

MOVEMENTS, FORAGING AREAS, HABITAT SELECTION, AND ROOST SITE  
SELECTION OF RED BATS IN AN INTENSIVELY MANAGED  
PINE FOREST IN MISSISSIPPI

By

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Little is known of red bat (*Lasiurus borealis*) ecology within forests intensively managed for pine (*Pinus* spp.) production. I radiomarked 46 red bats June - September 2000 and May - July 2001 to examine movements, foraging areas, habitat selection, and day roosts of red bats within a managed pine forest in Mississippi. Overall, mean minimum distance traveled from roost sites to foraging locations was 101.38  $\pm$  18.70 m, whereas mean maximum distance was 1,259.84  $\pm$  204.09 m. Red bats switched roosts every 1.2 days, moving 95.39  $\pm$  13.03 m between roosts. Foraging areas ( $\bar{A} = 94.41 \pm 20.16$  ha) were considerably smaller than others have reported. Radiomarked bats did not select habitat within the study area ( $P = 0.743$ ) nor within their home ranges ( $P = 0.954$ ). Red bats roosted in 16 species of hardwoods (70% of roosts) and loblolly pine (*Pinus taeda*; 30% of roosts). Unlike other studies in the southeastern United States, red bats in this area roosted routinely in pine trees and midstory hardwoods. This indicates roost site requirements by red bats may exhibit greater plasticity than previously thought.

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## CHAPTER I

### INTRODUCTION

#### **Literature Review**

Research on population biology and species-habitat relationships of insectivorous bats has been limited because bats are secretive, nocturnal, and small (Barclay and Bell 1988). Most information from initial studies of bat ecology was provided through direct observation (Constantine 1958, Constantine 1966) or by implementing marking techniques borrowed from studies of other species (e.g., bird leg bands used as wing bands; Barclay and Bell 1988 ). Wing bands, ultrasonic detectors, light tags, or combinations of these techniques have been used to document roost sites, habitat use, or movements (Burford and Lacki 1995).

Until recently, radiotelemetry studies of smaller bats were not feasible due to weight limitations of radiotransmitters (Aldridge and Brigham 1988). However, development of miniaturized radiotransmitters has allowed collection of more detailed information on roost selection, habitat use, foraging areas, and movement patterns of individual bats as compared with previously available equipment and techniques (Bradbury et al. 1979). Technological advances have facilitated the means to expand our knowledge of bats and enabled us to acquire more detailed and complete information.

Because roost sites are vital components of bat ecology, this topic has been studied intensively (Fenton 1997). Historically, research in bat roosting ecology focused on species associated with caves or man-made structures (Kunz 1982, Barclay et al. 1988). Species found in these types of roosts are more likely to be colonial (Gaisler 1979) and vulnerable to disturbance from man (Barbour and Davis 1969, Clark et al. 1993).

Endangered bat species and their roost preferences have been studied extensively. Kurta et al. (1993) and Callahan et al. (1997) documented small maternity colonies of Indiana bats (*Myotis sodalis*) that predominantly roosted under the bark of decaying hardwoods and in hardwood snags in Michigan and Missouri, respectively. Sherwin et al. (2000) found that colonies of Townsend's big-eared bats (*Corynorhinus townsendii*) in Utah were more likely to roost in caves or mines with low (<1.5 m in height) entrances and preferred roosting in caves to mines. Humphrey and Kunz (1976) discovered thermal insulation capabilities of roosts determined if a site was suitable for Townsend's big-eared bats. Similarly, Lacki et al. (1994) proposed thermal warming may be an important roost site selection factor for Virginia big-eared bats (*C. t. virginianus*).

Only recently has much attention been given to bat ecology in managed forests, with the bulk of this focusing on the Pacific Northwest and Canada. Campbell et al. (1996) documented roost use by silver-haired bats (*Lasionycteris noctivagans*) in coniferous forests of Washington. Bats roosted <3.5 km from their capture sites in decaying trees with cracks and crevices. Vonhof (1996) investigated roost sites of silver-

haired bats and big brown bats (*Eptesicus fuscus*) in British Columbia. He found both species roosted in large decaying hardwoods, preferably trembling aspen (*Populus tremuloides*). The only detectable difference between the 2 species= roosting sites was silver-haired bats= tendency to roost farther below mean canopy height. Vonhof and Barclay (1996) documented the first occurrence of western long-eared bats (*Myotis evotis*) roosting in tree stumps left in clearcuts of British Columbia.

Foraging behavior of endangered bat species has been investigated in an attempt to provide and manage for activity areas used. Clark et al. (1993) found Ozark big-eared bats (*C. t. ingens*) in Oklahoma selectively foraged in wooded edge habitats of streams. Dobkin et al. (1995a) in Oregon documented Townsend=s big-eared bats used open, forested, and edge habitats, likely in proportion to insect availability. Similarly, Wethington et al. (1996) found Ozark big-eared bats use habitat in response to insect abundance.

Bat activity within managed forests has been documented using bat detectors. Grindal and Brigham (1999) discovered edge habitat was an important foraging habitat for bat species in fragmented forests of British Columbia. Jung et al. (1999) monitored bat activity in a predominantly coniferous area adjacent to a managed forest in central Ontario. They found activity of multiple bat species to be 2.7 - 14.0 times greater in old-growth forest than mixed woods, mature stands, and selectively logged pine stands. Erickson and West (1996) investigated habitat use of bats in the Cascade mountains of Washington using Anabat II bat detectors; most detections were recorded in mature (50 -

70 year old) stands. Thomas (1988) found bat activity in the Cascade mountains of Washington and the Oregon Coast Range to be greater in old-growth forests (>200 years old) than in mature (100 - 165 years old) or young stands (<75 years old). Using bat detectors, Hayes and Adam (1996) found bat activity to be 4.1 - 7.7 times greater in forested stands than in nearby logged areas of managed forests in Oregon. Humes et al. (1999) recorded greater bat activity in old-growth (≥200 years old) and thinned stands (50 - 100 years old) than in unthinned stands (50 - 100 years old) in Oregon.

Because roosting and foraging requirements of bats influence habitat selection (Fenton 1990), it is important to examine roost sites in conjunction with foraging areas to gain a more complete understanding of bat community ecology. Brigham (1991) simultaneously explored roosting and foraging behavior. He found that although bats should choose roosts near their foraging areas to reduce energy expenses (Kunz 1982), big brown bats in British Columbia, routinely foraged ∓4 km from roost sites. Crampton and Barclay (1998) examined roost selection and foraging habitats of little brown bats (*Myotis lucifugus*), northern long-eared bats (*Myotis septentrionalis*), hoary bats (*Lasiurus cinereus*), and silver-haired bats to assess impacts of timber harvests on bats in Alberta. They found bats preferentially foraged in old stands and roosted in tall decaying trees. Dobkin et al. (1995a) monitored movements, roost use, and foraging activity of Townsend=s big-eared bat in Oregon and found little roost fidelity. They concluded that foraging areas were more likely a function of prey abundance than roost site location. Grindal (1999) reported forested edge habitats create corridors thereby facilitating access

to roosts. Hurst and Lacki (1999) discovered that Rafinesque's big-eared bats (*C. rafinesquii*) in Kentucky foraged close to roost sites in oak (*Quercus* spp.) and oak-hickory stands (*Quercus-Carya*). Leonard and Fenton (1983) investigated roosting and foraging behavior of spotted bats (*Euderma maculatum*). *E. maculatum* roosted on cliff faces and preferentially foraged in open areas encompassed by ponderosa pine (*P. ponderosa*). Waldien and Hayes (2001) found activity areas of long-eared myotis in Oregon included a water source but not their respective day roosts. Based on guano surveys, Zielinski and Gellman (1999) compared bat activity in unfragmented old-growth redwood forests with activity in fragmented, commercial, old-growth redwood (*Sequoia sempervirens*) forests in California. The authors reported bats roosted in fragmented old-growth forests more often but foraged equally in both sites.

The red bat (*Lasiurus borealis*) is one of the most common and widely distributed bat species in North America (Barbour and Davis 1969, Shump and Shump 1982, Wilson and Ruff 1999). Still, until 1998, roosting information on this species was limited to anecdotal accounts (Constantine 1958, Constantine 1966). Red bats typically roost in the outer branches of live trees where they hang concealed among foliage (Barbour and Davis 1969, Shump and Shump 1982, Sealander and Heidt 1990). The red bat is generally a solitary roosting species, although females are routinely found roosting with their young (Shump and Shump 1982, Sealander and Heidt 1990, Wilson and Ruff 1999).

Menzel et al. (1998, 2000) documented preferential use of large diameter deciduous species by red bats in Georgia and South Carolina. *L. borealis* also were found

to prefer live hardwood roosts in mature upland forests of Kentucky (Hutchinson and Lacki 2000). Mager and Nelson (2001) documented red bat roost use in an urban area of Illinois. Although red bats were found roosting in roof shingles, leaf litter, and grass, most red bats (89%) were found roosting in or on large deciduous trees.

As stated above, previous research suggested red bats favor large deciduous trees in Georgia and South Carolina (Menzel et al. 1998, Menzel et al. 2000), Kentucky (Hutchinson and Lacki 2000), and Illinois (Mager and Nelson 2001). However, red bats composed >60% of bat captures in mist-net surveys (Miller 2003) conducted in intensively managed loblolly (*Pinus taeda*) pine plantations in Mississippi. Therefore, the role intensively managed pine plantations play in the annual cycle of bats is crucial to developing and incorporating management options. I used the red bat to begin examining these species-habitat relationships.

Pine plantations are quickly becoming a major habitat type throughout the Southeast. Total area of pine plantations is expected to reach 18.6 million ha by 2030, more than double the area occupied by pine plantations in 1985 (Allen et al. 1996). Loblolly pine, the primary commercially planted pine species, is native to the Southeast and not without habitat value if managed appropriately (Allen et al. 1996).

Forest fragments and edge habitat resulting from timber harvest have been documented as important foraging sites for many bat species (e.g., *L. borealis* [Furlonger et al. 1987], *L. cinereus* [Furlonger et al. 1987, Grindal and Brigham 1999], *Myotis* spp. [Furlonger et al. 1987, Brigham et al. 1992, Crampton and Barclay 1998, Grindal and

Brigham 1999], *C. townsendii ingens* [Clark et al. 1993], *C. townsendii* [Dobkin et al. 1995a, Erickson and West 1996], and *L. noctivagans* [Erickson and West 1996, Hayes and Adam 1996, Crampton and Barclay 1998, Grindal and Brigham 1999, Jung et al. 1999]). However, timber harvest leads to a loss of older trees and stands that may provide foraging areas (Erickson and West 1996, Hayes and Adam 1996) and roost sites for certain species of bats. Research is needed to determine how best to manage for roosts and foraging habitats of bats in industrial forests of the Southeast.

### **Study Area**

My study was conducted on approximately 24,000 ha of mostly contiguous land, owned and managed by Weyerhaeuser Company for the production of pine sawtimber, in Kemper County, Mississippi. This area in east-central Mississippi (Figure 1.1) was dominated (>70 %) by intensively managed stands of loblolly pine, although mixed pine-hardwood (MPH) stands, streamside management zones (SMZ), and permanent food plots were present. My study site (32<sup>N</sup>49'N, 88<sup>N</sup>30'W) was located roughly 6 km southwest of Scooba, Mississippi and 48 kilometers north-northeast of Meridian, Mississippi. Average temperatures for summers of 2000 (June, July, August, and September) and 2001 (May, June, and July) were 26.6 and 24.6<sup>N</sup> C, respectively. Average monthly precipitation for summers of 2000 and 2001 was 2.64 and 4.63 cm, respectively (National Oceanic and Atmospheric Administration, [www.srh.noaa.gov](http://www.srh.noaa.gov)). I defined my study site (approximately 4,000 ha) as the area encompassing all foraging

locations by radiomarked red bats, all roost trees used by radiomarked red bats, and all sampled random trees, with a 100 m buffer around the entire area (Figure 1.1).

I classified stands within my study site, including those under private ownership using ground-truthing, with a Geographic Information System (GIS) developed by Weyerhaeuser Company, and information from Weyerhaeuser foresters. I characterized 5 habitat types within my study area based on stand type and thinning history. They included: (1) young, open stands (approximately 0 B 8 year old pine plantations with open canopies), (2) closed canopy stands (approximately 9 B 15 year old pre-thinned pine plantations with closed canopies), (3) thinned (approximately 13 - 37 year old post-thinned pine plantations with open canopies), (4) mixed pine-hardwood (150 ha stand of private, unmanaged forest with closed canopy; approximately 10-15 years old), and (5) streamside management zones (SMZ) that include pines and hardwoods #80 years old.

### **Objectives and Hypotheses**

Within a forested landscape intensively managed for production of loblolly pine, my objectives included:

- 1.) Documenting movement patterns of red bats;
- 2.) Estimating foraging area of red bats;
- 3.) Determining habitat selection of red bats;
- 4.) Examining roost site selection of red bats;
- 5.) Developing roost selection models of red bats.

I achieved these objectives by testing the following hypotheses:

H<sub>01</sub>: There is no difference in minimum and maximum distances moved from day roost sites to foraging locations with respect to bat classes (i.e., male/female, juvenile/adult) or seasons (i.e., month/year).

H<sub>02</sub>: There is no difference in distances traveled between successive roost sites with respect to bat classes or seasons.

H<sub>03</sub>: There is no difference in maximum distance traveled among roost sites with respect to bat classes or seasons.

H<sub>04</sub>: There is no difference in minimum distance traveled among roost sites with respect to bat classes or seasons.

H<sub>05</sub>: There is no difference in foraging area size with respect to bat classes or seasons.

H<sub>06</sub>: There is no difference in habitat variables (e.g., canopy closure, species diversity, basal area) of roost trees and random trees with respect to all bats, bat classes, or seasons.

H<sub>07</sub>: Species of roost trees are used similar to availability.

