | 25.4 | 4.12 | 0.144[a] |
| Nearest tree height (m) | 13.9 | 1.02 | 14.2 | 1.79 | 0.893 |
| Distance to nearest taller tree (m) | 14.3 | 2.96 | 3.9 | 0.97 | 0.019[a] |
| Nearest taller tree dbh (cm) | 39.5[b] | 2.69 | 45.7 | 9.37 | 0.917[a] |
| Nearest taller tree height (m) | 21.6[b] | 1.78 | 22.0 | 3.68 | 0.982[a] |
| Mean tree dbh (cm) | 23.1 | 0.82 | 26.3 | 0.84 | 0.015 |
| BA (m²/ha) | 18.8 | 0.99 | 22.8 | 1.11 | 0.061 |
| Understory density (0-1 m) [c] | 9.4 | 1.61 | 15.7 | 5.50 | 0.249[a] |
| Understory density (1-2 m) [c] | 6.1 | 1.12 | 9.3 | 2.75 | 0.354[a] |
| Total understory density [c] | 15.4 | 2.28 | 25.0 | 7.81 | 0.304[a] |

[a] Wilcoxon Rank Sum Test was used.
[b] n = 24.
[c] (# per plot).

Tree density was the most important variable associated with red bat roost microhabitat (Table 2.14). Landscape aspect, midstory height, and the understory stem density (0-5 cm dbh) were also important variables (Table 2.14). The model classified 75.0% of used sites correctly, 70.8% of non-used sites correctly, incorrectly identified 28.0% of used sites as non-used, and misclassified 26.1% of non-used sites as used.

## Macrohabitat Selection

Red bats primarily used mature hardwood-dominated stands. Further, all stands used had not been recently disturbed by management activities (last 15 years) (S. Knight Cox, pers. comm.). Mean age of stands used by red bats on the CEF was 63 years (range 28 – 85 years) and mean stand area was 19.12 ha (n = 9 stands). Hardwood-dominated stands (n = 8) had a mean age of 67.4 years (range = 45 – 85 years), whereas the 1 pine-dominated stand was 28 years old. In 6 different instances an individual red bat roosted only within 1 stand. There were also 3 different instances where an individual bat roosted in 2 stands of the same type but different ages. Additionally, there were 2 instances of individual red bats roosting in 2 stands of different types. One red bat roosted in a large yellow-poplar located on the edge of a loblolly pine stand, while the other 3 verified roost trees were in an adjacent upland hardwood stand. The other red bat roosted in a horse pasture on private property, then traveled 0.5 km across a 2-lane road and roosted in 3 trees in the yard of an adjacent private property.

Red bats used stand types (n = 14) disproportionately to availability on the CEF (df = 6, P < 0.001). Pine-dominated stands and agricultural areas were used less than

Table 2.14 Comparison of microhabitat stand variables between red bats roost plots and non-used plots using logistic regression during the summers 2002 & 2003.

| Microhabitat Variable | Roost sites | | Non-used sites | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SE | Mean | SE | Estimate | SE | $\chi^2$ | P-value |
| Tree density (trees per plot) | 20.7 | 1.25 | 23.5 | 1.37 | -0.214 | 0.080 | 7.15 | 0.008 |
| Landscape aspect (°) | 331.9 | 14.79 | 7.8 | 19.07 | -0.016 | 0.006 | 6.70 | 0.010 |
| Midstory height (m) | 7.1 | 0.29 | 6.3 | 0.43 | 0.764 | 0.306 | 6.23 | 0.013 |
| Understory stem density (0-5 cm dbh) (# per plot) | 21.0 | 3.36 | 16.8 | 2.78 | 0.048 | 0.025 | 3.53 | 0.060 |

available, whereas bottomland hardwood, cove hardwood, pine-hardwood, and upland hardwood forest types were used in proportion to their availability (Table 2.15).

Pipistrelles used a cove hardwood stand, a pine-hardwood stand, and a loblolly pine stand on the CEF. Mean stand age was 39.5 years and mean stand area was 34.33 ha (n = 3 stands). Stand selection for pipistrelles was not determined due to a small sample size.

## Unusual Roosting Behavior

One post-lactating red bat was radiotracked from late July to early August 2002 to 4 roost trees located in unusual locations. Most of this bat's roosts were not located in contiguous forest as were found for all of the other red bats tracked on or around the CEF during this study. The first roost tree located was a black walnut located in a horse pasture on private property. The second roost tree, a white oak, was located in an adjacent private residence's front yard. This front yard had been maintained as a lawn and contained approximately 2 dozen overstory trees, mostly oaks. The microhabitats surrounding each roost tree contained only a few overstory trees, no midstory, and no understory component except for grasses. The two other roost trees located were within 5 m of a garage behind the private home of the landowner.

## Discussion

### Eastern Red Bat Roosting

Red bats roosted within the live foliage of a variety of hardwood trees which were primarily located in hardwood-dominated stands. They selected hickories at the stand and landscape scales, and used larger diameter trees more than they were available at the

Table 2.15  Red bat macrohabitat stand selection (n = 14 stands) on the CEF during summers 2002 & 2003.

| Stand Type | Total ha | Proportion of CEF ($p_{io}$) | Number of stands observed | Expected number of stands observed | Proportion observed in each stand ($p_i$) | Bonferroni 95% CI on (CI $p_i$) |
|---|---|---|---|---|---|---|
| Bottomland hardwood | 112.70 | 0.015 | 3 | 0.2 | 0.214 | $0 \leq p_1 \leq 0.519$ |
| Cove hardwood | 1159.40 | 0.154 | 4 | 2.2 | 0.286 | $0 \leq p_2 \leq 0.617$ |
| Pine-hardwood | 1052.30 | 0.140 | 2 | 2.0 | 0.143 | $0 \leq p_3 \leq 0.408$ |
| Upland hardwood | 1066.60 | 0.142 | 4 | 2.0 | 0.286 | $0 \leq p_4 \leq 0.617$ |
| Pine-dominated | 3160.60 | 0.421 | 1 | 5.9 | 0.071 | $0 \leq p_5 \leq 0.276$ |
| Agriculture | 741.06 | 0.099 | 0 | 1.4 | 0 | $0 \leq p_6 \leq 0.036$ |
| Other | 214.88 | 0.029 | 0 | 0.4 | 0 | $0 \leq p_7 \leq 0.036$ |
| Total | 7507.54 | | 14 | | | |

stand scale. The area surrounding their roost trees contained fewer trees, a taller midstory, and more understory stems (0-5 cm dbh) than those surrounding non-used trees. Their roost trees were usually located within a small area of a stand. Red bats often switched roost trees (3.3 days per switch), however they had less roost fidelity later in the maternity season.

Lewis (1995) found that roost fidelity is related to roost type, with fidelity positively related to more permanent roosts and inversely related to the availability of the roost. In general, foliage roosting vespertilionid bat species are thought to exhibit low roost fidelity since foliage structures are considered ephemeral and more available (Lewis 1995). Roost fidelity on the CEF (3.3 days per switch) was higher than previously reported in Mississippi (1.2 days, Welch 2003), South Carolina (1.2 days, Menzel et al. 2000), and Kentucky (2.3 days, Hutchinson and Lacki 2000a). Further, there were 3 instances where red bats on or around the CEF stayed in the same roost for $\geq 10$ continuous days. However, high fidelity (11 days) was documented for 1 lactating red bat in eastern Kentucky (Hutchinson and Lacki 2000b). Benefits of roost fidelity are being familiar with optimal roosts, increased value to occupied roosts, and maintenance of social relationships (Lewis 1995). The previously reported studies on red bat roosting usually combined data across sexes and ages, which may have led to differences in fidelity since male and non-reproductive female bats do not have the same energetic demands as reproducing female bats.

