AVAILABILITY AND SEASONAL USE OF DIURNAL ROOSTS BY RAFINESQUE'S BIG-EARED BAT AND SOUTHEASTERN MYOTIS IN BOTTOMLAND HARDWOODS OF MISSISSIPPI

By

Candice LeeAnn Stevenson

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Approved:

Jeanne C. Jones Associate Professor of Wildlife and Fisheries (Director of Thesis)	Darren A. Miller Adjunct Assistant Professor of Wildlife and Fisheries (Committee Member)
David M. Richardson Adjunct Assistant Professor of Wildlife and Fisheries (Committee Member)	Francisco J. Vilella Professor of Wildlife and Fisheries (Committee Member)
Bruce D. Leopold Professor and Head of Wildlife and Fisheries Graduate Coordinator (Committee Member)	George M. Hopper Dean of the College of Forest Resources

Name: Candice LeeAnn Stevenson

Date of Degree: December 12, 2008

Institution: Mississippi State University

Major Field: Wildlife and Fisheries Science

Major Professor: Dr. Jeanne Jones

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Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) and southeastern myotis (*Myotis austroriparius*) are listed as species of concern in Mississippi. They use bottomland hardwood forests for roosting habitat; however, much of these forests in Mississippi have been lost or degraded. I seek to characterize availability and evaluate use of diurnal tree roosts for these presumably rare bats.

Approximately 1,250 ha of bottomland hardwood forest on Noxubee National Wildlife Refuge were surveyed. I measured characteristics of 622 cavity trees. Analyses revealed that these bats most often used cavities of large diameter trees ($\geq$70 cm DBH). Rafinesque's big-eared bat and southeastern myotis roosted commonly in baldcypress (*Taxodium distichum*), black tupelo (*Nyssa sylvatica*), and American sycamore (*Platanus* *occidentalis*). This research will be used to provide guidance for management plans to conserve these bats and their habitat.

Key words: Rafinesque’s big-eared bat, southeastern myotis, cavity tree

DEDICATION

This work is dedicated to my husband Stacy and my daughter Cheyenne. Your sacrifice made this possible. Thank you.

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There are numerous students and faculty at the College of Forest Resources that contributed to this research. I appreciate the CFR staff for their support through the years, and especially Dr. Bruce Leopold for welcoming me to the CFR family and giving me a chance. I offer my deepest thanks to my major professor, Dr. Jeanne Jones who served as a mentor and friend for many years. Thank you for sharing your knowledge and appreciation of natural resources, your passion for conservation, and for those moments when we could let our hair down! I will carry these lessons throughout my career.

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CHAPTER I

INTRODUCTION

Bats serve a variety of ecological roles such as insect predators, prey, pollinators, and seed dispersers. As a taxonomic group, bats serve as indicators of forest health (Fenton 2003) because of their sensitivity to pollution (Hickey et al. 2001) and habitat disturbances (Medellin et al. 2000). However, research on bats has been limited in the field of wildlife management and conservation. Miller et al. (2003) reported that only 56 studies concentrating on habitat management for forest-roosting bats have been published from 1980 to 2001. This paucity of research on forest-dwelling bats is most likely due to their elusive behavior that makes them difficult to find and easily overlooked. In comparison, O'Shea et al. (2003) documented an increasing interest in bats in scientific research. They found 29 articles concerning bats published in "*The Journal of Wildlife Management*" and "*The Wildlife Society Bulletin*" between 1992 and 2001, of which, 22 were published from 1999 to 2001. This increase in publications could allow researchers to understand and identify life requirements and habitat use by bats, increasing likelihood of more efficient conservation planning for the species. To meet requirements for biodiversity management in forested systems, increased information is needed on ecological aspects that retain or create habitat components needed by bats and other wildlife species. For more effective conservation of forest dwelling bats, additional information is needed on development of cavity trees and use of these trees by bats as roost sites. A greater understanding of influential factors in cavity development among different tree species and age classes within different habitat types and successional stages can allow managers to plan for cavity tree retention and recruitment over time (Fan et al. 2003*a*).

Due to few research and monitoring programs, conservation status of many bat species is unknown. Research conducted on Rafinesque's big-eared bat *(Corynorhinus rafinesquii)* and southeastern myotis *(Myotis austroriparius)* have indicated use of certain roosting habitat; however, population status remains unknown (O'Shea et al. 2003). Research has shown that many bats in the southeast including Rafinesque's big-eared bat (RBEB) and southeastern myotis (SEM) use bottomland hardwoods (Cochran 1999, Hoffman 1999, Clark 2003, Trousdale and Beckett 2005). Fredrickson et al. (2005) reported that over 80% of bottomland hardwood forests of the southeastern United States have been lost or degraded. Due to this loss of possible roosting habitat within the range of RBEB and SEM, populations are suspected to be declining throughout. Further studies are needed to address actual numbers and what factors, if any are limiting.