## **General Methods**

### *Capture and Marking Techniques*

I captured bats over water at 4 separate sites using 4-tier mist nets during June - September 2000 and May - August 2001. I set nets at 1 or 2 sites during any given

session, which I define as a period of consecutive trapping (i.e., netting) nights. Mist-netting was conducted for #4 consecutive nights, or until a maximum of 10 red bats had been radiomarked. I recorded species, gender, age, weight (g), forearm length (cm), and reproductive status (e.g., scrotal, lactating, non-lactating) of all captured bats (Racey 1988). I classified bats as adults or juveniles by shining a light through the wing membrane and observing degree of fusion of the finger joints (Anthony 1988). I used a Pesola<sup>7</sup> spring scale to weigh bats and a standard ruler to measure forearm length. All red bats weighing  $\geq 8$  g received a 0.47 - 0.54g LB-2 radiotransmitter (Holohil Systems Limited, Ontario, Canada; battery life = 14 - 28 days). Mean radiotransmitter load was 4.66% (range = 3 - 6.75%) of the body mass of radiomarked bats as suggested by Aldridge and Brigham (1988). I trimmed the fur between the scapulae prior to radiotransmitter attachment with Skin-bond<sup>7</sup> surgical cement (Smith and Nephew United, Largo, Florida, USA). This project was conducted under the auspices of the Mississippi State University Institutional Animal Care and Use Committee protocol number 00-038.

### *Radiotelemetry*

I established radiotelemetry stations ( $n = 165$ ) throughout the study area, generally separated by approximately 350 meters. Stations were individually numbered and flagged. I recorded universal transverse mercator (UTM) coordinates using a Trimble GeoExplorer II (Trimble Navigation, Limited 1996) global positioning system (GPS). I used Wildlife Materials TRX-2000S radio receivers (Wildlife Materials, Inc.,

Carbondale, Illinois, USA) within the 148.000-149.999 MHZ frequency range and 3-element Yagi antennas to obtain locations of radiomarked bats.

In general, I began nocturnal tracking of radiomarked bats the evening after transmitter application and continued for approximately 10 nights or until the transmitter could no longer be heard. The exception to this was the tracking period in June 2000, September 2000, and July 2001. Equipment problems in June 2000 postponed nocturnal radiotelemetry for 8 days. Red bats tagged in September 2000 were thought to be transient or migratory because none remained in the area for more than 4 nights, thereby precluding radiotelemetry data collection. Other equipment problems in July 2001 limited my radiotelemetry session to #5 nights. I did not monitor bats during the night of their capture to avoid recording unusual movements. I located bats from one-half hour before sunset until they roosted the following morning. Two or 3 observers stayed in contact via 2-way radios and simultaneously recorded azimuths from nearby radiotelemetry stations and attempted to triangulate each radiomarked bat every 15 minutes.

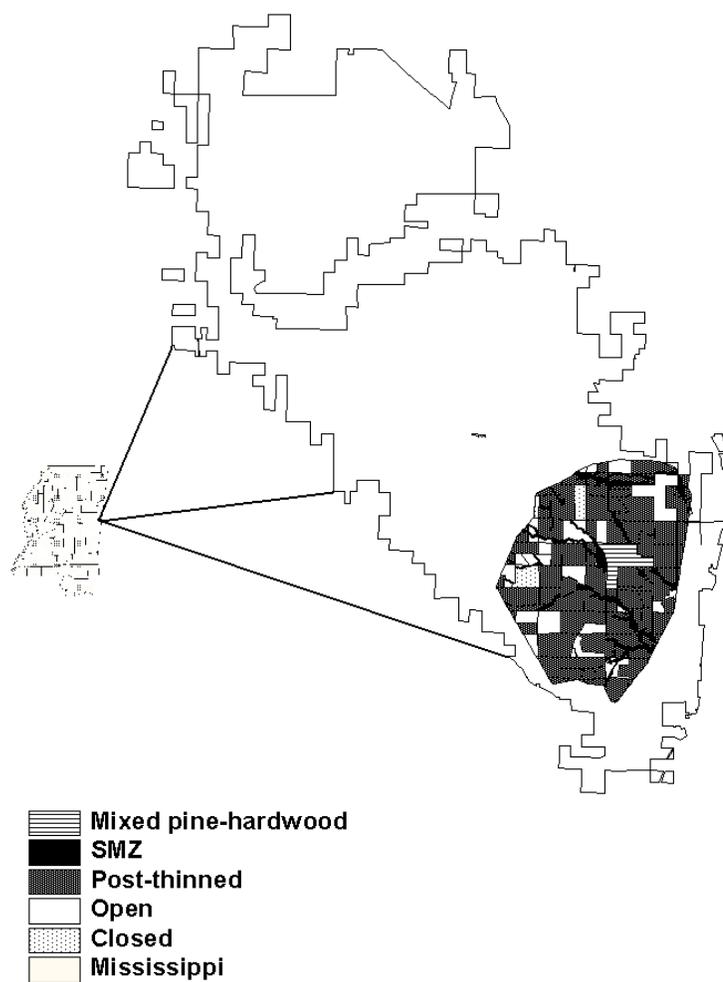
### *Vegetation Sampling*

Each day following radiotelemetry, I flagged day roosts of all monitored bats for future habitat sampling. If possible, I determined aspect and height of the roosting bat using strongest signal strength of the radiotransmitter. For each roost tree located, I selected a random tree. I located random trees by pacing a random distance and direction

from a random radiotelemetry station in the study area. I recorded species, diameter at breast height (DBH, cm), percentage canopy closure (at 2 and 10 m from the roost or random tree), distance to nearest forested edge (m), and distance to nearest water source (m) for each roost and random tree.

Roost and random trees (i.e., center trees) served as the center of 2 nested circular plots. I established midstory plots of 0.004 ha (radius = 3.5 m) and overstory plots of 0.04 ha (radius = 11.35 m) around each roost or random tree. I recorded species and DBH for all shrubs 3 - 10 cm DBH within the midstory plot and all trees  $\geq$ 10 cm DBH within the overstory plot. I estimated total, pine, and hardwood basal areas ( $\text{m}^2/\text{ha}$ ; Wenger 1984), stems/ha, and species diversity using Shannon's Diversity Index (Ludwig and Reynolds 1988) within midstory and overstory plots.

Figure 1.1 Location of study area and study site (shown with defined habitat types) in Kemper County, Mississippi, 2000-2001.



## CHAPTER II

### MOVEMENTS, FORAGING AREAS, AND HABITAT SELECTION

#### **Introduction**

Many techniques, such as light tags, ultrasonic bat detectors, and radiotransmitters have been used to determine movements, foraging areas, and habitat selection by bats. Light tags are gelatin pill capsules filled with a luminescent chemical (e.g., Cyalume; Buchler 1976). While light tags are inexpensive and lightweight, investigators have reported bats dying from biting capsules and ingesting the contents (LaVal et al. 1977). Ultrasonic bat detectors, which record bat echolocation calls, often are used because they are noninvasive (Fullard 1989), requiring no handling or manipulation of the animal. This is an especially useful technique when working with very small (i.e., <8 g) or endangered species or when interest is limited to detecting presence or absence of bats. However, when using ultrasonic bat detectors it is impossible to ascertain if calls are being made by many bats or one bat intensively using the habitat (O'Farrell et al. 1999) and adequacy of bat detectors to ascertain habitat selection has been questioned (Miller et al. 2003). Although radiotelemetry is manpower intensive and more intrusive than other procedures, this technique allows collection of detailed movement and behavior

information on individually marked bats over a longer period of time and comparisons between individuals to be made (Wilkinson and Bradbury 1988).

Intraspecific variation often exists between dissimilar landscapes. Furlonger et al. (1987) found red bats in southwest Ontario active over terrestrial habitats (e.g., fields and forests) significantly more than water habitats (e.g., ponds and streams). This differs from Hutchinson and Lacki (2000) who found red bats in forest-dominated areas of Kentucky foraged over water more than expected. In the White Mountain National Forest in New Hampshire, red bats were most active over water, but within forests, their activity did not differ between hardwood and softwood habitats (Krusic and Neefus 1996). Therefore, comparisons of red bats between different biogeographical regions may not be appropriate. No studies have investigated roost site selection, movements, foraging areas, or habitat selection of red bats in intensively managed pine forests in the Southeast.

## **Methods**

### *Radiotelemetry*

Beginning the evening after capture (see chapter 1 for capture details), I located radiomarked bats to document foraging area size and habitat selection. Radiotelemetry began 30 minutes before sunset, ended 30 minutes after sunrise, and continued for #10 consecutive nights or until the transmitter could no longer be heard. Loss of a transmitter signal can be caused by battery failure, transmitter damage, emigration of the bat out of the study area, or the transmitter being dropped by the bat. Two or 3 field personnel

equipped with TRX-2000S receivers, 3-element Yagi antennas, compasses, and 2-way radios recorded simultaneous azimuths on radiomarked bats from established radiotelemetry stations. I recorded bat activity (determined by fluctuating radiotransmitter signal strength) as an indication of whether the bat was foraging or night roosting, and signal strength (provides a weak approximation for the proximity of a bat because height above or below canopy and forest density also affect signal strength) for each bearing.

Because bearings were obtained at irregular intervals and were more easily and commonly recorded near the roosting areas of the bats, many bearings were discarded so that only bearings taken  $\geq 30$  minutes apart were included in analysis. The result is a more realistic view of how red bats foraged and what habitats they selected. Moreover, it helps meet the assumption of independence of successive locations (Swihart and Slade 1985, White and Garrot 1990).

### *Movements*

I measured distances between successive roosts of individual bats by creating a *Apolyline* from these point files using the *Movements* extension (Hooge and Eichenlaub 1997) in ArcView 3.2 (ESRI 2000). This not only generated successive distances bats moved between roosts, but also rendered minimum and maximum distances moved among roosts. I only calculated distances between roosts found on consecutive days (i.e., distances between 2 roosts used on non-consecutive days were not measured).

Using the bat as the experimental unit, I used a mixed model 2-way analysis of variance (ANOVA; PROC MIXED, SAS Institute 2001) to test the null hypotheses that (1) mean distance moved among successive roost sites does not differ among bat classes, (2) minimum distance moved between roost sites does not differ among bat classes, and (3) maximum distance moved between roost sites does not differ among bat classes. If these results were not significant, I tested for differences among seasons. These hypotheses were tested using gender, age, and season as independent variables and mean, minimum, and maximum distances moved between successive roosts as dependent variables.

The mixed model ANOVA (PROC MIXED, SAS Institute 2001) technique is robust enough to detect significant differences of nonparametric data. Therefore, I only tested my data for homogeneity of variance using Levene=s test (PROC GLM *options* = hovtest, SAS Institute 2001). Data with unequal variances were reciprocally transformed to meet homogeneity of variance assumptions (Zar 1974). Data that did not meet homogeneity of variance assumptions after transformation were analyzed using Kruskal-Wallis tests (PROC NPAR1WAY, SAS Institute 2001). All data were analyzed using SAS 8.0 (SAS Institute 2001). Data are presented as means  $\forall$  standard errors (SE). Significance level was set at  $P \neq 0.05$ .

For each tracking night, I generated minimum and maximum distances (m) from day roost sites to foraging locations for every radiotagged bat using the spider distance function of the XTools extension (DeLaune 2000) in ArcView 3.2 (ESRI 2000). I then

calculated a mean minimum distance for each individual by averaging minimum distances traveled each night. Likewise, mean maximum distance was calculated for each bat by averaging maximum distances traveled each night.

I used a mixed model 2-way ANOVA (PROC MIXED, SAS Institute 2001) to determine if differences existed among bat classes regarding mean minimum and mean maximum distances moved from roost sites to foraging sites. If these results were not significant, I tested for differences among seasons (i.e., month combined with corresponding year). Gender, age, and season were independent variables; mean minimum distances and mean maximum distances traveled from roosts to foraging sites were dependent variables; the bat was the experimental unit.

#### *Estimation of Foraging Areas*

I used program Locate II (Nams 2000) to generate UTM coordinates of bat locations using 2-3 bearings taken from radiotelemetry stations with known UTM coordinates. I imported location coordinates for each bat into ArcView 3.2 (ESRI 2000) and generated home ranges using the 95% adaptive kernel estimator within the Animal Movement extension (Hooge and Eichenlaub 1997). The adaptive kernel technique generates areas of use based upon number of locational crosses found in these given areas. I used the adaptive kernel method (Worton 1989) because it is a nonparametric technique that is less affected by fewer observations than are other techniques (Hansteen et al. 1997). Home range estimation of mammals is often feasible using 20 - 40 independent radiotelemetry locations (Hawes 1977, Seaman et al. 1999). Except for one

bat, only bats ( $n = 17$ ) with  $\geq 30$  locations were included in this analysis; bat # 046 only had 24 locations, but was included because so few juvenile females were captured. This number of locations is similar to what other bat studies have used in the Southeast (e.g., Adam et al. 1994, Menzel et al. 2001).

With the bat as the experimental unit, I tested the null hypothesis that no difference in foraging area existed among bat classes. If these results were not significant, I tested for differences among seasons. These hypotheses were tested with a mixed model 2-way ANOVA (PROC MIXED, SAS Institute 2001) with gender, age, and month as independent variables and foraging areas as the dependent variable.

### *Habitat Analysis*

Allredge and Ratti (1986) suggested limiting number of habitat types included in habitat analyses to reduce likelihood of Type II errors (failing to detect existing differences). Similarly, if many habitat types are included, this will result in smaller individual habitats (Aebischer et al. 1993). This makes defining habitat availability more difficult. Therefore, only 5 habitats were designated (see Chapter 1).

Timber harvest resulted in landscape changes within and between years. Consequently, 4 Asnapshots@ were designated (Table 2.1) by creating 4 coverages. Bat foraging areas were overlaid on their respective coverage in ArcView 3.2 (ESRI 2000), depending upon when they were tracked.

I used Euclidean distances (Conner and Plowman 2001) to investigate habitat selection of radiomarked red bats. Euclidean distances, like compositional analysis (Aebischer et al. 1993), uses the animal as the sampling unit. Similar to Johnson=s

(1980) third-order habitat selection model, when investigating habitat selection within an animal's foraging area, animal locations represent habitat use and each foraging area represents available habitat.

The Euclidean distance procedure measures distances from an individual's ( $i$ ) estimated locations and generated random points to the nearest representative of each habitat type within the foraging area and study area; a distance value of zero was applied to habitats in which locations were found (Conner and Plowman 2001). If habitats are used at random, then average distances between an animal's locations and its associated habitats ( $A_i$ ) should be equal to average distances between random locations for the  $i$ th animal and their associated habitats ( $R_i$ ). If habitats are used more than expected, then the ratio of  $A_i : R_i$  will be  $<1$ . Likewise, if habitats are used less than expected, then the ratio of  $A_i : R_i$  will be  $>1$ . An average  $A_i : R_i$  (hereafter defined as  $d_i$ ) was generated for each bat. All  $d_i$ s were averaged to yield a mean vector ( $\bar{d}$ ). Using multivariate analysis of variance (MANOVA), I tested for differences between  $\bar{d}$  and a vector of 1s.