Reproducing female red bats had less fidelity to roosts during the end of the maternity season. Reasons for being labile may include response to disturbance, avoidance of predators, changes in the microclimate and roost structure, and avoidance of

parasitism (Lewis 1995). Several studies have reported lower fidelity in females of non-foliage roosting species prior to and just after weaning their young compared to during the early lactation period (Vaughan and O'Shea 1976, Wolz 1986, Krull et al. 1991). However, no studies have reported lower fidelity across the maternity season for foliage roosting bat species.

Higher fidelity of pregnant or lactating females may be due to energetic constraints of carrying the nonvolant young to new roosts (Bradbury 1977a, 1977b). Lactating females of other bat species have been found to shift roosts less often than non-breeding females since energy may be required for the cost of transporting young to a new roost (Kurta et al. 1996, Mattson et al. 1996, Vonhof and Barclay 1996, Menzel et al. 2001). Also, lactating females must budget energy for feeding, nursing, and raising young. For example, average daily energy expenditure for big brown bats during lactation is more than double than during pregnancy (Kurta et al. 1990). Also, water flux for pregnant and lactating little brown bats (*Myotis lucifigus*) was 3-5 times greater than non-reproductive bats (Kurta et al. 1989). In contrast, post-lactating bats probably have fewer energetic costs to their young since they have been weaned by this point and are usually volant. Thus, post-lactating females may choose roosting locations without the energy costs of nursing or moving young to alternate roosts. Also, it has been suggested that post-lactating females may become more labile when their young become volant to familiarize them with the variety of roosting and foraging locations (Vaughan and O'Shea 1976, Wolz 1986).

Individual bats were only tracked for a short period within the maternity season, thus variability in each individual bats' roosting behavior may have biased the results.

Further research should determine individual bats roosting fidelity over the course of the maternity season. Also, since red bats may require more roost trees later in the maternity season, forest management practices should retain groups of suitable roost trees for roosting during the post-lactation period.

The small roosting area found on the CEF (0.35 ± 0.14 ha) is not uncommon for red bats in other areas (Menzel et al. 1998, Welch 2003) and has been documented for other bat species (Lewis 1995). Also, many bats that roost in tree cavities or under bark also have small roosting areas (Kunz and Lumsden 2003). In Mississippi, red bat roosting area was 0.6 ha (Welch 2003) and in South Carolina it was 2.6 ha (Menzel et al. 1998). In contrast, Mager and Nelson (2001) found a mean roosting area of 90 ± 51 ha (range 2-629 ha). They attributed the larger size to the spatial arrangements of the woodlots which contained a lower density of suitable roost trees. However 82% of roosts on consecutive days were < 100 m apart (Mager and Nelson 2001). Many of the female red bats on or around the CEF were usually located < 30 m from the previously used tree. The roosting areas for red bats were considerably smaller than the mean size of stands in which they were located (19.12 ha). Many times roosting areas were located within 1 stand, although some bats roosted in 2 stands. This was usually the result of 1 roost tree being on the edge of the adjacent stand. In most cases, the stands were the same type but different ages. Bat species that switch roosts frequently usually remain faithful to a particular area, probably benefiting from being familiar with the site (Lewis 1995). Since radio-tracked red bat roost trees were located in a relatively small area, forest management practices should retain groups of suitable roost trees (i.e., large hardwoods) to benefit red bat and roosting.

Red bats in and around the CEF were only tracked for a brief period and observed roost ranges may not reflect true ranges throughout the maternity season. However, 1 red bat was tracked for 32 continuous days. She was captured on 25 May 2003 and was classified as pregnant. During the following 32 days, she only used 2 roost trees, a hickory 179 m from the capture site and a white oak 199 m from the capture site. The trees were approximately 30 m apart. The bat used the hickory first for 14 days of observation after which she moved to the white oak for 3 days. She then moved back to the hickory for 12 days, and moved back to the white oak for 3 days at which point the transmitter battery failed. This bat had been captured as a juvenile in the same area on 24 July 2002. Observations of this individual illustrate both the potentially high year to year site fidelity and also roost tree fidelity of a young adult female red bat as well as the small roosting area during the pregnancy and lactation periods.

Adult female red bat roost trees were located approximately 0.8 km from capture locations. Although few data are available for comparison, distance from capture to roost for bats on the CEF was rather small compared to studies in other geographic areas. For example, a male red bat in Arkansas traveled 1.6 km from capture site to roosting site (Saugey et al. 1998). A red bat in Missouri traveled > 15 km during home range tracking (S. Amelon, pres. comm.).

Red bats on and around the CEF mainly roosted in yellow-poplar, hickories, and oaks (88%). Further, they selected hickories more than they were found available at the stand and landscape spatial scales. Other recent radiotracking studies have also found red bats using a diversity of hardwood trees (Menzel et al. 1998, Hutchinson and Lacki 2000a, Menzel et al. 2000, Mager and Nelson 2001, Limbert and Birch 2003, Welch

2003). In Mississippi, red bats (both sexes and ages combined) selected hickories and sweetgum more than they were available (Welch 2003). Hutchinson and Lacki (2000*a*) found a variety of hardwoods species used with hickories and yellow-poplar used most often, but not more than found available.

All verified roost structures in and around the CEF were within live foliage (n = 17, 100%). However 2 of the foliage roosts were located within the vicinity of clusters of dead leaves, 1 each in a hickory and black walnut. Hutchinson and Lacki (2000*a*) also found many red bat roosts (male and female) near clusters of dead, furled, ruset-colored leaves in yellow-poplar and hickory trees in eastern Kentucky. Bats of the genus *Lasiurus* are believed to be cryptically colored to resemble dead leaves when roosting (Dalquest and Walton 1970). Further, female red bats have a dull reddish-brown pelage and may resemble a dead leaf while hanging within foliage. Female red bats may be selecting tree species that contain more clusters of dead leaves, such as hickories, which could help them avoid being detected by predators, such as blue jays (*Cyanocitta cristata*) (Hoffmeister and Dowes 1964) and probably raptors. Possible reasons for the abundance of clumps of dead leaves in trees include damage from wind storms, ice storms, and/or pest insect infestations. The twig girdler insect (*Oncideres cingulata*) girdles twigs and small branches of primarily hickories and deposits larvae within the branches, creating clusters of dead leaves (USDA Forest Service 1985, Solomon 1995). Other common insects which can create these dead leaf structures in eastern forests are the twig pruner (*Anelaphus villosus*) which targets a variety of hardwoods including oaks and hickories, and the oak twig pruner (*A. parallelus*) which prefers oaks and occasionally hickories (Solomon 1995). All of these species are common forest pests on

the CEF (R. Hedden, pers. comm.). On the other hand, selection of hickories may have been a statistical artifact related to past management practices that reduced regeneration of this species. From 1958 to the mid 1970's, undesirable "weedy" stems on the CEF, including hickories, were removed through spot-herbicide application, girdling, and cutting (S. Knight Cox, pers. comm.). These weedy species were removed to promote regeneration of more valuable timber species such as yellow-poplar, pines, and oaks. This practice was common during this period throughout much of southern forests (S. Knight Cox, pers. comm.). During 2002 and 2003 study, hickories only represented 8% of the trees at the stand spatial scale, and 4% at the landscape spatial scale.