Previous habitat analysis methods (Aebischer et al. 1993, Neu et al. 1974) have investigated occurrence of animal locations (habitat use) in different habitats and compared habitat use to habitat availability for animals. As the Euclidean distance approach measures distances and does not require the animal to be assigned to a particular habitat, it is robust to radiotelemetry error (Conner and Plowman 2001).

## Results

### *Movements*

I captured 163 individual bats, including 64 red bats (Figure 2.1), June-August 2000 and June-July 2001 in Kemper County, Mississippi. I attached radiotransmitters to 46 red bats (20 adult females, 11 adult males, 5 juvenile females, and 10 juvenile males).

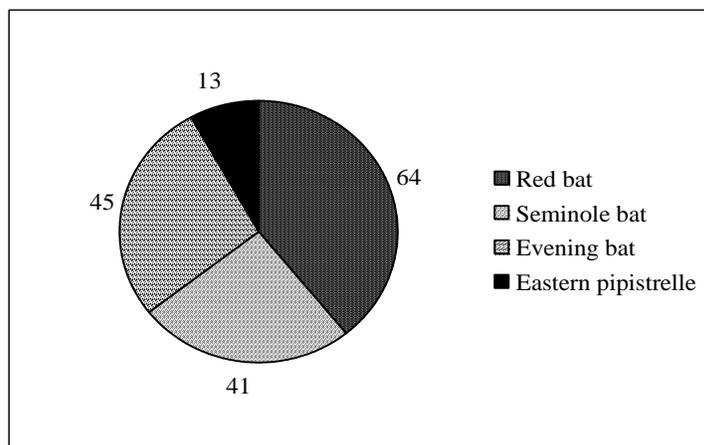
Investigating bats that used  $\geq 2$  roosts (one bat used only one roost and thus was not included in this analysis), I found that 140 roosts (including one roost tree that was not found during habitat sampling and therefore not included in other analyses) were used by 25 bats, including 9 adult females, 5 adult males, 5 juvenile females, and 6 juvenile males. Each bat used an average of 5.6 roosts (range 2 - 12 roosts), switching roost trees, on average, every 1.2 days (range 1 - 7 days). Red bats in the study area moved, on average,  $95.39 \pm 13.03$  m (range 1.80 - 1,037.22 m; Table 2.2) between successive roosts. Adults and juveniles did not differ regarding mean distances traveled between successive roosts ( $F_{1,21} = 0.02$ ,  $P = 0.88$ ), minimum distances traveled between successive roosts ( $F_{1,21} = 0.16$ ,  $P = 0.696$ ), or maximum distances traveled between successive roosts ( $F_{1,21} = 0.31$ ,  $P = 0.583$ ). Males and females did not differ regarding mean distances traveled between successive roosts ( $F_{1,21} = 0.76$ ,  $P = 0.393$ ), minimum distances traveled between successive roosts ( $F_{1,21} = 2.46$ ,  $P = 0.132$ ), or maximum distances traveled between successive roosts ( $F_{1,21} = 2.51$ ,  $P = 0.128$ ). There was no age

by gender

interaction effect

regarding mean

distances traveled



between successive roosts ( $F_{1, 21} = 0.43$ ,  $P = 0.518$ ), minimum distances traveled between successive roosts ( $F_{1, 21} = 0.07$ ,  $P = 0.793$ ), or maximum distances traveled between successive roosts ( $F_{1, 21} = 0.01$ ,  $P = 0.906$ ). Season did not affect mean distances traveled between successive roosts ( $F_{5, 19} = 0.78$ ,  $P = 0.577$ ), minimum distances traveled between successive roosts ( $\chi^2_5 = 2.13$ ,  $P = 0.831$ ), or maximum distances traveled between successive roosts ( $F_{5, 19} = 0.57$ ,  $P = 0.723$ ).

Overall, the mean minimum distance traveled from roost sites to foraging locations was  $101.38 \forall 18.70$  m, whereas the mean maximum distance was  $1,259.84 \forall 204.09$  m (Table 2.3). Adults ( $61.99 \forall 8.11$  m;  $n = 10$ ) moved significantly ( $F_{1, 14} = 5.80$ ,  $P = 0.03$ ) shorter minimum distances between roost sites and foraging locations than juveniles ( $150.63 \forall 34.37$  m;  $n = 8$ ). Differences between adults and juveniles were not detected ( $F_{1, 14} = 0.04$ ,  $P = 0.852$ ) for mean maximum distance traveled from roost sites to foraging locations. Males and females did not differ regarding mean minimum ( $F_{1, 14} = 0.41$ ,  $P = 0.531$ ) or mean maximum ( $F_{1, 14} = 0.03$ ,  $P = 0.867$ ) distances traveled between roost sites and foraging locations. There was no age by gender interaction effect regarding mean minimum ( $F_{1, 14} = 1.25$ ,  $P = 0.282$ ) or mean maximum ( $F_{1, 14} = 1.92$ ,  $P = 0.188$ ) distance traveled between roost sites to foraging locations. Season affected mean maximum distance traveled. Bats traveled farther ( $F_{4, 13} = 4.73$ ,  $P = 0.014$ ) from roost sites to foraging locations during June 2001 ( $2,250.38 \forall 397.11$  m) than they did during June 2000 ( $935.72 \forall 353.67$  m,  $P = 0.013$ ), July 2000 ( $491.84 \forall 170.63$  m,  $P = 0.002$ ),

August 2000 (799.02  $\forall$  114.74 m,  $P = 0.007$ ), and July 2001 (1,186.38  $\forall$  279.74 m,  $P = 0.025$ ). All other seasons were similar to one another ( $P \# 0.05$ ).

Radiomarked bats were often located  $>3$  km from their roost sites. Due to the short radiotransmitter range ( $<2$  km), lack of accessible roads in some parts of the study area, and the ability of red bats to travel quickly between areas, it is likely that distances between roost sites and foraging locations reported here are underestimates.

#### *Foraging Area Estimates*

Red bats included in foraging area analysis ( $n = 18$ ) had an average of 46.9 locations (range 24  $\exists$  128, Table 2.4) per bat. Average size of foraging areas was 94.41  $\forall$  20.16 ha (Table 2.4). Male foraging area size (94.23  $\forall$  26.73 ha,  $n = 8$ ) did not differ ( $F_{1,14} = 0.00$ ,  $P = 0.964$ ) from female foraging area size (94.55  $\forall$  30.62 ha,  $n = 10$ ). Adult foraging area size (101.64  $\forall$  28.87 ha,  $n = 10$ ) did not differ ( $F_{1,14} = 0.24$ ,  $P = 0.631$ ) from juvenile foraging area size (85.36  $\forall$  29.35 ha,  $n = 8$ ).

Adult females ( $n = 7$ ) had a mean foraging area of 82.28  $\forall$  31.72 ha. Adult males ( $n = 3$ ) had a mean foraging area of 146.83  $\forall$  63.23 ha. Juvenile females ( $n = 3$ ) had a mean foraging area of 123.18  $\forall$  80.22 ha. Juvenile males ( $n = 5$ ) had a mean foraging area of 62.67  $\forall$  11.72 ha (Table 2.4). No difference was detected among foraging areas regarding an age by gender interaction ( $F_{1,14} = 2.02$ ,  $P = 0.178$ ). June foraging area sizes ( $n = 8$ ) were 123.95  $\forall$  31.32 ha. July foraging area sizes ( $n = 7$ ) were 72.75  $\forall$  35.74 ha.

August foraging area sizes ( $n = 3$ ) were  $66.45 \pm 22.94$  ha. No differences were detected among foraging areas regarding month ( $F_{4,13} = 1.53, P = 0.252$ ).

Except for roost # 134 used by an adult female (# 010), bat roosts were located within their respective bats foraging areas. Foraging areas were composed of 1 - 7 distinct areas of activity. Foraging areas of red bats captured at the same site often overlapped.

### *Habitat Selection*

Stands were being harvested and thinned throughout the study. Usually, harvesting occurred in stands not being used by monitored bats. However, during one session, harvesting was taking place in the same area where I was tracking bats. This harvesting continued for approximately 4 days, resulting in a dynamic landscape. I excluded 2 adult female bats (#s 033 and 034) from habitat analyses as I could not ascertain what habitats were available in this stand. Therefore, 16 red bats (5 adult females, 3 adult males, 3 juvenile females, and 5 juvenile males) were included in habitat analyses.

Monitored red bats in Kemper County, Mississippi exhibited no preferences for particular habitats within foraging areas ( $F_{5,8} = 0.20, P = 0.954$ ). Males and females did not select habitat differently ( $F_{5,8} = 1.00, P = 0.476$ ) within foraging areas. Adults and juveniles did not select habitat differently ( $F_{5,8} = 0.07, P = 0.995$ ) within foraging areas.

No age by gender interaction for habitat selection within foraging areas was detected ( $F_{5,8} = 0.67, P = 0.66$ ). Overall, habitats within the study area were used randomly ( $F_{5,8} = 0.54, P = 0.743$ ). Habitat selection within the study area was not detected with regards to age ( $F_{5,8} = 0.57, P = 0.726$ ), gender ( $F_{5,8} = 0.49, P = 0.775$ ), or age by gender interaction ( $F_{5,8} = 0.63, P = 0.68$ ).

## Discussion

### *Movements*

No differences existed between males and females nor adults and juveniles regarding distances moved between successive roosts. This may be because juveniles roost with their mothers throughout most of the summer. As late as 12 August 2000, a juvenile male red bat (# 014) was found roosting very close, possibly even clinging to another bat (presumably, his mother). Because juvenile bats were seen frequently roosting with other bats (presumably, their mother and siblings), it is probable that distances moved between successive roosts for juveniles should closely match those of adult females.

Audit (1990) found juvenile mouse-eared bats (*Myotis myotis*) had a more direct path, albeit slower flight, back to the roost than adults. In my study, there was no

difference in mean maximum distances traveled between roost sites and foraging locations between adults and juveniles. However, adults traveled significantly shorter distances between roost sites and foraging locations than did juveniles. Kunz (1974) found newly weaned juvenile cave bats (*Myotis velifer*) had shorter foraging distances than adult females because the adults leave the roost earlier to decrease intraspecific competition. Shiel et al. (1999) found that juvenile Leisler's bats (*Nyctalus leisleri*) were more likely than adults to roost away from the colony and foraging distances of juveniles increased with time, possibly due to exploration. Shorter mean minimum foraging distances of adult bats in my study may be from adults returning more quickly and often to their day roosts, whereas juveniles used alternate night roosts rather than returning to the day roost to rest and digest their food. Alternately, it may result from a greater degree of experience or familiarity with the area.

### *Foraging Areas*

Foraging area sizes were considerably smaller than those reported by Hutchinson and Lacki (1999) in upland hardwood forests. Landscape components present throughout the study area, including abundant water sources and structural diversity within pine plantations, provided breeding sites for many insect species. Therefore red bats may not need to travel far in search of prey. Except for one roost used by bat # 010, all foraging areas contained their respective bat roosts and a water source (i.e., SMZ habitat). This may help reduce energy expenditure due to commuting (Kunz 1982).

Due to difficulties inherent in this type of study (e.g., short transmitter range, lack of roads in some parts of the study area, and the ability of red bats to travel quickly over large distances), I occasionally lost contact with radiomarked bats. Therefore, reported sizes of foraging areas may be underestimated. Because of small sample sizes ( $n = 18$ ), it also is possible that differences among bat classes exist but were not detected.

### *Habitat Selection*

Numerous studies have shown bats most active in mature forest stands within managed forests (e.g., Thomas and West 1991, Erickson and West 1996, Kalcounis et al. 1999). Using ultrasonic detectors, Hayes and Adam (1996) found bat activity to be 4.1 - 7.7 times greater in wooded habitats than in nearby logged areas in a managed forest in Oregon. Similarly, Jung et al. (1999), examining bat activity in selectively harvested pine forests of Ontario, recorded twice the number of *Myotis* calls in mature pine and mixed woods as logged areas. However, within the same managed pine plantations, red bats preferred open areas to all other habitat types (Jung et al. 1999). Although my study site provided red bats with open and mature stands in which to forage, no habitat selection by red bats within my study area was detected. Given the mild climate, abundance of water, and structural diversity created by midstory and understory vegetation, it is likely that insects are ubiquitous throughout the study area. Likewise, red bats may have used roads to a large degree. These roads may have been situated around any habitat type, resulting in random use of habitats. However, it is more likely that lack of habitat selection is a result of red bats' inability to distinguish between habitat types. Most (85.58%) of the

pine plantations in Kemper County have open canopies, being either open or post-thinned stands (Table 2.1). It is possible that these habitats offer similar foraging space for red bats, resulting in equally efficient foraging in all habitats.

Table 2.1 Respective percentages of habitat types as they existed in the 4 Asnapshots@ as the landscape was altered by timber harvest throughout the study in Kemper County, Mississippi, 2000-2001. (Open = open canopy pine plantations, Closed = closed canopy pine plantations, Post-thinned = post-thinned pine plantations, MPH = mixed pine-hardwood, and SMZ = streamside management zone)

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	<u>Open</u>	<u>Closed</u>	<u>Post-thinned</u>	<u>MPH</u>	<u>SMZ</u>
June-July 2000	17.24	3.12	68.33	3.77	7.53
August 2000	18.48	3.12	67.11	3.77	7.53
June 2001	22.36	3.12	63.23	3.77	7.53
July 2001	25.28	3.12	60.31	3.77	7.53



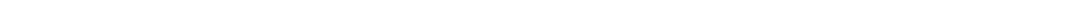
Table 2.2 Red bats captured and radiomarked in Kemper County, Mississippi in 2000 and 2001 with their corresponding age [adult (A) or juvenile (J)], gender [male (M) or female (F)], tracking month, tracking year, and mean, minimum, and maximum distances (m) traveled between successive day roosts.



Table 2.3 Red bats captured and radiomarked in Kemper County, Mississippi in 2000 and 2001 with their corresponding age [adult (A) or juvenile (J)], gender [male (M) or female (F)], tracking month, tracking year, and mean minimum and mean maximum distances traveled from day roosts to foraging sites.



Table 2.4 Red bats captured and radiomarked in Kemper County, Mississippi with  $\exists 24$  locations with their corresponding age [adult (A) or juvenile (J)], gender [male (M) or female (F)], tracking month, tracking year, number of locations, and foraging area size (ha) in 2000-2001.



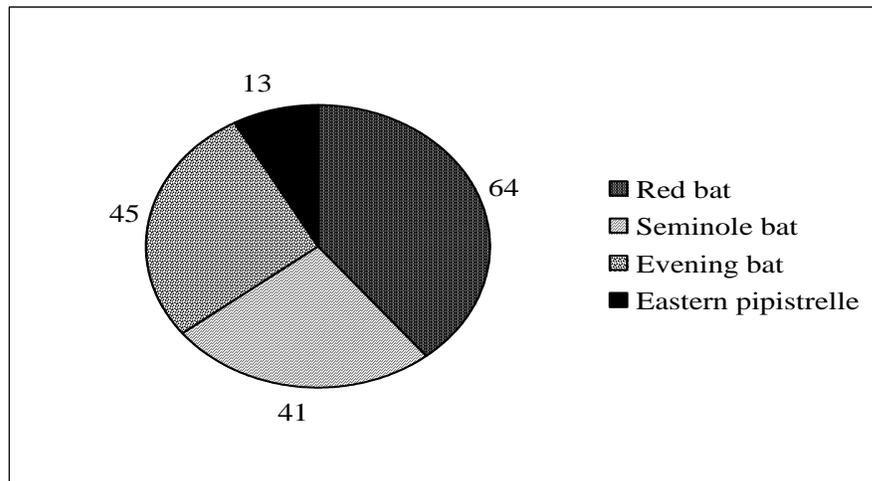


Figure 2.1 Species composition with numbers of bat captures in Kemper County, Mississippi, 2000-2001.

## CHAPTER III

### ROOST SITE SELECTION

#### **Introduction**

Roosts are vitally important structures to bats, providing mating and nursery sites, and protection from heat, cold, and predators (Kunz 1982, Vonhof and Barclay 1996). Species that switch roosts may obtain benefits such as decreased parasite loading, increased thermoregulation, predator avoidance, escape from disturbance (Lewis 1995), and decreased commuting distances between roosting and foraging sites (Kunz 1982). Trade-offs for the advantages include increased energy expenditure during searches for new roosts and decreased foraging efficiency due to unfamiliarity with new surroundings (Alcock 1989).

Many bat species roost in abandoned buildings, mine shafts, caves, or other semi-permanent structures. Protection of such permanent structures may involve use of gates or bars to protect bats from human disturbance. The result is a relatively simple and viable management option for many bat species (Wilson 1997). Understandably, most studies involving bats that roost in semi-permanent structures have focused on locating and preserving roost sites (Hutchinson and Lacki 2000). However, preservation of more ephemeral roost sites such as trees may not be a viable option (Fenton 1997). Many

studies suggest forest management on a larger scale may be necessary to protect roosts of forest-dwelling bats (Brigham et al. 1997, Crampton and Barclay 1998, Kalcounis and Brigham 1998, Rabe et al. 1998).

*Lasiurus* is the only North American bat genus that is adapted to roost in foliage of live trees (Barbour and Davis 1969, Shump and Shump 1982, and Sealander and Heidt 1990). However, comparatively little is known of this group. Only recently has much attention been brought to 2 Lasiurine species. Menzel et al. (1998) examined roost use by Seminole bats (*Lasiurus seminolus*) and red bats in landscapes dominated by pines, mixed pine-hardwood communities, and hardwoods. They found Seminole bats roosted almost exclusively in pines, whereas red bats preferred roosting in white oak species. Similarly, Hutchinson and Lacki (2000) documented red bats roosting in live hardwood trees in mature upland forests. Mager and Nelson (2001) documented red bat roost use in an urban area Illinois. Although red bats were found roosting in roof shingles, leaf litter, and grass, most red bats (89%) were found roosting in or on large deciduous trees (Mager and Nelson 2001). Given red bats= apparent preference for large hardwoods and red bat abundance on the study site (Miller 2003), it was of interest to determine roost site selection of red bats in a landscape of intensively managed pine.

## **Methods**

### *Vegetation Sampling*

I located and flagged day roosts of all radiomarked bats daily for approximately 10 days, beginning 2 mornings after capture. I did not document roosts of bats the day after capture to minimize roosts selected by bats while adjusting to the stress of capture. For each roost tree located, I selected a random tree. A random tree was the closest tree to a point located by traveling a random distance and direction from a randomly selected radiotelemetry station. Because no monitored red bat roosted in a snag, only live trees were selected for random sampling. UTM coordinates were recorded for roost and random trees and overlaid on a GIS coverage of the area.

For each roost and random tree, I recorded species, DBH (cm), percentage canopy closure (at the cardinal directions, 2 and 10 m from the base of the tree) using a spherical densiometer (Lemmon 1957), distance to nearest forested edge (m), and distance to nearest potential water source (m). Because the nearest forested edge was usually delineated by a road, this distance was calculated by performing a spatial join of the tree and road attributes in the Geoprocessing Wizard in ArcView 3.2 (ESRI 2000). However, when the nearest forested edge was a loading deck or clearcut, the distance was measured by pacing. The distance to nearest potential water source was calculated by performing a spatial join of the tree and SMZ attributes in the Geoprocessing Wizard in ArcView 3.2 (ESRI 2000). Due to drought conditions in 2000, water was not always present in SMZs; therefore only distances to potential water sources are known.

Two nested circular plots were created around each roost and random tree. Within a midstory plot of 0.004 ha (radius = 3.5 m), I recorded the species and DBH of

all trees 3 - 10 cm DBH. I also recorded the species and DBH of all trees  $\geq 10$  cm DBH within an overstory plot of 0.04 ha (radius = 11.35 m). Using this information, I calculated species diversity using Shannon's Diversity Index, (Ludwig and Reynolds 1988), stem density, and total, pine, and hardwood basal area ( $\text{m}^2/\text{ha}$ ).

### *Roost Habitat Selection*

To explore the possibility that habitat type influences roost selection, I measured distances from each roost and random tree to the edge of the nearest representative of each habitat type (i.e., I measured the distances from each tree to the edge of the nearest open canopy pine plantation, closed canopy pine plantation, post-thinned pine plantation, MPH, and SMZ plantations). A distance value of zero was assigned to the habitat in which the roost or random tree was found (Miller et al. 2000). Often times I could not be sure of the distance to open habitat due to ongoing timber harvest. In these cases, no measurements were made. No distances to open habitat were known for juvenile females ( $n = 5$ ).

### *Data Analysis*

I tested data for homogeneity of variance using Levene's test (PROC GLM *options = hovtest*, SAS Institute 2001). I reciprocally transformed most data prior to analysis to meet homogeneity of variance assumptions. However, data in which zeros occurred often (e.g., basal area, species diversity, and stem density) were transformed prior to analysis using the formula:  $1/x+1$  (Zar 1974) to correct for nonhomogeneous variance. Data that did not meet homogeneity of variance assumptions were analyzed

using Kruskal-Wallis tests (PROC NPAR1WAY, SAS Institute 2001). I divided the data into 4 classifications (i.e., adult females, adult males, juvenile females, and juvenile males) prior to testing. All other data were tested using a mixed model 2-way ANOVA (PROC MIXED, SAS Institute 2001) to determine if differences existed among bat classes. In cases where there was no significant effect due to age, gender, or an age by gender interaction, I used 1-way ANOVA (PROC GLM, SAS Institute 2001) or Kruskal-Wallis tests, whichever was appropriate, to examine differences between seasons. I used a Chi-square to test the hypothesis that tree species were used proportionally to availability by comparing roost species to random species sampled. Significance level was set at  $P \leq 0.05$ .

### *Roost Site Modeling*

To develop roost site models, I grouped bats into 4 age/gender classifications and randomly divided random trees into 4 classifications such that the number of random trees was equal to number of roost trees. I used a 1-way ANOVA or Kruskal-Wallis test to compare tree variables of the age/gender classes with corresponding random tree variables. Often smaller  $P$ -values are set by the investigator to reduce the risk of Type II errors. This may result in loss of biologically significant results (Pielou 1977). Therefore, significance level was set at  $P \leq 0.10$  for 1-way ANOVA or Kruskal-Wallis tests comparing roost and random tree variables.

I conducted stepwise logistic regression (PROC LOGISTIC, SAS Institute 2001) with maximum likelihood estimators (Hosmer and Lemeshow 2000) on variables that

differed between roosts and randoms to develop roost site models. Logistic regression may be used to model data with binary (e.g., roost vs. random) distributions (Hosmer and Lemeshow 2000). Stepwise logistic regression is a tool used to effectively reduce the number of variables from a model, keeping only those that render the largest likelihood ratio statistic; significance is determined through likelihood ratio chi-square tests (Hosmer and Lemeshow 2000). It is especially useful in studies in which one does not know which variables affect the dependent variables (Hosmer and Lemeshow 2000). All data were analyzed using SAS 8.0 (SAS Institute 2001). Data are presented as means  $\pm$  standard errors (SE).

## Results

I documented 141 roost trees used by 27 red bats ( $\bar{x} = 5.22$ , range of 1 - 12 different roost trees per bat). Except for adult females roosting with young, most bats roosted alone. However, bats 014 and 015, both juvenile males, shared a pine roost (# 172) on 16 August 2000. Therefore, this roost is included twice in the analyses. These bats shared no other roost while I was tracking them.

Investigating bats that used  $\geq 2$  roosts, I found that 140 roosts (including one roost tree not found during habitat sampling and therefore not included in other analyses) were used by 25 bats, including 9 adult females, 5 adult males, 5 juvenile females, and 6 juvenile males. Each bat used an average of 5.6 roosts (range 2 - 12 roosts), switching roost trees, on average, every 1.2 days (range 1 - 7 days).

Monitored bats roosted in loblolly pine (on bark, in vines, and in canopies) and 16 species of hardwoods, including 2 red oaks (*Quercus* spp.) that could not be identified to species. Only live trees were used as roosts. The 141 sampled random trees were composed of loblolly pine and 20 species of hardwoods, including a red oak (*Quercus* sp.) that could not be identified to species. Hardwood roost trees averaged  $18.06 \pm 1.4$  cm DBH (range 2.3 - 83.5 cm); I neglected to measure DBH for 2 hardwood roosts. Hardwood random trees averaged  $7.5 \pm 0.6$  cm DBH (range 1.2 - 40 cm). Pine roost trees averaged  $37.10 \pm 0.9$  cm DBH (range 26.5 - 57.0 cm); pine random trees averaged  $33.2 \pm 1.3$  cm DBH (range 5.4 - 53.0 cm). Hardwoods made up 70% of day roosts and 64.5% of the random trees. Pines made up the remaining 30% of roosts and 35.5% of the random trees. Mean distance from forested edge was  $130.78 \pm 9.34$  m (range 1.00 - 417.41 m) for roosts and  $65.04 \pm 4.43$  m (range 1.00 - 291.00 m; truncated at 300 m) for randoms. Mean distance to a potential water source was  $239.45 \pm 12.40$  m (range 10.35 - 516.34 m) for roosts and  $317.50 \pm 17.69$  m (range 2.47 - 941.23 m) for randoms.

### *Roost Sites*

Roost species used differed ( $\chi^2_4 = 19.53, P < 0.001$ ) from availability. Roost and random trees were placed into 1 of 5 categories [i.e., loblolly pine, hickories (*Carya* spp.), sweetgum (*Liquidambar styraciflua*), oaks, and other]. Hickories ( $\chi^2_1 = 7.08, P = 0.008$ ) and sweetgum ( $\chi^2_1 = 4.45, P = 0.035$ ) were used disproportionately more than availability. Pines ( $\chi^2_1 = 0.53, P = 0.468$ ) and oaks ( $\chi^2_1 = 2.47, P = 0.116$ ) were used in proportion to availability. Others ( $\chi^2_1 = 5.00, P = 0.025$ ) were used disproportionately

less than availability. Females roosted in trees with larger DBHs ( $26.52 \forall 1.57$  cm,  $n = 78$ ;  $F_{1, 135} = 5.14$ ,  $P = 0.025$ ) than males ( $20.66 \forall 1.89$  cm,  $n = 61$ ). DBH of adult roosts ( $24.86 \forall 1.86$  cm,  $n = 70$ ) did not differ ( $F_{1, 135} = 0.24$ ,  $P = 0.623$ ) from that of juveniles ( $23.06 \forall 1.61$  cm,  $n = 69$ ) and there was no age by gender interaction ( $F_{1, 135} = 1.00$ ,  $P = 0.319$ ). Distance from roosts to forested edge did not differ between adults ( $94.87 \forall 9.94$  m) and juveniles ( $168.24 \forall 14.80$  m;  $F_{1, 137} = 0.01$ ,  $P = 0.942$ ), males ( $118.23 \forall 11.26$  m) and females ( $140.91 \forall 14.19$  m;  $F_{1, 137} = 0.68$ ,  $P = 0.411$ ), and there was no age by gender interaction ( $F_{1, 137} = 1.77$ ,  $P = 0.186$ ). There also was no effect due to season ( $F_{5, 135} = 1.11$ ,  $P = 0.36$ ). Juveniles ( $293.37 \forall 16.48$  m) roosted farther from a potential water source than did adults ( $190.07 \forall 16.03$  m;  $F_{1, 137} = 11.13$ ,  $P = 0.001$ ). Distance to nearest potential water source did not differ between roosts used by males ( $268.86 \forall 19.98$  m) and females ( $217.01 \forall 14.76$  m;  $F_{1, 137} = 2.25$ ,  $P = 0.136$ ); there was no age by gender interaction ( $F_{1, 137} = 1.01$ ,  $P = 0.316$ ). An age by gender interaction effect exists for roost canopy closure ( $F_{1, 137} = 18.40$ ,  $P < 0.001$ ). Mean separation showed juvenile females roosted in plots with less canopy closure ( $84.00 \forall 2.61$  %) than adult females ( $94.33 \forall 1.13$  %;  $P < 0.001$ ), adult males ( $90.63 \forall 2.19$  %;  $P = 0.015$ ), and juvenile males ( $94.42 \forall 1.14$ ;  $P < 0.001$ ).