I found no red bats roosting in coniferous trees. Similarly, only 2 of 64 roost trees used by red bats in a pine-dominated landscape in the Coastal Plain of South Carolina were pines (Menzel et al. 1998). In contrast, red bats in Mississippi used hardwoods (70%) and loblolly pines (30%) in a pine-dominated landscape (Welch 2003). However, juvenile females made up the majority of bats using pines (22/43, 51%), whereas adult females and males preferred to roost in hardwood trees. In summary, it appears that reproductive adult female red bats use hardwoods in hardwood- and pine-dominated landscapes, but will also occasionally use conifers in pine-dominated landscapes.

Female red bats in and around the CEF mainly used overstory trees (94%) and only two midstory trees (6%), and selected the larger dbh trees in the stand and avoided smaller trees (10.2 – 19.9 cm dbh). Other studies have also found red bats use/select larger trees in a stand (Menzel et al. 1998, Hutchinson and Lacki 2000a, Menzel et al. 2000, Mager and Nelson 2001, Welch 2003). During summer months, these large overstory trees probably contain more vegetative structures (i.e. leaves) that may reduce

detection by predators and can reduce variability in extreme summer temperatures of the surrounding microclimate within the tree (Hutchinson and Lacki 2001).

No other published red bat studies have documented other bats emerging from the tree containing the radiotracked bat. Particular trees, such as the large black walnut located in the middle of a field, may serve as a colony roosting location for bats prior to fall migration. Also, since there is no way of determining the relationship of these bats, it is unknown if volant young and post-lactating females continue to roost in the same trees towards the end of the maternity season.

Roost trees were located closer to the nearest edge than non-used trees. Further, several roost trees had permanent roads located within the 12.6 m radius circular plots, and several roost tree plots had small streams (2-3 m wide) located within them. Many times after bats flew from their roosts they were observed flying back and forth along these openings probably either foraging or orienting themselves within the forest. Thus, secondary impacts to forests from silvicultural practices such as logging roads did not appear to negatively affect red bat roosting behavior.

Red bats selected trees in areas which were relatively open. The microhabitats surrounding roost trees had significantly fewer trees surrounding the roost tree which was the most important variable predicting adult female bat roosting presence. Hutchinson and Lacki (2000a) also found that fewer trees surrounding roost trees were the most important predictor of adult red bat presence in eastern Kentucky. However, Welch (2003) found greater overstory (mainly pines) and midstory (mainly hardwoods) tree density surrounding adult female red bat roost plots than in random plots. Red bats forage in areas which are more open such as forest gaps (Menzel et al. 1998), and have

been predicted to use more open areas due to their larger body size and higher wing loading (Fenton 1990). Further, reproductive females carrying their young have increased wing loading and consequently are less maneuverable (Norberg and Rayner 1987, Hayssen and Kunz 1996). Thus, reproductive adult female red bats may be using areas with fewer trees which would reduce the energetic costs of navigating and maneuvering during flight.

Landscape aspect was another important variable in predicting red bat roost use. Red bats used areas with a north-northwest aspect. A single male red bat in Arkansas also roosted in west and north aspects (Saugey et al. 1998). However, no other studies documented landscape aspect. North facing aspects are usually associated with more mesic habitats in the northern hemisphere. Tree species associated with mesic conditions, such as yellow-poplar, are usually located in sites more protected from solar radiation and commonly found at the bottom of slopes. However, red bat roost trees were found at different slope positions from bottomlands to less protected ridge tops. In this study red bats also used many tree species commonly located on upper slopes and ridge tops which are usually associated with more xeric sites, such as red oaks and hickories.

Red bats also used areas that had a taller midstory and more understory stems 0–5 cm dbh. Red bats may use these areas to reduce detection by ground and/or aerial predators. Further, there may be a relationship between the understory stem density and overstory tree density. Areas that contain fewer trees may have denser and taller understories since light can penetrate down to lower canopy levels.

Due to the small sample size, it was difficult to determine stand type selection. But, red bats appeared to use mature hardwood stands on the CEF. Almost all stands

containing roost trees on CEF were mature hardwood stands. Although use of all hardwood stand types did not differ from availability, this was likely due to low statistical power related to the low sample size. Several studies have documented red bat usage of hardwood-dominated stands (Hutchinson and Lacki 2000*a*, Mager and Nelson 2001), even in pine-dominated landscapes (Menzel et al. 1998, 2000). However, adult female red bats in Mississippi use mainly young, thinned loblolly pine plantations in a pine-dominated landscape, even though they use midstory hardwoods as roost trees. In Arkansas, male and female red bats use mature unharvested pine-hardwood or hardwood dominated stands (Thill and Perry 2003). They also use recently harvested pine stands in which overstory hardwood trees were retained (Thill and Perry 2003).

## Eastern Pipistrelle Roosting

Pipistrelles roosted in live foliage and clusters of dead foliage in primarily oak trees located in hardwood- and pine-dominated stands. The habitat surrounding their roost trees contained larger diameter trees and higher basal areas than the habitats surrounding non-used trees. Pipistrelles often switched roost trees which were located within a small area of a stand.

Roost fidelity for pipistrelles on and around the CEF (3.3 days per switch) was similar to that documented for reproductive adult female pipistrelles in Indiana (3.9 days per switch) (Veilleux et al. 2003). However, pipistrelle roost fidelity was higher than the eastern red bat in other areas (Menzel et al. 1998, Hutchinson and Lacki 2000*a*, Menzel et al. 2000, Mager and Nelson 2001, Welch 2003), but the same as red bats on and around the CEF (3.3 days per switch).

Adult reproductive female pipistrelles on the CEF were tracked to 7 roost structures, 4 foliage roosts and 3 within clusters of dead leaves (one each in a post oak, white oak, and yellow-poplar). Other studies have documented pipistrelles using clusters of dead leaves (Vielleux et al. 2003), as well as similar structures, such as old man's beard in Nova Scotia (Quinn and Broders 2003) and Spanish moss in the Florida coast (Menzel et al. 1999). These structures hide bats from visual predators (Vielleux et al. 2003). Since more than one bat emerged from these dead leaf clusters containing a recently captured pregnant pipistrelle, they may be serving as maternity colony roosts. Wind storms, ice storms, and forest insect pests (such as the twig girdler and oak twig pruner mentioned earlier) may be important for the creation of these dead leaf clusters.

Pipistrelles predominately used oaks as roost trees (n = 6, 86%) on the CEF, which was consistent with studies in other geographic areas (Carter et al. 1999, Kurta et al. 1999, Vielleux et al. 2003). Vielleux et al. (2003) found adult reproductive female pipistrelles in Indiana used primarily oaks and maples, with oaks being used more than expected. All roosts were located in overstory trees, which is also consistent with previous studies (Carter et al. 1999, Veilleux et al. 2003), although a single adult pipistrelle in Florida roosted exclusively in the understory (Menzel et al. 1999).

Pipistrelle roost trees were located closer to nearest water than non-used trees. Proximity to water has been found to be important for bat roost site selection (Campbell et al. 1996, Mattson et al. 1996, Ormsbee and McComb 1998) and may reduce energetic costs of commuting to water sources (Kunz and Lumsden 2003). However, 1 bat used 3 roost trees within 20 m of a stream in a cove hardwood forest, and may have skewed the data.

The microhabitat surrounding pipistrelle roost trees contained a taller overstory and midstory, a larger mean dbh of trees in the surrounding plot, and a higher basal area than non-used sites. These results suggest the areas surrounding roost trees contained larger trees and that pipistrelle roost selection, unlike red bats, may be influenced by the size of the surrounding trees and not the density of trees. The larger trees in these areas may contain more limbs and leaves, which may increase the amount of mechanical clutter. Since pipistrelles are predicted to have low wing loadings and are more maneuverable (Fenton 1990), the high mechanical clutter of these habitats may not deter their use and may provide extra cover from predators.