#### *Overstory Vegetation Variables*

I detected an age by gender interaction for total basal area of roost overstory plots ( $F_{1, 137} = 5.21$ ,  $P = 0.024$ ). Mean separation indicated juvenile females used roosts with

less total basal area ( $15.90 \forall 1.03 \text{ m}^2/\text{ha}$ ) than adult females ( $19.16 \forall 1.01 \text{ m}^2/\text{ha}$ ;  $P = 0.046$ ). Total basal area for roost overstory plots were similar for all other age/gender classes. Differences existed among age/gender classes ( $\chi^2_3 = 12.26$ ,  $P = 0.007$ ) in pine basal area of roost overstory plots. Adult males roosted in plots with less overstory pine basal area ( $8.36 \forall 1.65 \text{ m}^2/\text{ha}$ ) than did juvenile females ( $14.37 \forall 0.87 \text{ m}^2/\text{ha}$ ;  $P = 0.002$ ) and juvenile males ( $13.68 \forall 1.04 \text{ m}^2/\text{ha}$ ;  $P = 0.005$ ), but was similar to that of adult females ( $11.11 \forall 1.25 \text{ m}^2/\text{ha}$ ;  $P = 0.121$ ). An age by gender interaction existed for hardwood basal area of roost overstory plots ( $F_{1, 137} = 5.33$ ,  $P = 0.023$ ). Hardwood basal area within roost overstory plots of juvenile females ( $1.53 \forall 1.01 \text{ m}^2/\text{ha}$ ) and juvenile males ( $4.10 \forall 0.97 \text{ m}^2/\text{ha}$ ) was less than that of adult females ( $8.13 \forall 1.34 \text{ m}^2/\text{ha}$ ;  $P < 0.001$  and  $P = 0.024$ , respectively) and adult males ( $10.20 \forall 2.31 \text{ m}^2/\text{ha}$ ;  $P < 0.001$  and  $P = 0.003$ , respectively).

Species diversity within roost overstory plots had a significant ( $F_{1, 137} = 5.21$ ,  $P = 0.024$ ) age by gender interaction. Mean separation indicated tree species diversity within overstory plots of juvenile females ( $S = 0.63 \forall 0.09$ ) was less than that of adult females ( $S = 1.17 \forall 0.99$ ;  $P < 0.001$ ), adult males ( $S = 1.11 \forall 0.14$ ;  $P = 0.004$ ), and juvenile males ( $S = 1.01 \forall 0.1$ ;  $P = 0.01$ ).

Stem density did not differ between adult ( $337.50 \forall 19.41$ ) and juvenile red bats ( $304.71 \forall 15.12$ ;  $F_{1, 137} = 0.41$ ,  $P = 0.523$ ), between male ( $329.76 \forall 18.97$ ) and female red bats ( $314.74 \forall 16.43$ ;  $F_{1, 137} = 0.15$ ,  $P = 0.699$ ), and there was no age by gender interaction ( $F_{1, 137} = 1.88$ ,  $P = 0.173$ ). Differences were detected among seasons ( $F_{5, 135} =$

3.70,  $P = 0.004$ ). During September 2000, roost overstory plots had fewer stems per ha ( $131.25 \nabla 25.77$ ) than plots sampled in June 2000 ( $346.15 \nabla 27.79$ ;  $P = 0.005$ ), July 2000 ( $385.00 \nabla 26.69$ ;  $P = 0.001$ ), August 2000 ( $326.09 \nabla 32.23$ ;  $P = 0.012$ ), and June 2001 ( $334.62 \nabla 33.77$ ;  $P = 0.008$ ). July 2001 had fewer stems per ha ( $269.59 \nabla 18.69$ ) than June 2000 ( $P = 0.035$ ) and July 2000 ( $P = 0.002$ ).

#### *Midstory Vegetation Variables*

An age by gender interaction was detected for total basal area for roost midstory plots ( $F_{1, 137} = 9.63$ ,  $P = 0.002$ ). Mean separation indicated juvenile females roosted in plots with less total basal area ( $1.48 \nabla 0.34 \text{ m}^2/\text{ha}$ ) than adult female plots ( $2.60 \nabla 0.28 \text{ m}^2/\text{ha}$ ;  $P = 0.008$ ) and juvenile males ( $2.91 \nabla 0.33 \text{ m}^2/\text{ha}$ ;  $P = 0.002$ ). Total basal area for roost midstory plots were similar for all other bat classes ( $P \geq 0.05$ ). No differences in pine basal area for roost midstory plots were detected between adults ( $0 \nabla 0 \text{ m}^2/\text{ha}$ ) and juveniles ( $0.01 \nabla 0.01 \text{ m}^2/\text{ha}$ ;  $F_{1, 137} = 0.93$ ,  $P = 0.337$ ) or males ( $0.02 \nabla 0.02 \text{ m}^2/\text{ha}$ ) and females ( $0 \nabla 0 \text{ m}^2/\text{ha}$ ;  $F_{1, 137} = 0.93$ ,  $P = 0.337$ ). Additionally, no age by gender interaction was detected ( $F_{1, 137} = 0.93$ ,  $P = 0.337$ ). No effect due to season was detected ( $F_{5, 135} = 0.55$ ,  $P = 0.736$ ). An age by gender effect exists for hardwood basal area for roost midstory plots ( $F_{1, 137} = 9.32$ ,  $P = 0.003$ ). Hardwood basal area within roost midstory plots of juvenile females ( $1.48 \nabla 0.27 \text{ m}^2/\text{ha}$ ) was less than that of juvenile

males ( $2.88 \forall 0.33 \text{ m}^2/\text{ha}$ ;  $P = 0.002$ ) and adult females ( $2.60 \forall 0.28 \text{ m}^2/\text{ha}$ ;  $P = 0.008$ ); adult males had similar hardwood basal area ( $2.09 \forall 0.353 \text{ m}^2/\text{ha}$ ) to all other bat classes.

An age by gender interaction effect existed for tree species diversity within roost midstory plots ( $F_{1, 137} = 5.31$ ,  $P = 0.023$ ). Mean separation indicated greater species diversity within midstory plots of adult females ( $S = 0.43 \forall 0.10$ ) compared to adult males ( $S = 0.68 \forall 0.07$ ;  $P = 0.047$ ) but similar to that of juvenile females ( $S = 0.51 \forall 0.08$ ;  $P = 0.555$ ), and juvenile males ( $S = 0.66 \forall 0.08$ ;  $P = 0.213$ ).

An age by gender interaction effect existed for stem density within roost midstory plots ( $F_{1, 137} = 7.49$ ,  $P = 0.007$ ). Mean separation indicated juvenile females in plots with fewer number of stems/ha ( $674.24 \forall 99.41 \text{ m}^2/\text{ha}$ ) than adult female plots ( $1,038.89 \forall 99.23 \text{ m}^2/\text{ha}$ ;  $P = 0.015$ ) and juvenile males ( $1,000.00 \forall 124.00 \text{ m}^2/\text{ha}$ ;  $P = 0.038$ ). Total basal area for roost midstory plots were similar for all other bat classes.

### *Roost Habitat Selection*

Six of the 45 roosts (13.3%) occupied by adult females ( $n = 9$ ) were located in SMZs, with the remaining 39 (86.7%) occurring in post-thinned pine plantations. Despite high usage of post-thinned pine plantations, only 17.8% of adult female roosts were pines. Ten of the 27 roosts (37%) occupied by adult males ( $n = 7$ ) were located in SMZs, whereas the other 17 (63%) occurred in post-thinned pine plantations; 14.8% of all adult male roosts were pines. All juvenile female roosts ( $n = 7$ ) were found in post-thinned stands; 66.7% of roosts were pine trees. Only 1 (2.8%) of the 36 roosts used by juvenile males ( $n = 6$ ) was found in an SMZ; the rest were in post-thinned pine plantations.

However, only 25% of juvenile male roosts were pines. No red bat roosts were found in open canopy pine plantation, closed canopy pine plantation, or mixed pine-hardwood stands.

An age by gender interaction occurred for distances to open habitat ( $F_{2, 88} = 6.71$ ,  $P = 0.002$ ), post-thinned plantations ( $F_{1, 137} = 5.46$ ,  $P = 0.021$ ), and MPH stands ( $F_{1, 137} = 14.21$ ,  $P < 0.001$ ). Compared to adult females (521.85  $\forall$  32.09 m;  $P < 0.001$ ) and juvenile males (491.62  $\forall$  19.07 m;  $P < 0.001$ ), adult males roosted in trees closer to open habitats (185.66  $\forall$  36.20 m). No distances to open habitats were known for juvenile female roosts. Adult males roosted farther from post-thinned plantations (29.68  $\forall$  12.55 m) than adult females (4.22  $\forall$  1.80 m;  $P < 0.001$ ), juvenile females (0  $\forall$  0 m;  $P < 0.001$ ), and juvenile males (1.71  $\forall$  1.71 m;  $P < 0.001$ ). Roosts of juvenile males were located greater distances from MPH stands (2097.51  $\forall$  55.08 m) than were those of adult females (1,550.26  $\forall$  85.94 m;  $P < 0.001$ ), adult males (1,725.96  $\forall$  185.96 m;  $P = 0.016$ ), and juvenile females (1,152.09  $\forall$  75.20 m;  $P < 0.001$ ). Juvenile females roosted shorter distances from MPH stands than adult females ( $P = 0.004$ ) and adult males ( $P < 0.001$ ).

I used the Kruskal-Wallis procedure to examine differences in distances to SMZs and closed pine plantations between bat classes (i.e., males, females, adults, juveniles) and age-gender combinations (i.e., adult females, adult males, juvenile females, and juvenile males). Differences existed among age-gender combinations ( $\chi^2_3 = 16.56$ ,  $P < 0.001$ ) for distances to SMZs. Adult females used roosts closer (151.37  $\forall$  27.90 m) to SMZ habitat than did adult males (258.93  $\forall$  58.74 m;  $P = 0.02$ ) and juvenile males

(252.32  $\forall$  20.69 m;  $P = 0.018$ ) but similar in distance to those of juvenile females (193.87  $\forall$  17.58 m;  $P = 0.325$ ).

Juveniles roosted closer (1,265.22  $\forall$  170.34 m) to closed habitat than adults (1,476.67  $\forall$  139.21 m;  $P = 0.035$ ). No difference was detected between males (1,654.89  $\forall$  209.34 m) and females (1,145.67  $\forall$  97.04 m;  $P = 0.272$ ) regarding distance from roosts to closed habitat.

### *Roost Site Modeling*

Comparing the 4 red bat classifications with the random equivalent classifications (PROC GLM, SAS Institute 2001) revealed differences between roost and random tree variables (Tables 3.1 - 3.4). Regression of roost and random tree variables indicated roosts of adult females closer to SMZ habitat (Wald= $s \chi^2_1 = 7.10$ ,  $P = 0.008$ ), water (Wald= $s \chi^2_1 = 8.48$ ,  $P = 0.004$ ), and closed habitat (Wald= $s \chi^2_1 = 5.71$ ,  $P = 0.017$ ) but farther from open habitat (Wald= $s \chi^2_1 = 9.59$ ,  $P = 0.002$ ). Adult female roosts had greater canopy closure (Wald= $s \chi^2_1 = 7.52$ ,  $P = 0.006$ ) and overstory (Wald= $s \chi^2_1 = 3.96$ ,  $P = 0.047$ ) and midstory (Wald= $s \chi^2_1 = 5.05$ ,  $P = 0.025$ ) stem density than their random counterparts. The model correctly classified roosts 79.4% of the time and randoms 83.3% of the time.

Regression indicated overstory hardwood basal area was the only variable necessary to classify adult male roosts. Adult male roost plots had larger overstory hardwood basal area (Wald= $s \chi^2_1 = 5.69$ ,  $P = 0.017$ ) than corresponding random plots. Randoms were correctly classified 88.9% of the time, whereas adult male roosts were

correctly classified only 52% of the time. This low percentage indicates little choice of roost characteristics on the part of adult males that have no parental responsibilities and may roost wherever is convenient.

Distance to closed habitat differed between juvenile female roosts and random trees, but was discarded from regression analysis because its inclusion resulted in a complete separation of data points. Complete separation occurs when independent variables used to classify an event or non-event are so dissimilar as to result in a vector that correctly partitions all observations to their response groups (So 1993). With complete separation, there is no maximum likelihood and therefore a less reliable model (So 1993). A greater DBH (Wald= $\chi^2_1 = 13.29$ ,  $P < 0.001$ ), greater distance to forested edge (Wald= $\chi^2_1 = 8.23$ ,  $P = 0.004$ ), and less overstory total basal area (Wald= $\chi^2_1 = 4.72$ ,  $P = 0.03$ ) were associated with juvenile female roosts. The model correctly classified roosts 90.9% of the time and randoms 87.9% of the time.

Increased distance to open habitat (Wald= $\chi^2_1 = 13.48$ ,  $P < 0.001$ ) and canopy closure (Wald= $\chi^2_1 = 8.90$ ,  $P = 0.003$ ) with less distance to closed habitat (Wald= $\chi^2_1 = 4.63$ ,  $P = 0.03$ ) were associated with juvenile male roost models. Juvenile male roosts were correctly classified 88.9% of the time; randoms were correctly classified 76.5% of the time. However, because juvenile males were found roosting with or clinging to other bats as late 12 August 2000, it is likely that juvenile males exhibited little roost site selection, leaving that to the mothers.

#### *Typical Roost Sites by Bat Category*

Within my study area, a typical adult female roost was a hardwood of relatively large diameter (i.e., 25 cm) located in a post-thinned pine plantation. These roosts were approximately 75 m from a forest edge and 200 m from a water source. Canopy closure in these roost plots was very high (94%), as was stem density (overstory and midstory). Overstory basal area (total, pine, and hardwood), midstory basal area (total, pine, and hardwood), and species diversity (overstory and midstory) were high to moderate. Adult female roosts, on average, were far from open habitat (>500 m), mixed pine-hardwood habitat (>1,550 m), and closed pine plantations (>1,300 m) but close to SMZs (150 m).