Pipistrelle macrohabitat use on the CEF was consistent with previous studies (Carter et al. 1999, Menzel et al. 1999, Veilleux et al. 2003). Pipistrelles roosting on the CEF were located in a cove hardwood, pine-hardwood, and pine-dominated stand types. This is the first documentation of a pipistelle radio-tracked to a diurnal roost tree in a loblolly pine stand; however the 2 roost trees were overstory northern red oaks located in the subcanopy. Menzel et al. (1999) found pipistrelles roosting in conifers in clumps of Spanish moss in a live oak and pine community. Vielleux et al. (2003) found pipistrelles roosting in upland hardwood stands which contained more white oaks than bottomland stands. All 3 stands located on the CEF including the 1 on private property were located in upland sites, and support the findings of Vielleux et al. (2003). Thus, it appears pipistrelles may be generalists and use either hardwood- or pine-dominated stands as diurnal roosting macrohabitat, as long as it contains oaks in the canopy or subcanopy.

## Comparison of Roosting Behavior Between Species

While both species are fairly common throughout their range, this is the first study comparing the roosting behavior between eastern red bats and eastern pipistrelles. Both species used similar roost tree species (hardwoods) and also had small roosting areas usually within 1 stand. However there was a difference between the roost structures, the microhabitats surrounding roost trees, and macrohabitats. Red bats only used live foliage as their roosting structure, whereas pipistrelles used both live foliage and clusters of dead leaves.

Microhabitats surrounding pipistrelle roosts had a taller midstory, a larger mean dbh of surrounding trees, and a larger overstory basal area than the microhabitat surrounding red bat roosts. Also, pipistrelle roost trees were located closer to the nearest taller tree than red bats. Thus, pipistrelle microhabitats had larger overstory trees, in contrast to red bats whose microhabitats had smaller trees. Use of different microhabitats may be the result of different preferences or morphological adaptations. Since red bats are larger and have a higher wing loading, they have been hypothesized to be restricted to forage within open habitats (Fenton 1990). In contrast, the smaller pipistrelle has a lower wing loading and has been hypothesized to maneuver through habitats that contain more structural clutter as well as be able to use open habitats (Fenton 1990). Since pipistrelles used areas with a taller midstory and larger diameter trees which contain more branches, twigs, and leaves and red bats used areas that had smaller trees, pipistrelles may be morphologically adapted to use areas with more structural clutter than red bats.

Both red bats and pipistrelles used mature hardwood-dominated stands, although pipistrelles also used a pine-hardwood stand and a loblolly pine stand. Thus, pipistrelles may have a wider range of suitable stand types than red bats.

## Summary and Conclusions

Red bats and pipistrelles used multiple roosts in hardwoods located in a relatively small area for maternal roosting. Both species used similar roost structures and may benefit from trees containing dead leaf clusters. Female red bats may use trees which contain these clusters since their coloration mimics dead leaves, and pipistrelles may use them as possible maternity colonies to raise young. Red bats had higher roost fidelity earlier in the maternity season (i.e., pregnancy and lactation) than later (post-lactation), and as a result switched roosts less often during this earlier period. Thus, these bats may be less likely to move during a disturbance. Future research should determine the influence of forest management practices conducted during this earlier period (May to mid-July) on their roosting behavior.

These bat species may be partitioning roosts located in different habitats to reduce interspecific competition. Red bats used mainly overstory trees, whereas pipistrelles used overstory and midstory trees. Microhabitats surrounding roost trees differed between species. Pipistrelles used areas that had a taller midstory, larger mean tree dbh, and higher basal area than red bats. These areas may have more mechanical clutter, thus pipistrelles may be more adapted to navigate within than red bats. Red bats primarily used hardwood-dominated stands, whereas pipistrelles used hardwood- and pine-dominated stands. However, only a few pipistrelles were radio-tracked.

CHAPTER 3

POTENTIAL EFFECTS OF FIRE AND FIRE SURROGATE TREATMENTS ON

RED BAT AND PIPISTRELLE ROOSTING HABITAT

Introduction

Both natural lightning ignited and anthropogenic fires have historically shaped the

forests of North America (Carroll et al. 2002, Stanturf et al. 2002). Native Americans

who entered the Piedmont approximately 12,000 years ago consistently burned many

eastern forests (Stanturf et al. 2002) to improve their quality of life by clearing the land

for hunting, agriculture, and easier travel. However, since the beginning of the 20th

century, both wildland fires and anthropogenic fires, such as prescribed or controlled

burning, have been suppressed to protect standing timber, people, and homes. Over the

last century, fire suppression has resulted in the build up of high fuel levels in many

forests of the U.S., leading to many of the recent catastrophic wildfires seen today.

The National Fire and Fire Surrogate Study (FFSS), funded by the Joint Fire

Science Program, was developed in 1999 to determine: 1) the effects of various fuel

reduction techniques on components and processes of forest ecosystems and 2) the

effectiveness of the treatments in reducing fuel loads. The treatments being tested are

prescribed burning, thinning, thinning/prescribed burning, and a control. Prescribed

burning reduces the amount of fine fuels on the forest floor, whereas thinning reduces

fuels in the understory and midstory. The study is nationwide with 13 sites from

Washington to Florida.

FFSS Objectives (Executive Summary 2000) are to:

1. Quantify the initial effects of fire and fire surrogate treatments on a number of specific core response variables within the first five years (i.e., vegetation, fuel and fire behavior, soils and hydrology, wildlife, entomology, pathology, and treatment costs and utilization economics).

2. Provide an overall research design that establishes and maintains the study as an integrated national network of long-term interdisciplinary research sites utilizing a common "core" design to facilitate broad applicability of results. This design should allow each site to be independent for purposes of statistical analysis and modeling, as well as being a component of the national network. Also, it must provide flexibility for investigators and other participants responsible for each research site to augment--without compromising--the core design as desired to address locally-important issues and to exploit expertise and other resources available to local sites.

3. During the first five years, establish cooperative relationships, identify and establish network research sites, collect baseline data, implement initial treatments, document treatment costs and short-term responses to treatments, report results, and designate FFS research sites as demonstration areas for technology transfer to professionals and for the education of students and the public.

4. Develop and maintain an integrated and spatially-referenced database format to be used to archive data for all network sites, facilitate the development of interdisciplinary and multi-scale models, and integrate results across the network.

5. Identify and field test, in concert with resource managers and users, a suite of response variables or measures that are: (a) sensitive to the fire and fire surrogate treatments, and (b) both technically and logistically feasible for widespread use in management contexts. This suite of measures will form much of the basis for management monitoring of operational treatments designed to restore ecological integrity and reduce wildfire hazard.

6. Quantify, over the life of the study, the ecological and economic consequences of fire and fire surrogate treatments in different forest types and conditions in the U.S. Develop and validate models of ecosystem structure and function, and successively refine recommendations for ecosystem management.

Wildlife communities studied at all sites include birds, small mammals, and herpetofauna. This study is 1 of 2 to examine the response of bats to FFSS treatments; the other is in the Ohio Hill Country. Loeb and Waldrop (in prep) of the U.S. Department of Agriculture, Forest Service, Southern Research Station (USFS-SRS) are

studying bat foraging activity within the FFSS treatments on the Clemson Experimental Forest (CEF). However, it is also important to study the effects of treatments on roosting habitat since bats spend half of their lives in roosts (Kunz and Fenton 2003). Maternity roost sites are important to ensure successful reproduction and long term viability of species (Kunz 1982).

Directly testing the effects of FFSS treatments on bat roosting behavior within these sites would be difficult. First, foliage roosting bats common to the CEF are primarily nocturnal, small-bodied, and well camouflaged within the overstory canopy. Thus it would be extremely time consuming to locate roosts within the complexity of these forests. Also, radio-tracking bats captured in the FFSS treatments during foraging activity would not be effective because 1) capturing within the treatments would be difficult, and 2) they are highly mobile and may not roost in the treatments. Thus, to test the potential response of bats to treatments, I determined the composition and structure of roosting habitats used by 2 bat species, the eastern red bat (*Lasiurus borealis*) and the eastern pipistrelle (*Pipistrellus subflavus*), and compared them to the characteristics of the habitats within the FFSS post-treatment plots. I used these comparisons to make inferences on the relative suitability of these treatment stands as potential habitat for both bat species.

Red bats roosted in large diameter overstory hardwood trees in mature hardwood-dominated stands. Thus, I predict the FFSS treatment sites will not provide an abundance of suitable roost trees since the overstory species in the stands of the FFSS sites are primarily pines. Further, the microhabitat surrounding their roost trees on and around the CEF contained fewer trees. Thus, I predicted that microhabitats would compare to the 3

fuel reduction treatments (burn, thin, thin/burn) since tree density will be reduced in these sites. Pipistrelles roosted in overstory and midstory hardwoods located in both hardwood- and pine-dominated forests. Thus, I predict the FFSS treatments will provide suitable roosting habitat since midstory hardwoods are located in these pine-dominated stands. Further, the habitat surrounding pipistrelle roost trees on and around the CEF contained a higher basal area than non-used trees. Thus, I predicted pipistrelle roost tree microhabitats would compare to the control treatment since higher basal area will remain at these sites.

The objectives of this chapter are to:

- Determine the availability of suitable maternal roost trees for each bat species in each of the FFSS treatment plots;

- Compare microhabitat characteristics, specifically stand density and basal area, surrounding red bat and pipistrelle maternal roost trees to habitat characteristics of the FFSS treatment plots;

- Compare macrohabitats used by each bat species during the maternity season to those within the FFSS treatment plots;

- Make inferences on how FFSS treatments affect the quality of red bat and pipistrelle maternal roosting habitat.

## Methods

### Experimental Design

The four treatments in the FFSS protocol were control, burning, thinning, and thinning/burning. The experimental design was a randomized complete block design, with tree size classes as the blocking factor. Replication 1 was dominated by pulpwood-sized trees (15-25 cm dbh); Replication 3 was dominated by sawtimber-sized trees (> 25 cm dbh); Replication 2 was a mixture of pulpwood and sawtimber-sized trees.

### Treatments

The 12 study sites were located on the CEF (described in Chapter 2) (Figure 3.1). Sites were chosen based on stand composition, size, age, and management history recommended by National FFSS protocol. Each site was a minimum of 14 ha and comprised a 10 ha measurement area. Stand ages varied from 15 to 60 years. None of the sites had been thinned in the last 10 years or had been burned in the last 5 years. All FFSS sites chosen were primarily loblolly (*Pinus taeda*) or shortleaf pine (*P. echinata*) stands with a diversity of hardwoods in the under- and mid-story (Waldrop 2000). Some sites contained small inclusions of pine-hardwood stands and hardwood-dominated stands. Common hardwood species were various oaks (*Quercus* spp.), yellow-poplar (*Liriodendron tulipifera*), and sweetgum (*Liquidambar styraciflua*). Within each block, treatments were randomly assigned to sites. A 20 m buffer surrounded the measurement area.
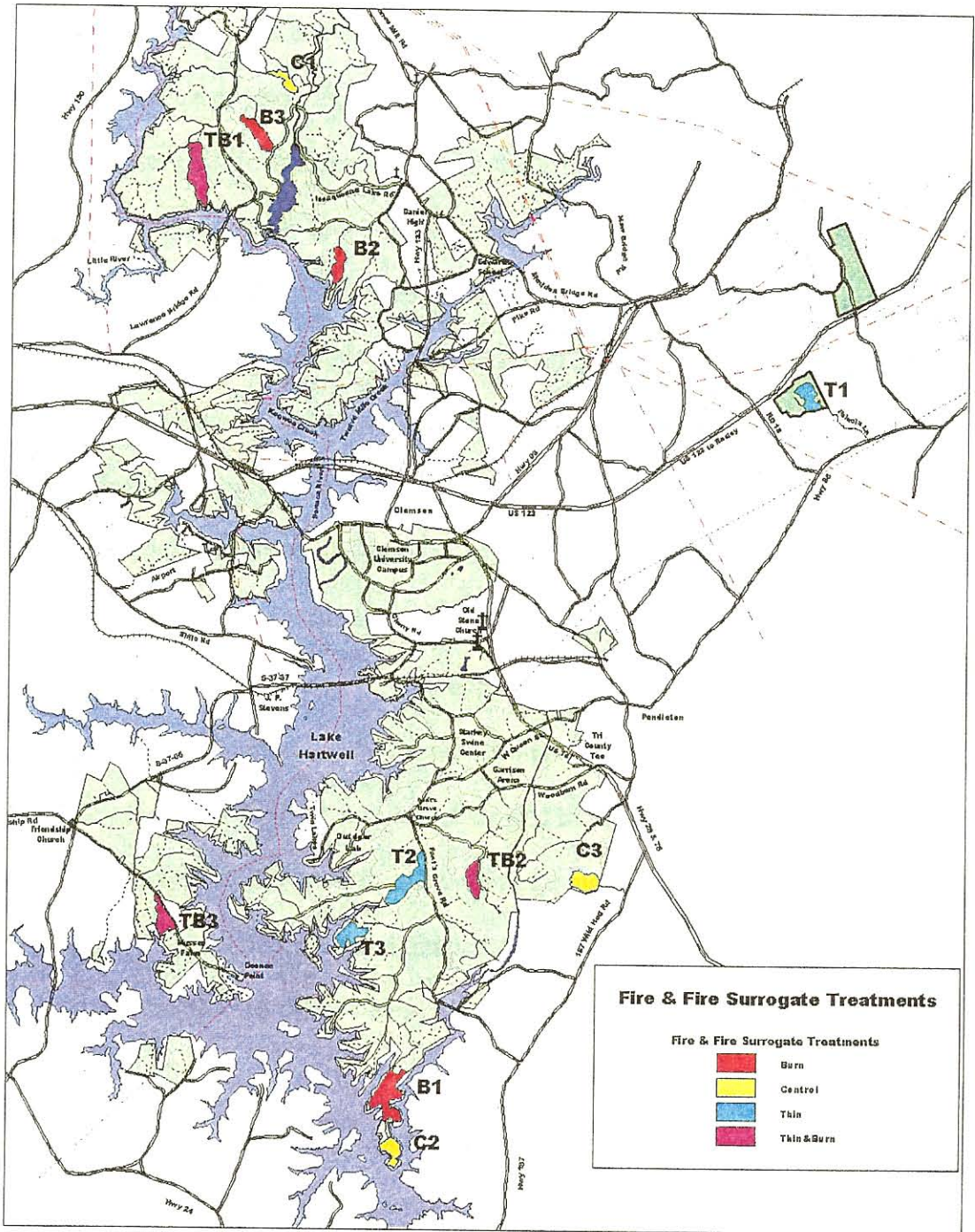
Figure 3.1  Locations of Fire and Fire Surrogate Study treatment sites on the Clemson Experimental Forest.