Similarly, a typical juvenile male roost was a hardwood of smaller diameter (i.e., 19 cm) located in a post-thinned pine plantation. These roosts were approximately 100 m from a forest edge and 300 m from a water source. Canopy closure in these roost plots was very high (94%), as was stem density (overstory and midstory). Overstory basal area (total, pine, and hardwood), midstory basal area (total, pine, and hardwood), and species diversity (overstory and midstory) were relatively high to moderate. Juvenile male roosts, on average, were far from open habitat (500 m), mixed pine-hardwood habitat (>2,000 m), and closed pine plantations (>1,600 m) but relatively close to SMZs (250 m).

A typical adult male roost was a hardwood of moderate diameter (i.e., 22 cm) and was more likely to be situated in an SMZ than other bat classifications. These roosts were roughly 125 m from a forest edge and 200 m from a water source. Canopy closure in these roost plots was high (90%), as was overstory stem density; midstory stem density was moderate. Overstory total basal area was moderate, overstory pine basal area was

low, and overstory hardwood basal area was high. Midstory basal area (total, pine, and hardwood), and species diversity (overstory and midstory) were moderate. Adult male roosts, on average, were far from mixed pine-hardwood habitat (>1,700 m) and closed pine plantations (>1,650 m) but close to open habitat (<200 m) and SMZs (250 m).

Juvenile females were the exception to the rule. A typical juvenile female roost was a loblolly pine of large diameter (i.e., 27 cm) and was always situated in a post-thinned pine plantation. These roosts were approximately 200 - 250 m from a forest edge and >250 m from a water source. Canopy closure in these roost plots was moderate (84%), as was overstory stem density; midstory stem density was low. Overstory total basal area and overstory pine basal area was low to moderate, and overstory hardwood basal area was low. Midstory basal area (total, pine, and hardwood), and species diversity (overstory and midstory) were low. Juvenile female roosts, on average, were relatively close to mixed pine-hardwood habitat (>1,000 m), closed pine plantations (850 m) and SMZs (250 m). Distance from juvenile female roosts to open habitat is not known. Because juvenile females tended to roost in post-thinned pine plantations, more specifically pine trees, it may be that intensive pine silviculture is beneficial to this important segment of the population, although future research may be necessary to discover the reason.

## **Discussion**

In a similar study conducted by Menzel et al. (1998, 2000) in areas of Georgia and South Carolina dominated by pines, only one occurrence of a red bat roosting in a pine

was found; all other roosts were overstory hardwood trees. Based on this, I assumed that radiomarked red bats in my study area would be found roosting in nearby SMZs where they were captured due to the presence of more large hardwoods in that habitat, as compared with other habitats in the area. Although I documented some roosts in SMZs ( $n = 17$ , 12.06%), most ( $n = 124$ , 87.94%) were located in post-thinned plantations. The most likely explanation for the spectrum of roost trees used within my study site is the fact that the red bat is a generalist species (Barbour and Davis 1969).

On average, red bats in my study switched roosts every 1.2 days. This is more often than Hutchinson and Lacki (2000) documented for red bats in Kentucky that switched every 2.3 days. Lewis (1994) concluded that roost lability is directly related to roost availability. In other words, the more plentiful appropriate roost sites are, the more likely it is for an animal to switch between sites. The frequency with which red bats in my study site switched roosts suggests that adequate roost sites were abundant in the area.

Midstory trees (<10 cm) composed 49.6% of random trees. However, red bats roosted more often in overstory hardwoods ( $\geq 10$  cm DBH; 74.0%) than in midstory hardwoods (<10 cm DBH; 26.0%). Red bat use of hardwoods may be a product of tree growth characteristics. Sweetgum and hickories (quickly-growing trees) were used more than availability, whereas oaks and others (e.g., red maple (*Acer rubrum*), and blackgum (*Nyssa sylvatica*)), which are slower-growing trees and unable to gain much height before timber harvest eliminates them, were used proportional to or less than available.

### *Roost Sites*

Females were found to roost in trees with larger DBH than males. Because DBH is proportional to tree height, it is possible that females chose taller trees to avoid terrestrial predators (Morrison 1980, Cramptom and Barclay 1998) or to remain cooler during the day (Hutchinson and Lacki 2001). Lack of familiarity with the area might explain why juveniles roosted farther from water. However, it is more likely that this, as well as lower canopy closure for juvenile females, is a product of more juvenile roosts being situated in post-thinned pine plantations.

#### *Overstory and Midstory Vegetation Variables*

Juvenile female roost sites exhibited many differences from other bat classifications. They had less overstory total basal area, overstory species diversity, midstory total basal area, midstory hardwood basal area, and midstory stem density. Intuitively, one would expect these variables to be smaller in post-thinned pine stands, in which trees have been removed, resulting in a more open forest.

Adult male and female roost sites similarly had less overstory pine basal area and greater overstory hardwood basal area than roost sites of juvenile males and females. This is to be expected because the adults roosted in SMZs much more often than juveniles did. Adult male roost plots had less midstory species diversity than adult female roosts. This may be due to the greater number of roosts found in SMZs. SMZs are predominantly composed of tall, large diameter trees, which grow closely together, shutting out most of the sunlight and impeding the growth of midstory trees.

### *Roost Habitat Selection*

Because only one small area of mixed pine-hardwood exists in the study area, I suggest that results of tests that include this variable offer little valuable information. The same may be argued for the few closed canopy pine plantation located far from capture and roost sites. The relatively high numbers of adult male roosts located in SMZs explains why adult male roosts were farther from post-thinned stands, which were the primary roosting areas for all other bat classifications. It is unknown why adult male roost sites are closer to open habitats. Neither adult males, nor any other bat group, selectively foraged in open habitat, therefore it may not be argued that males roosted near open sites to decrease energy expenditure from roosting to foraging sites (Kunz 1982). This most likely results from low sample sizes.

I was surprised that so many males roosted in SMZs. I expected to find more adult females roosting in SMZs in large hardwoods that potentially provide greater cover, insulation, and protection from predators. However, predator avoidance may explain why adult females roosted less often in SMZs. Adult female red bats in my area roosted predominantly in hardwoods (82% of roosts), which offer better camouflage, cover, and insulation, but only 13.3% of roosts were found in SMZs. Because SMZs contain the only water sources and may constitute a linear corridor for many species, it is possible that predators are more concentrated here. Adult female bats and their noisy young would profit from avoiding areas of high predator concentrations. It seems plausible that the red

bat population in my study area will benefit given stand management, resulting in different aged plantations, and SMZs are maintained across the landscape.

Table 3.1 Variables for adult female roosts and a group of random sites in Kemper County, Mississippi 2000-2001 with means, standard errors, and test statistics generated through comparisons of the 2 groups (variables in bold indicate significance).

Table 3.2 Variables for adult male roosts and a group of random sites in Kemper County, Mississippi 2000-2001 with means,

standard errors, and test statistics generated through comparisons of the 2 groups (variables in bold indicate significance).

Table 3.3 Variables for juvenile female roosts and a group of random sites in Kemper County, Mississippi 2000-2001 with means, standard errors, and test statistics generated through comparisons of the 2 groups (variables in bold indicate significance).



Table 3.4 Variables for juvenile male roosts and a group of random sites in Kemper County, Mississippi 2000-2001 with means, standard errors, and test statistics generated through comparisons of the 2 groups (variables in bold indicate significance).



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CHAPTER IV  
SUMMARY, MANAGEMENT IMPLICATIONS, AND  
FUTURE RESEARCH NEEDS

**Summary**

The recent miniaturization of radiotransmitters allows more complete and detailed information on bat ecology to be gained. I used standard radiotelemetry techniques to document movements, foraging areas, habitat selection, and day roosts of red bats within an intensively managed pine forest in Mississippi. I radiomarked 46 red bats June - September 2000 and May - July 2001 to examine movements, foraging areas, habitat selection, and day roosts of red bats within a managed pine forest in Mississippi.

Forest fragments and edge habitat resulting from timber harvest are important foraging sites for many bat species (e.g., *L. borealis* [Furlonger et al. 1987], *L. cinereus* [Furlonger et al. 1987, Grindal and Brigham 1999], *Myotis* spp. [Furlonger et al. 1987, Brigham et al. 1992, Crampton and Barclay 1998, Grindal and Brigham 1999], *C. townsendii ingens* [Clark et al. 1993], *C. townsendii* [Dobkin et al. 1995a, Erickson and West 1996], and *L. noctivagans* [Erickson and West 1996, Hayes and Adam 1996, Crampton and Barclay 1998, Grindal and Brigham 1999, Jung et al. 1999]). However, final timber harvest leads to a loss of older trees that are common roost sites for red bats.

Red bats in my study area behaved much differently than red bats in pine, mixed pine-hardwood, and bottomland hardwood forests of Georgia and South Carolina (Menzel et al. 1998, Menzel et al. 2000), upland forests of Kentucky (Hutchinson and Lacki 2000), and urban areas in Illinois (Mager and Nelson 2001). Nearly all previously documented roosts of red bats have been tall, deciduous, live trees with large diameters. Although SMZs, containing large hardwoods, were located throughout my study site, red bats routinely roosted in pines and midstory hardwoods. Most roosts were located in post-thinned pine stands ( $n = 124$ , 87.94%). I expected red bats in my study area to concentrate their foraging activity near SMZs, which offered a water source and, possibly, a greater prey density for bats. However, radiotagged bats neither selected foraging habitat within the study area nor within their home ranges. Further research would be useful to determine how best to manage for bats in industrial forests.

The purpose of this project was to further the knowledge of red bat ecology and examine red bat ecology within a forest intensively managed for loblolly pine so that viable management practices for red bats might be implemented on Weyerhaeuser property. Because pine plantations are rapidly becoming a major component of the landscape throughout the Southeast (Allen et al. 1996), it is critical to understand how bats exploit these forests to ensure proper management of this important and diverse group of mammals. It is hoped that knowledge acquired during this study may be extended to other managed pine forests in the southeastern United States and beyond.

### **Management Implications**

Timber harvest on Weyerhaeuser property in Kemper County, Mississippi peaks during summer (D. A. Miller, Weyerhaeuser Company, personal communication). This coincides with the birth of red bat pups. Radiotagged red bats regularly roosted in pines and post-thinned pine stands. Although timber harvest effects to non-volant bats are unknown, it would likely be beneficial to this population for timber harvest to be postponed until late July or early August when red bats are fully volant.

Most of the pine stands in Kemper County, Mississippi were planted during the 1970s, resulting in a predominantly even-aged forest. Due to their age, most stands are at or near harvesting age. Because such a narrow window of time (i.e., approximately 15 years based on local timber practices) exists within which trees may be adequate roost sites, stand management, resulting in different aged plantations across the landscape, must continue.

### **Future Research Needs**

Often, female foraging areas change throughout summer (Adam et al. 1994, Wethington et al. 1996). Foraging area size may be a product of additional weight due to pregnancy early in summer affecting foraging behavior (Aldridge and Brigham 1988) or young becoming volant, thereby increasing competition for foraging space (Kunz 1974). Because we were able to quickly capture and radiotag #10 juvenile bats with poorly honed senses, we rarely netted long enough to capture the more elusive adults. Therefore

6 of the 7 radiomarked adult female red bats were captured in June and I was not able to determine if foraging areas changed throughout the season. By selecting which red bats to radiotagged each month, more adult females could be radiomarked to evaluate home range changes. Selectively choosing adult female red bats would also allow one to test for differences in roost switching behavior between lactating females and adult females with volant young.

No studies have specifically addressed winter roosting sites of red bats. Because many red bats are known to winter in this area (Barbour and Davis 1969), knowledge of winter roosting requirements would enhance capabilities to manage red bats more effectively. Moorman et al. (1999) reported red bats roosting in leaf litter during winter. However, given that Seminole bats (*Lasiurus seminolus*), a close relative of the red bat, roost in pines during summer (Menzel et al. 1998, Menzel et al. 1999) and have been documented roosting under exfoliating bark (Sealander 1979), it is possible that red bats may be able to use tree cavities and snags, which offer greater insulation from the cold during winter. Vonhof and Barclay (1997) found Western long-eared bats (*Myotis evotis*) often roosted beneath the loose bark of stumps in clearcuts. Although undocumented, many bat species in Kemper County, Mississippi also may be able use snags in clearcuts if they are left standing.

Timber harvest leads to a loss of older trees in post-thinned plantations that provide roosts and roosting areas for red bats in my study area. Further research into how timber harvest affects survival, spatial fidelity, and roost site selection is critical. For

example, during timber harvest in 2001, an adult male bat (# 036) was forced from his roost to another roost during the day because his roost tree was being harvested. On the second day of harvesting, he was found roosting in an SMZ, 430 m away from the area in which he had roosted the previous 4 days. Although I can not determine if this bat would have moved into a different habitat (i.e., from a post-thinned plantation to a SMZ) if timber harvest was not occurring, I assumed roost selection was occurring and included his roosts in my analyses. This bat rarely was active when I monitored him and moved only short distances from his roosting site. He was found dead and intact 8 days after capture. All radiotelemetry data from this bat were discarded due to his strange behavior, his death, and landscape changes resulting from harvesting. Whether his death was a result of stress due to habitat changes, capture and handling, or an illness is unknown. Therefore, effects of timber harvest should be investigated and handling time should be kept to a minimum. Prior to radiotransmitter application, I clipped fur between the scapulae to prolong radiotransmitter attachment. However, Dobkin et al. (1995b) found no difference in retention time of radiotransmitters by fur-clipped and unclipped Townsend's big-eared bats. By not clipping fur prior to radiotransmitter application, handling time, and possibly, handling stress to bats would be reduced.