The levels of prescribed burning and thinning were defined by the FFSS protocols. Treatments were conducted from December 2000 to March 2002 (Table 3.1). All thinnings were conducted from December 2000 to April 2001 (Table 3.1). Thinning operations were contracted to local timber companies. The operation was specified as a fifth row thin with selection between rows. Trees infected by southern pine beetle infestations or small, merchantable-sized trees (< 10 cm dbh) were selected first. The objective was to reduce the stand to a residual basal area of 18 $m^2$/ha.

All prescribed burns were set and monitored by personnel from the USFS-SRS, Clemson University Forest Management Office (FMO), and graduate students from the Department of Forestry and Natural Resources at Clemson University. Backing fires and strip headfires, set in parallel lines 3 - 5 m apart, were commonly used. Prescribed burns were conducted in April 2001 for the burn-only sites (Table 3.1). The prescription for burn-only sites was to remove forest floor fuels and to produce flames of sufficient intensity to kill a few overstory trees. Actual fire intensity for burn-only sites was usually low with flame heights below 1 m and temperatures below 200 ° Celsius (C). Moderate intensity fires occurred in localized areas with flames reaching into tree crowns and exceeding 750 ° C.

Prescribed burns for the thin/burn treatment were delayed one year after thinning to allow logging slash to partially decompose and were burned in spring 2002 (Table 3.1). The prescription for burning in thin/burn sites was to keep flames low and to remove forest floor fuels. Intensity when burning the thin/burn sites remained low with flames always below 1.5 m and mean temperatures below 350 ° C.

Table 3.1  Dates of treatments for FFSS study on the CEF.

| Treatment | Replicate | Date |
|---|---|---|
| Burn | 1 | 10 April 2001 |
| Burn | 2 | 12 April 2001 |
| Burn | 3 | 11 April 2001 |
| Thin | 1 | 8 March 2001 – 4 April 2001 |
| Thin | 2 | 18 December 2000 – 18 January 2001 |
| Thin | 3 | 5 February 2001 – 21 February 2001 |
| Thin/burn | 1 | Thin: 3 January 2001 – 18 January 2001<br>Burn: 7 & 8 March 2002 |
| Thin/burn | 2 | Thin: 25 January 2001 – 31 January 2001<br>Burn: 25 March 2002 |
| Thin/burn | 3 | Thin: 26 February 2001 – 7 March 2001<br>Burn: 28 March 2002 |

## FFSS Habitat Methods

Personnel from the USFS-SRS established forty permanent grid points within the measurement area of each of the 12 sites. The distance between grid points was 50 m. They drove a 1 m rebar into the ground to mark these grid points and a numbered aluminum tag was attached for future identification. Ten 20 m X 50 m sample plots (0.10 ha) were randomly established at selected grid points. Personnel identified all single stem woody vegetation (> 10 cm dbh) to species and measured the dbh with a dbh tape in each of the 10 plots of the 12 replicates. Inventory dates were between May 2001 and July 2002 (Table 3.2). Basal area ($m^2$/ha) and stand density (number of trees/ha) of live trees in each of the 12 sites after treatment were determined by USFS-SRS personnel.

## Bat Roosting Habitat

Red bats roosted in a variety of live hardwood tree species with most having a dbh > 20 cm (n = 30, 94%) (Chapter 2). Thus, all hardwoods > 20 cm dbh were classified as suitable for red bat roosts. Pipistrelles primarily used live hardwoods > 10 cm (n = 7, 100%) (Chapter 2), and their suitable trees were classified as hardwoods > 10 cm dbh. Microhabitats surrounding red bat roosts had a basal area of $18.8 \pm 0.99$ $m^2$/ha and a tree density of $413.6 \pm 25.07$ trees/ha, whereas microhabitats surrounding pipistrelle roosts had a basal area of $22.8 \pm 1.11$ $m^2$/ha and a tree density of $345.7 \pm 31.08$ trees/ha (Chapter 2). Red bats primarily used hardwood stands (11 hardwood-dominated stands, 2 pine-hardwood stands, and 1 pine stand), and pipistrelles used 1 hardwood-dominated stand, 1 pine-hardwood stand, and 1 pine stand (Chapter 2).

Table 3.2  Inventory dates of live trees in post-treatment FFSS sites on the CEF.

| Treatment | Replicate | Inventory date |
| --- | --- | --- |
| Burn | 1 | Sept. 2001 |
| Burn | 2 | Sept. 2001 |
| Burn | 3 | Aug. 2001 |
| Control | 1 | May 2002 |
| Control | 2 | May 2002 |
| Control | 3 | June 2002 |
| Thin | 1 | May 2001 |
| Thin | 2 | May 2001 |
| Thin | 3 | May 2001 |
| Thin/burn | 1 | July 2002 |
| Thin/burn | 2 | July 2002 |
| Thin/burn | 3 | July 2002 |

## Statistical Analysis

Student's t-tests were used to test for differences between the tree densities and basal areas of the microhabitats surrounding each bat species roosts and the mean stand densities and basal areas of the 4 FFSS treatments (control, burn, thin, and thin/burn). For bats, the experimental unit was each individual roost plot, whereas for treatments, the experimental unit was each replicate. The 10 subplots were summed to obtain the basal area and stand density of each replicate. An alpha level of 0.10 was used to reduce the probability of committing a Type II error and to determine significant differences between means. All data are reported as mean $\pm$ 1 standard error. Control Replicate 1 was considered an outlier and removed from data analysis, since a large number of pine trees was killed as a result of a southern pine beetle infestation during 2000 – 2001 (Boyle 2002).

## Results

### Roost Tree Availability

Ten percent or less of trees in each of the 4 treatments were suitable red bat roost trees (Figure 3.2). Non-suitable trees for red bats were primarily large pines or trees < 20 cm dbh. Potential pipistrelle roost trees were more abundant than potential red bat roost trees (Figure 3.2). Control and thin sites contained more suitable pipistrelle roost trees than burn or thin/burn treatments (Figure 3.2). Non-suitable trees for pipistrelles were primarily large pines.
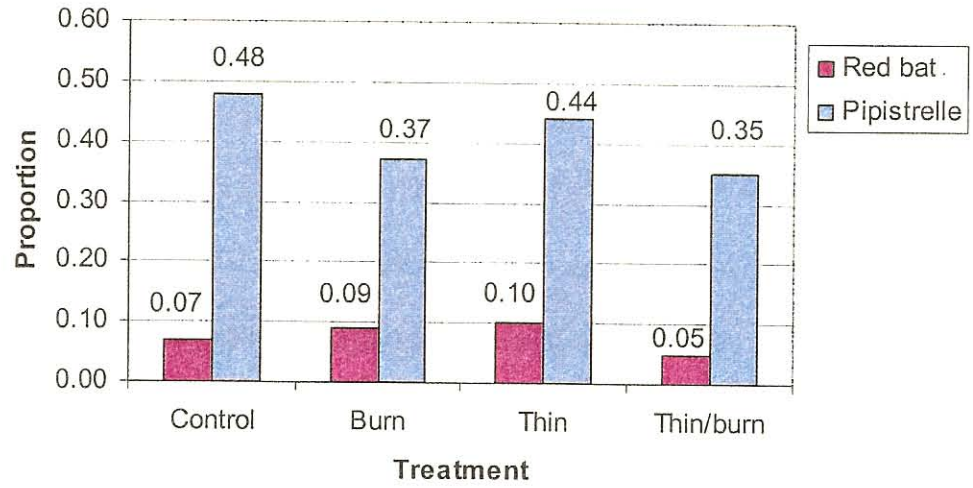
Figure 3.2 Proportion of trees in FFSS treatment plots that were suitable as red bat and pipistrelle roost trees.