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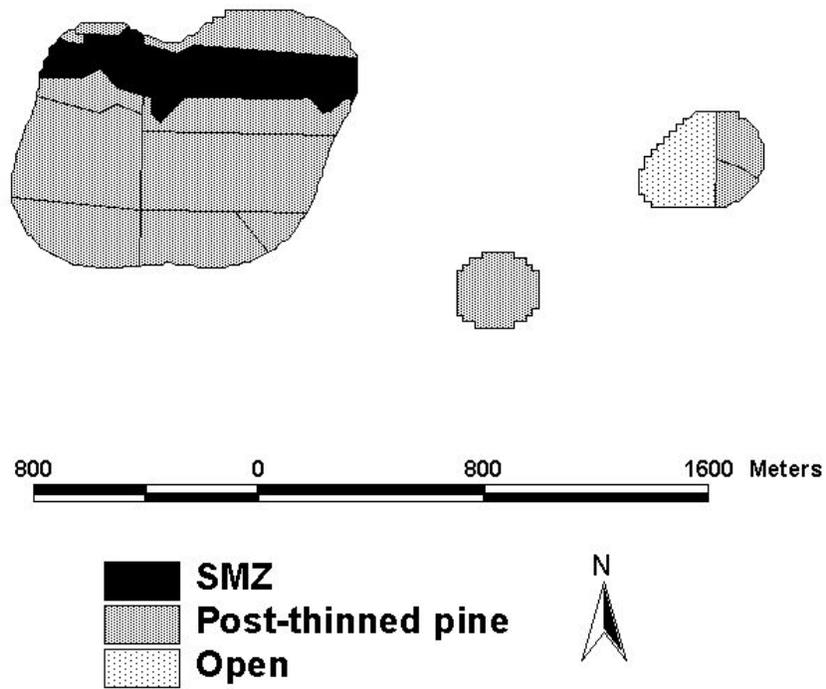
APPENDIX A

FORAGING AREAS OF RED BATS IN KEMPER COUNTY, MISSISSIPPI,

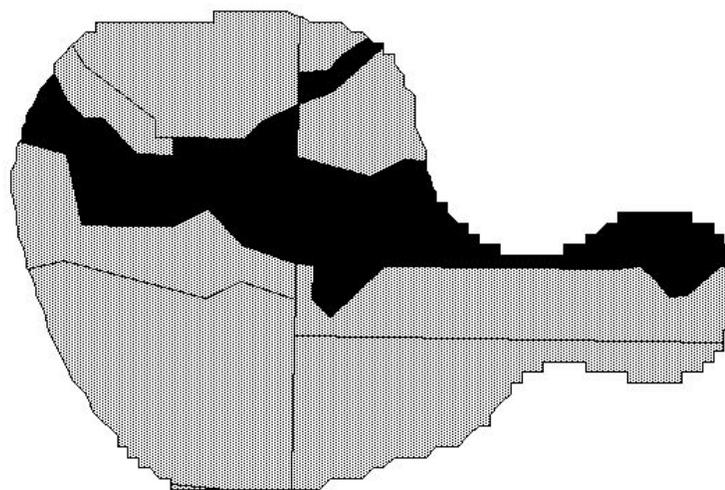
SUMMERS 2000-2001 (Refer to Table 2.4 for age and gender of bat)



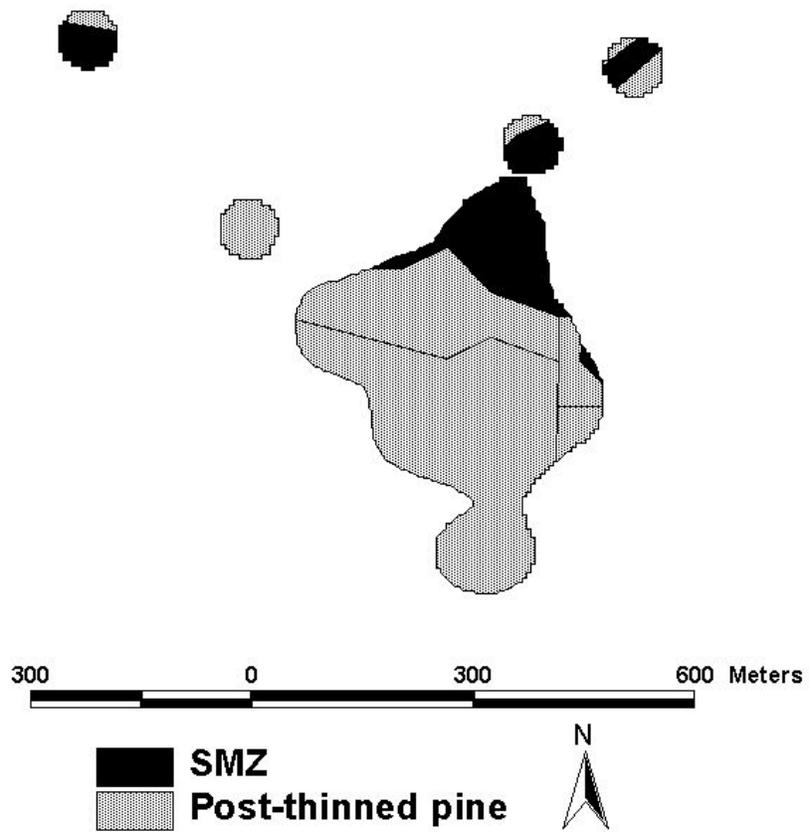
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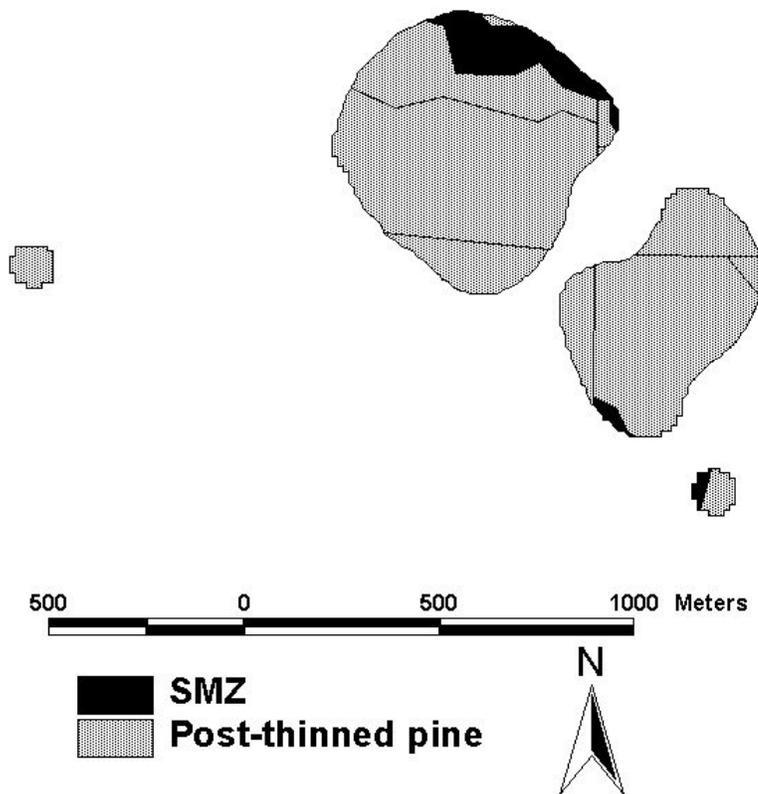
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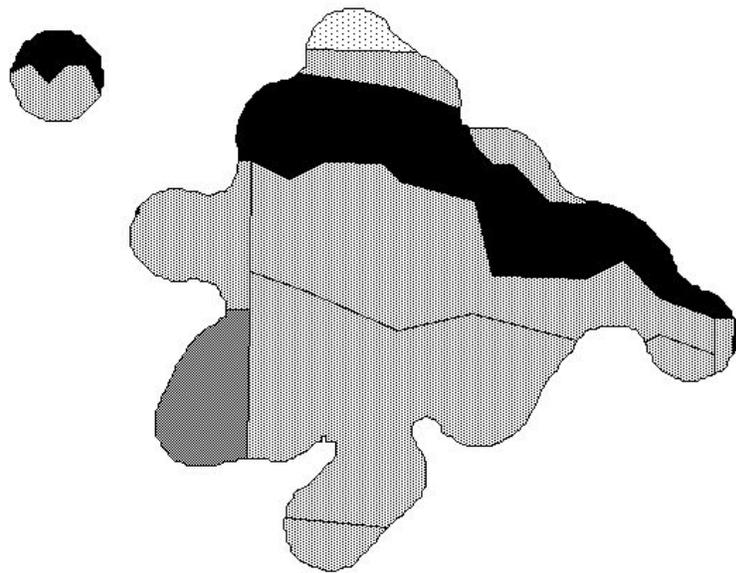
# Bat 006



# Bat 007



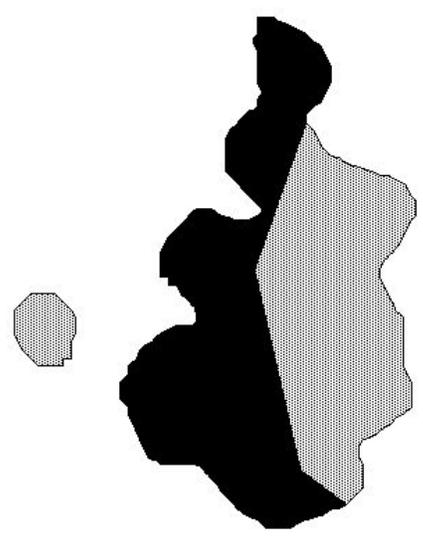
# Bat 008



-  **SMZ**
-  **Post-thinned pine**
-  **Open**
-  **Closed**



# Bat 010

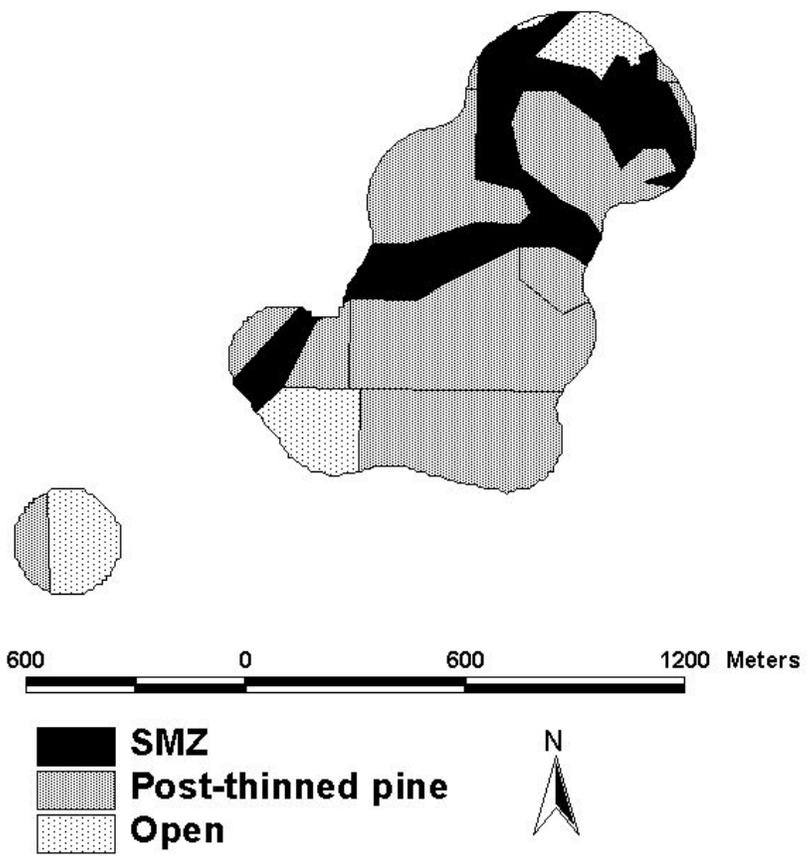


 **SMZ**  
 **Post-thinned pine**

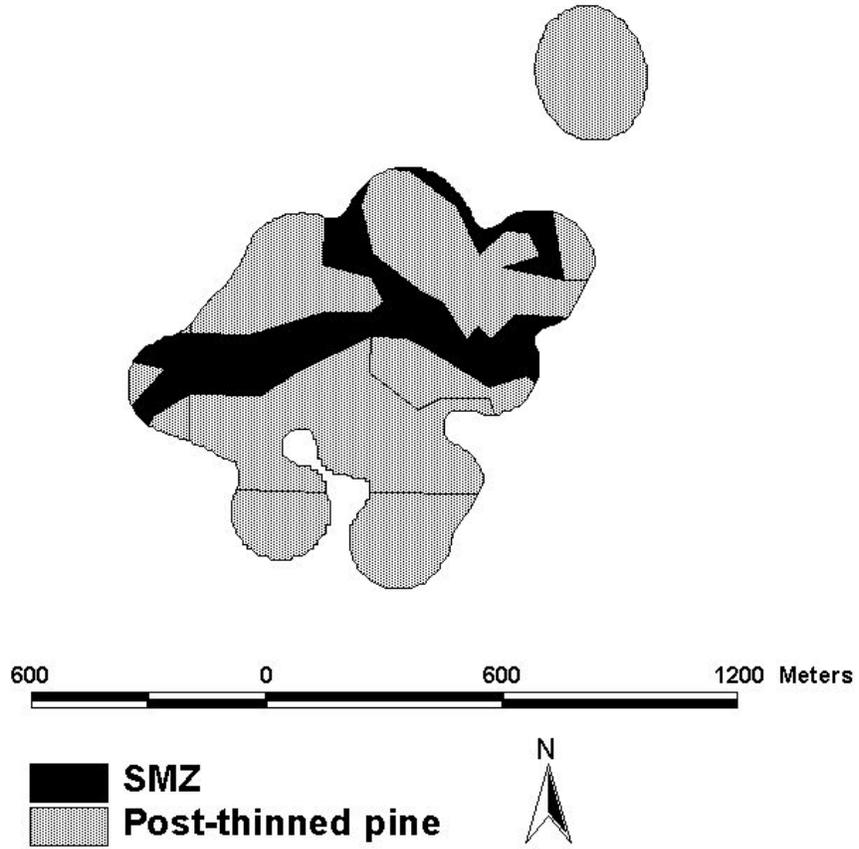




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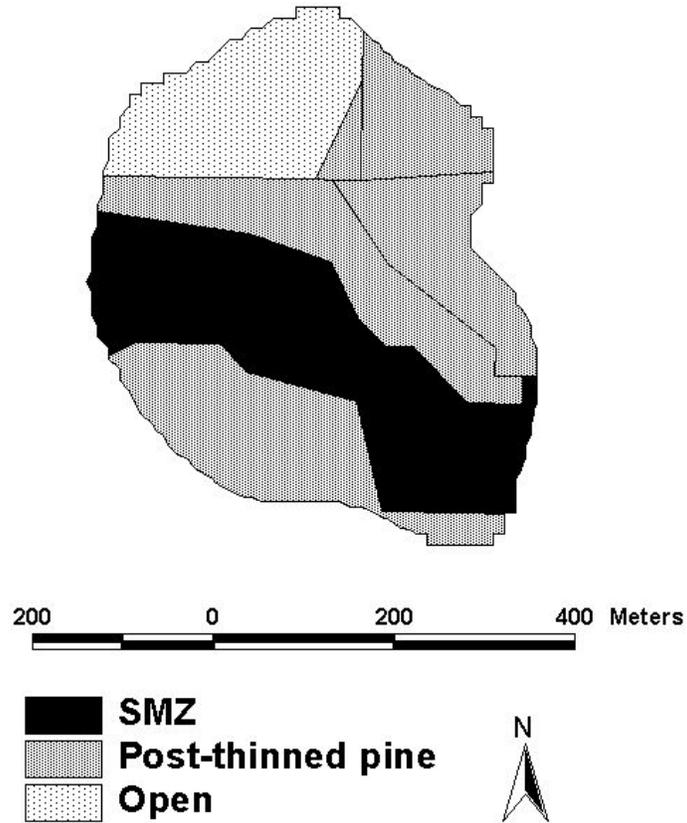