## Microhabitat Comparison

Burn, thin, and thin/burn treatments had significantly lower tree densities than microhabitats surrounding red bat roost trees (Table 3.3). There was no significant difference between the tree density of the control treatment and red bat roost microhabitats (Table 3.3). Basal areas of the burn, thin, and thin/burn treatments were not significantly different from the basal areas of live trees in the microhabitat surrounding red bat roost trees (Table 3.4). Basal areas of control treatment plots were significantly higher than red bat roost sites (Table 3.4).

There was no significant difference between stand densities of the burn, control, and thin treatments and tree density of the microhabitat surrounding pipistrelle roost trees (Table 3.3). However, the thin/burn treatment had a significantly lower tree density than pipistrelle roost tree microhabitats (Table 3.3). There was no significant difference between the basal areas of burn, control, and thin treatment plots and the basal area of the microhabitat surrounding pipistrelle roost trees (Table 3.4). The basal area of thin/burn treatment plots was significantly lower than basal areas of pipistrelle roost sites (Table 3.4).

## Macrohabitat Comparison

The FFSS sites were predominately in loblolly pine or shortleaf pine stands with varying levels of hardwoods in the under- and mid-story. However, occasional pine-hardwood stands and small inclusions of hardwood stands were in the plots. Since red bats primarily used hardwood-dominated stands, only a small proportion of FFSS plots probably provide suitable habitat. However, pipistrelles used hardwood- and pine-

Table 3.3  Post-treatment stand densities of FFSS plots and results of t-tests between FFSS stand densities and tree densities surrounding red bat roost trees ($413.6 \pm 25.07$ trees/ha, n = 28) and pipistrelle roost trees ($345.7 \pm 31.08$ trees/ha, n = 7).

| Treatment | Mean | Std. error | Red bat Test stat. | Red bat P-value | Pipistrelle Test stat. | Pipistrelle P-value |
|---|---|---|---|---|---|---|
| Control | 322.0 | 21.00 | 1.54 | 0.133 | 0.31 | 0.760 |
| Burn | 266.3 | 40.74 | 3.19 | 0.003 | 1.60 | 0.136 |
| Thin | 288.0 | 35.09 | 2.72 | 0.010 | 1.16 | 0.268 |
| Thin/burn | 220.0 | 29.02 | 4.19 | 0.002 | 2.53 | 0.026 |

Table 3.4  Post-treatment basal area of FFSS plots and results of t-tests between FFSS basal area and basal area surrounding red bat roost trees ($18.8 \pm 0.99$ m$^2$/ha, n = 28) and pipistrelle roost trees ($22.8 \pm 1.11$ m$^2$/ha, n = 7).

| Treatment | Mean | Std. error | Red bat Test stat. | Red bat P-value | Pipistrelle Test stat. | Pipistrelle P-value |
|---|---|---|---|---|---|---|
| Control | 28.3 | 1.33 | 2.84 | 0.008 | 1.46 | 0.169 |
| Burn | 18.6 | 1.79 | 0.08 | 0.934 | 1.73 | 0.109 |
| Thin | 21.3 | 3.58 | 1.03 | 0.309 | 0.64 | 0.534 |
| Thin/burn | 16.7 | 1.89 | 0.87 | 0.391 | 2.50 | 0.028 |

dominated stands. Thus, the FFSS plots may provide more habitat for pipistrelles than red bats.

## Discussion

Red bats on and around the CEF roosted in the canopies of large diameter live hickories, yellow-poplar, and oaks located primarily in mature hardwood-dominated stands. Within stands, they selected areas with lower tree density. Pipistrelles primarily roosted in live hardwood trees with various diameters in either hardwood- or pine-dominated stands. They selected trees within a stand that were surrounded by a tall overstory and midstory and contained large diameter trees. In contrast, FFSS treatment plots primarily contained loblolly and shortleaf pine stands with small hardwood inclusions. None of the stands within the FFSS treatment plots had been recently thinned before the study, and thus, hardwoods had developed in the subcanopy, midstory, and understory layers in many of the stands.

Large diameter hardwoods found as roost trees for red bats on and around the CEF were similar to those reported in other geographic areas of the U.S. (Menzel et al. 1998, Hutchinson and Lacki 2000a, Mager and Nelson 2001, Limpert and Birch 2003, Thill and Perry 2003, Welch 2003). Further, red bats on and the around the CEF used a number of trees primarily within a small area. Since large hardwoods were not common in the pine stands of the FFSS treatment plots, these treatments sites probably do not provide adequate densities of suitable tree habitat for red bats. In contrast, pipistrelles used both small and large diameter hardwood trees on and around the CEF, which is consistent with previous reports in other geographic areas of the U.S. (Carter et al. 1999, Kurta et al. 1999, Menzel et al. 1999, Veilleux et al. 2003). The FFSS treatment plots

provided more suitable tree roosting habitat for pipistrelles since they contained an abundance of smaller diameter hardwoods. Further, red bats on and around the CEF primarily used mature hardwood-dominated stands, whereas pipistrelles used both hardwood- and pine-dominated stands. Since FFSS treatments were predominately located in pine-dominated stands, these treatments are probably more suitable for pipistrelles than red bats. These results suggest that pine stands throughout the Piedmont and possibly in other geographic landscapes of the U.S. comparable to the CEF may provide more tree roosting habitat for pipistrelles than red bats.

I predicted that since the microhabitat surrounding red bat roost trees on and around the CEF contained fewer trees, their microhabitat would compare to sites that have reduced obstacles and clutter such as the 3 fuel reduction treatments (burn, thin, and thin/burn). However, the tree density of the burn, thin, and thin/burn treatments had significantly fewer trees than red bat microhabitats, whereas the tree densities in control plots did not differ. The basal area of the control sites were significantly higher than red bat roost microhabitats, whereas there was no difference between the other 3 treatments and red bat roost microhabitats. Since tree density was the most important variable predicting red bat roosting presence for this study and for adult red bats in eastern Kentucky (Hutchinson and Lacki 2002a), red bats may be selecting particular areas based solely on the tree density of the surrounding habitat. Studies have documented higher red bat activity in stands that were previously thinned or opened with gaps (Menzel et al. 2002, Tibbels and Kurta 2003), however these studies determined foraging activity and not roosting behavior. While red bats prefer areas with a lower tree density, the densities in the burn, thin, and thin/burn treatments may be too low for reproductive female red bat

roosting. However, tree mortality from Southern pine beetle infestations may have additionally reduced stand densities in FFSS treatment sites.

Although most red bats used trees in contiguous forests, there appears to be variation in their roosting behavior. One post-lactating red bat was tracked to 2 trees in unusual habitats. The first was located in a black walnut tree (*Juglans nigra*) in a horse pasture, and the second was located in a white oak (*Q. alba*) in a private residence's yard. Both of these trees were located in rather open habitats compared to all other red bat roosts which were in more contiguous forests. Since both microhabitats surrounding the roost trees contain relatively few overstory and midstory trees and no vegetation in the understory layer other than grasses, they appear to compare structurely to a stand that has been recently thinned and burned. While these were the only observations, it suggests that post-lactating red bats may use habitats that structurely compare to habitats resulting from thin/burn treatments.

Since pipistrelles on and around the CEF preferred areas with a higher basal area, I predicted that the pipistrelle microhabitat would be more similar to the control plots since these sites should have higher basal areas. The stand density and basal area surrounding pipistrelle roost trees were similar to control, burn, and thin treatments. However, the thin/burn treatment had a significantly lower stand density and basal than pipistrelle roost microhabitats. This difference may have resulted from increased tree mortality due to a combination of prescribed burning, thinning, and/or Southern pine beetle infestation. These results suggest that thinning or burning as well as no treatment probably do not negatively affect pipistrelle roosting behavior. A study in Michigan found more pipistrelle activity in red pine stands with openings than stands without

openings (Tibbels and Kurta 2003). However, pipistrelle activity and foraging in the coastal plain of South Carolina were not different between harvested and undisturbed forests (Menzel et al. 2002). Pipistrelles have been hypothesized to use complex or open forest structures for foraging (Fenton 1990). However, reproductive females, particularly those that are pregnant, must carry the additional weight of their young and thus have a higher wing loading which causes decreased maneuverability (Norberg and Rayner 1987, Hayssen and Kunz 1996). Thus, these treatments may have a positive effect by reducing forest structure to create more open habitat for easier navigation to access roosting habitat. Further, pipistrelles appear to use stands with larger trees surrounding their roost trees regardless of stand type or management. Thus it appears they may use mature pine stands comparable to those in Block 3 which contained sawtimber-sized trees. However, only 4 pipistrelles were radiotracked and further research should be conducted to determine the effects of FFSS treatments in pine dominated forests on pipistrelle roosting behavior.

The CEF is a managed forest and regular silvicultural practices are conducted; however no radiotracked bats in this study used recently burned, thinned, or thinned/burned stands. Areas which have been recently burned and/or thinned usually lack a developed understory layer and may be the reason why bats are not using these areas, since this layer can provide protective cover from the environment and ground predators. Thus, these treatments may initially reduce understory levels too low for suitable roosting. However, 1-2 years after treatment, when the understory layer is more developed, the FFSS treatment plots may provide suitable roosting habitat.

## Summary and Conclusions

Reproductive female red bats roosted in large diameter hardwoods and did not roost in pine trees or pine-dominated stands. Since few large hardwoods are found in the pine-dominated FFSS treatments, these stands probably do not provide suitable roost tree habitat. Further, the 3 fuel reduction treatments appear to reduce tree density and basal below optimal red bat roosting levels. However, 1 post-lactating red bat was tracked to 2 roost trees whose surrounding microhabitat would compare structurally to thin/burn areas. Overall the FFSS treatment sites probably do not provide roosting habitat for red bats.

Reproductive female pipistrelles roosted in hardwood trees in hardwood-dominated stands and mature pine-dominated stands, and would be more likely to roost in FFSS treatment plots since more suitable trees were available. Stand density and basal area of the microhabitat surrounding pipistrelle roost trees was comparable to control, burn, and thin treatments. However, thin/burn treatments had a significantly lower basal area and stand density than pipistrelle microhabitat which may have been a result of the treatments or tree mortality from Southern pine beetle infestation. Thus burn, thin, and control treatments appear to provide suitable roosting habitat for pipistrelles. However, since only a few pipistrelles were radiotracked, further research is required to determine the actual effects of fuel reduction treatments on pipistrelle roosting behavior.

CHAPTER 4

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

My research objectives were to: 1) determine the maternal roosting ecology and behavior of eastern red bats (*Lasiurus borealis*) and eastern pipistrelles (*Pipistrellus subflavus*) in the southeastern Piedmont (Chapter 2), and 2) make inferences on how Fire and Fire Surrogate Study (FFSS) fuel reduction treatments can affect habitat for these bats species (Chapter 3).

Reproductive female eastern red bats roosted within live foliage of a variety of hardwood tree species. They mainly used large diameter hickories (*Carya* spp.), yellow-poplar (*Liriodendron tulipifera*), and several species of oaks (*Quercus* spp.). However they showed selection for hickories, which may have been a result of past management practices that prevented hickory regeneration. Red bats roosted in the larger diameter trees (> 30 cm dbh) and avoided smaller trees (10.2 – 19.9 cm dbh) in a stand. The microhabitats surrounding their roosts had a lower density of trees which was the most important microhabitat variable predicting their presence. Because red bats are predicted to be less maneuverable than smaller bats, they may prefer areas with less mechanical and acoustical clutter. They primarily used mature hardwood-dominated stands that have not been recently disturbed by management activities.

Since reproductive female red bats mainly used mature hardwood-dominated stands, a major threat to their roosting habitat throughout the Piedmont is the conversion of hardwood stands to planted pine (*Pinus* spp.) stands. Thus, tracts of mature, undisturbed hardwood stands should be conserved for maternal red bat roosting habitat in

the Piedmont. Mid-rotation forest management practices, such as thinning of hardwood stands, may benefit reproductive female red bats by providing fewer trees within a stand. Suitable trees (e.g. larger diameter hickories, yellow-poplar, and oaks) should be retained. Single tree selection harvests may also favor their roosting by creating openings throughout the stand. Further, shelterwood harvests that retain groups of large diameter hardwoods may be beneficial to red bat maternal roosting since red bats roosted in larger diameter trees located within a small area (approx. 0.35 ha) of a stand.

Red bats showed higher roost fidelity earlier in the maternity season than later. This may be due to increased energetics involved in raising young and carrying them to new roosts. Thus, these bats may be less likely to move to a new roost during a disturbance. Forest management practices conducted in the Piedmont during the early part of the maternity season (May through mid-July) may negatively affect red bat reproductive success. Future research should determine their behavior and reproductive success during localized disturbances to their roost trees in this early part of the maternity season.

Pipistrelles roosted within live foliage and clusters of dead leaves primarily in oaks in hardwood- and pine-dominated stands. The microhabitats surrounding pipistrelle roosts had a tall overstory and midstory, and contained larger diameter trees than non-used sites. While only a few pipistrelles were tracked, my results suggest that pipistrelles are generalists and will use a variety of stand types (pine or hardwood) as long as they contain oaks in the overstory or midstory.

Pipistrelles used stands which contained large diameter trees. Thus, conservation of tracts of forest containing larger diameter trees would probably be beneficial for their

maternal roosting. Like red bat roosts, pipistrelle roost trees were located in a small area of the stand. Thus, forest management practices, such as shelterwood harvests, which retain groups of large diameter hardwoods may also be beneficial for pipistrelle maternal roosting.

Since red bats used mature hardwood stands, the FFSS sites probably do not provide suitable habitat since they are predominately pine stands. In contrast, the FFSS sites might provide more suitable habitat for pipistrelles since they used both hardwood- and pine-dominated stands. Further, the pine-dominated stands of the FFSS treatments provided a number of potentially suitable roost trees for pipistrelles since they contained many hardwoods 10-20 cm but few hardwoods > 20 cm. The stand densities and basal areas in the control, burn, and thin sites were comparable to microhabitats surrounding pipistrelle roosts, whereas the 3 fuel reduction treatments (burn, thin, and thin/burn) were not comparable to the microhabitats surrounding red bats roosts. Burn and thin treatments may create more suitable pipistrelle roosting habitat by reducing the number of obstacles and associated clutter. However, thin/burn treatments may be reducing overstory basal areas and tree densities too low for pipistrelle roosting. These results suggest that pipistrelles are probably more likely to roost in the FFSS sites than red bats.

Future research should be directed to determine the extent of pipistrelle roosting in pine-dominated stands on the CEF and to test if FFSS treatments can create suitable roosting habitat. Also, the roosting ecology and behavior of both sexes and ages classes should be determined since variation may occur between them.

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