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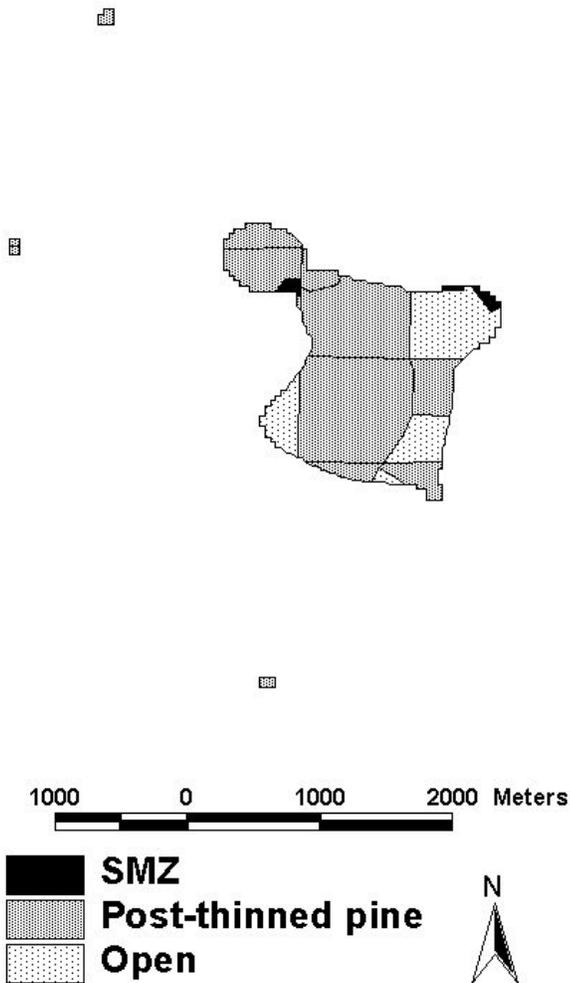




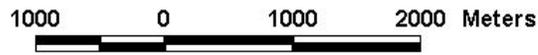
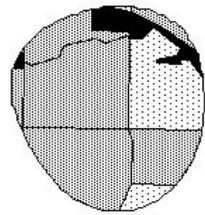
# Bat 017



# Bat 026

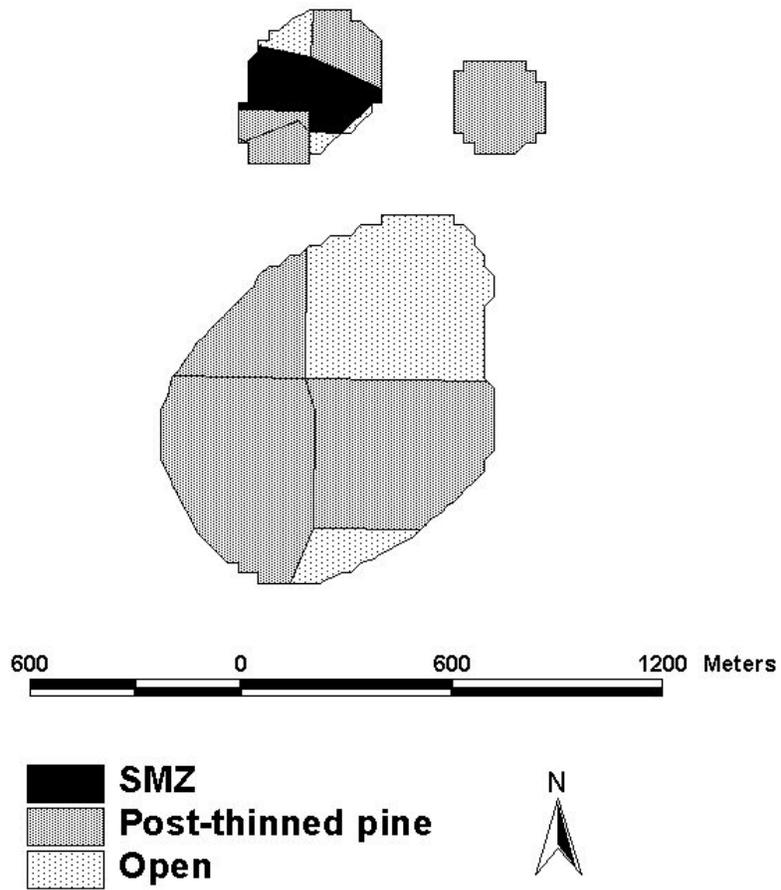


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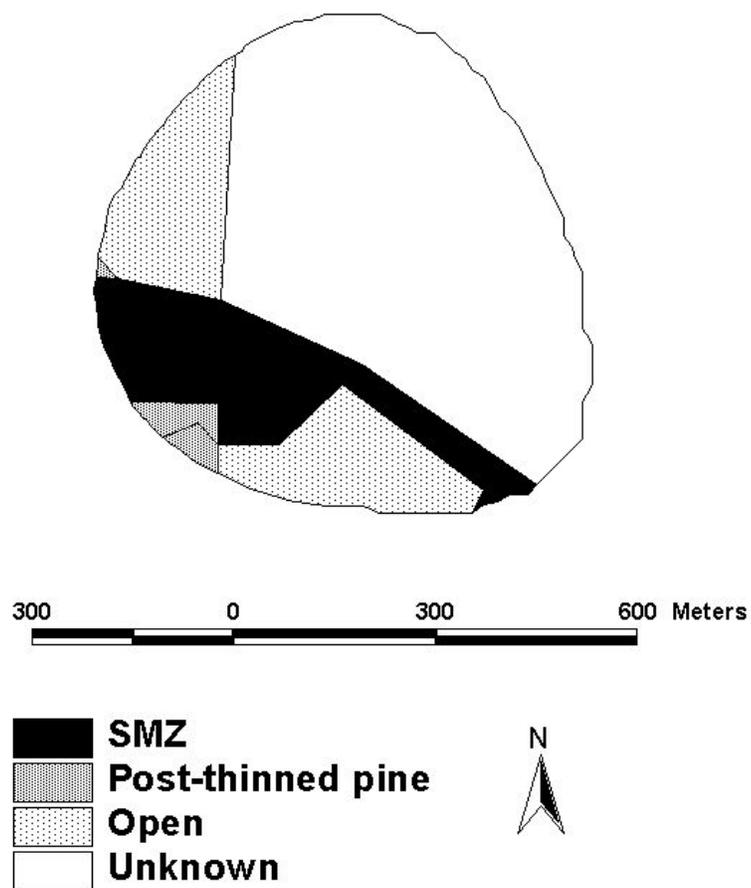




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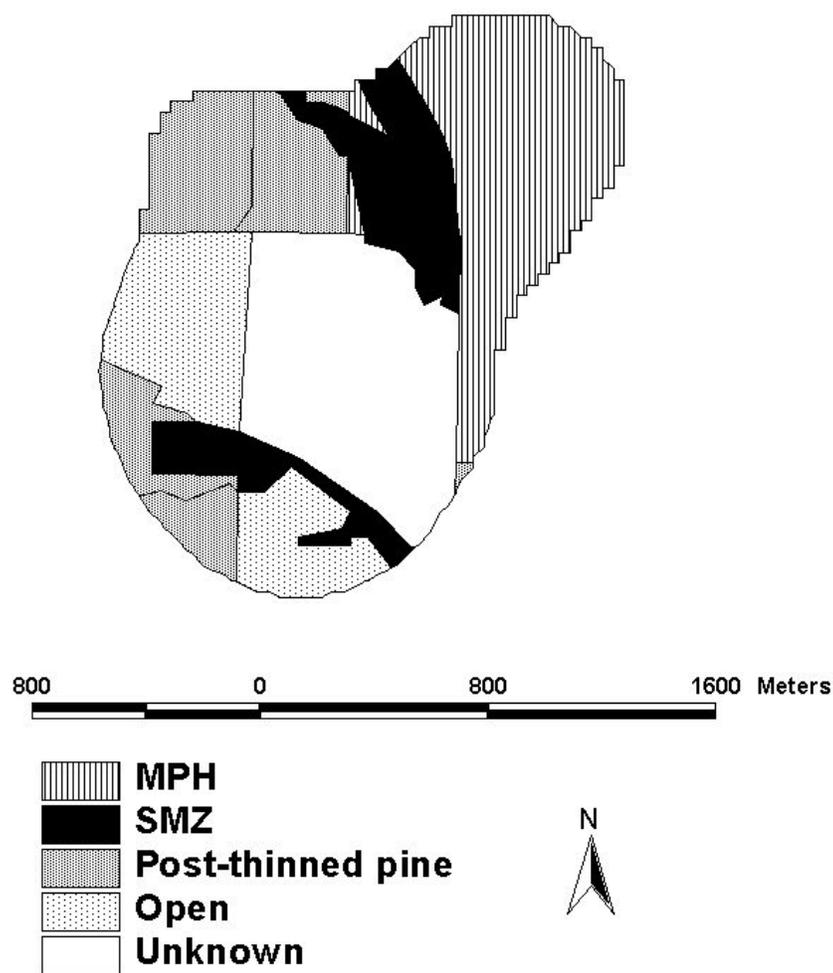


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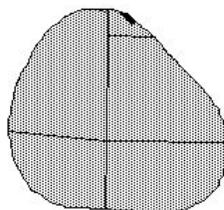


# Bat 034

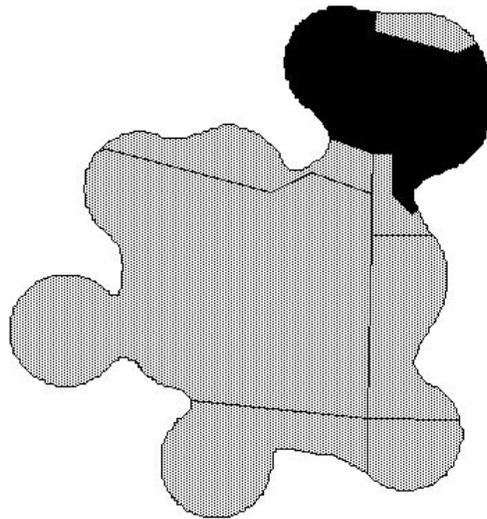




# Bat 037

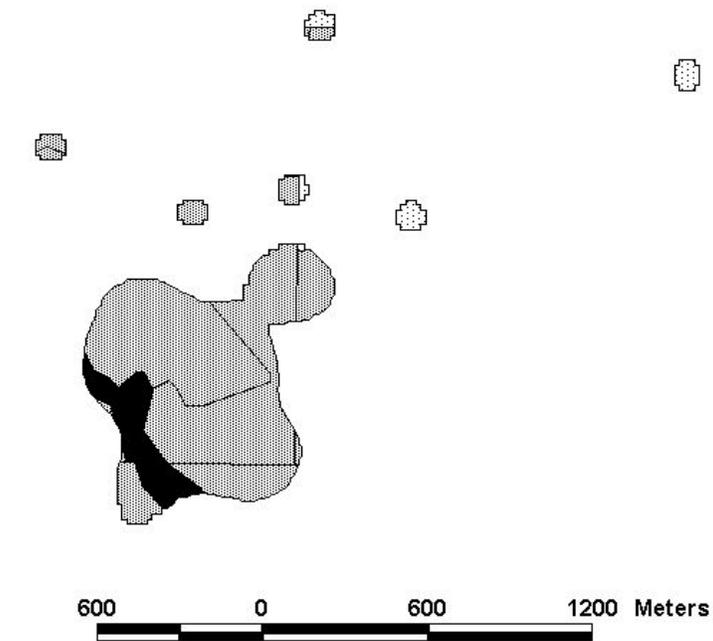


# Bat 042

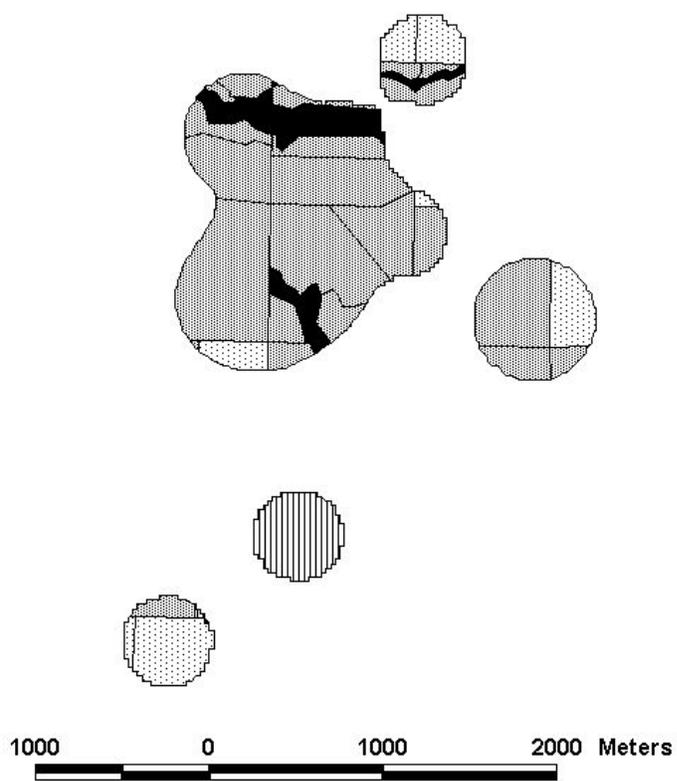




# Bat 045



# Bat 046



-  **MPH**
-  **SMZ**
-  **Post-thinned pine**
-  **Open**