Some studies have documented use of large diameter cavity trees as roosts by RBEB and SEM thus suggesting that conservation of such trees that have cavities or those with potential to produce cavities is important (Cochran 1999, Hoffman 1999, and Trousdale and Beckett 2005). Other studies have reported *Nyssa spp.* to be an important roosting site for RBEB and SEM (Cochran 1999, Hoffman 1999, Lance et al. 2001, Gooding and Langford 2004, Mirowsky et al. 2004). However, extensive research has not been conducted to define specific tree characteristics that may influence roost selection or use by bats. Furthermore, no published studies have reported seasonal changes in roost availability or roost selection by these species. Kunz (1982) suggested that few studies have determined cavity availability to assess type of cavities bats are using as roosts. Miller et al. (2003) stated that researchers should distinguish between male and female roost site and habitat selection among different species. According to Miller et al. (2003), future research should focus on one or two species for radiotelemetry studies because different species or different gender of the same species can have specific habitat or roost selection criteria.

In this study, I address the paucity of information on diurnal tree roost sites used by RBEB and SEM in bottomland hardwood forests of the Upper Gulf Coastal Plain of the southeastern United States. The primary objectives of this study were to characterize availability of diurnal roosts for RBEB and SEM and to evaluate bat use of diurnal roosts on a seasonal basis by these species. This study will help develop habitat conservation measures and silvicultural approaches that integrate retention of natural roost sites with forest management in bottomland hardwood forests.

Literature Review

Various questions arise when inspecting published literature on bat ecology, especially habitat use and roosting requirements. To discern solitary or colonial use of roost sites, we must first define a colony. Chung-MacCoubrey (2003) defined a colony numerically as ≥ 5 bats while investigating repeated use of trees by bats. Fenton (2003) suggested that bats using the same tree cavities, but in different clusters may be different colonies. It may be difficult for field researchers to discern separate colonies where this occurs. Bat species or individuals in colonies may use resources differently than those roosting solitary, and it is important to refine these differences. Research could be more efficient and management could be more site and species specific if colony behavior and movement patterns were defined. However, trees or structures that consistently support groups of bats may be important to maintain on the landscape. Therefore, research defining habitat use by large groups of bats is needed regardless of colony definitions. This information may be especially important for advancing knowledge concerning conservation of bats that occur in lower numbers than more abundant species (J. Gore, Florida Wildlife Commission, personal communication).

Clark (2003) stated that 61% (11 species) of bats in the southeast occur in bottomland hardwood forests including RBEB and SEM. Several studies have shown importance of conserving large diameter cavity trees, particularly *Nyssa spp.*, and have recommended conservation of bottomland hardwoods and retention of living cavity trees for cavity roosting bats (Cochran 1999, Hoffman 1999, Gooding and Langford 2004, Mirowsky et al. 2004, and Trousdale and Beckett 2005). It has been assumed that potentially low population numbers of RBEB and SEM are due to loss of roosting sites in bottomland hardwood forests (Clark 2003). However, other possible limiting factors need to be researched if conservation of these species and their habitats is warranted. Potential factors that may inhibit RBEB or SEM from using available roost sites or habitats are not fully investigated. Radiotelemetry of RBEB in South Carolina by Menzel et al. (2001), revealed use of upland pine habitat types for foraging. This habitat association was not previously known, and they indicated that RBEB could be influenced by forest management practices in upland forests (Menzel et al. 2001). These associations need further investigation to determine what factors influence use of these habitat types by RBEB and if SEM have similar habitat requirements. Surrounding habitats or landscape variables may influence bat use of some areas. Future research of foraging habitat of these bats may reveal important habitat associations that have not yet been considered. This increased knowledge could provide management guidelines for upland forests juxtaposed with bottomland hardwoods containing these potentially rare bat species.

Limited information is available for determining roost-tree selection by bats. Radiotelemetry allows researchers to record data on individuals and may provide indications of roost fidelity. Roost counts and observation can give information on resource use. Long-term studies of re-use of roost trees by bats have been conducted within pinyon-juniper (*Pinus edulis – Juniperus spp.*) woodlands of New Mexico (Chung-MacCoubrey 2003). In this study, 15 roost trees were observed to be re-used by a colony of unspecified bat species 3 out of the 4 summers they were monitored. Chung-MacCoubrey (2003) found that long-term fidelity existed due to the fact that certain trees were re-used more than others. However, absence of bats does not necessarily indicate non-use. She suggested protection of existing roost trees and recognized a need to identify characteristics of re-used trees. Other studies have examined use of more permanent man-made roosting sites. Artificial roosting structures may have greater longevity than cavity trees, and in some cases are easier to locate making roost site fidelity easier to determine. Lance et al. (2001) found that bats frequently alternated use of bridge and tree roosts. They also found that RBEBs more often roosted under bridges found near mature hardwood forests. This relationship shows that bats use both natural tree roosts and available man-made structures. Trousdale and Beckett (2005), radiotracked bats found under bridges to 14 roost trees in southeastern Mississippi. Bats were found in water tupelo *(Nyssa aquatica)* and southern magnolia *(Magnolia grandiflora)*. In this study, RBEBs roosted in large trees (mean diameter at breast height = 80cm) and distances between tree roosts remained small (mean distance = 356.7 m). Lewis (1995) suggested that availability of roosts affects roost site fidelity by bats - where roost availability is low, roost site fidelity is high; conversely, where roost availability is high, roost site fidelity will be low. In the latter scenario, bats may show a more opportunistic behavior when choosing from an abundance of roosting sites. However, studies have not shown relationships between roost site availability and use by bats. Collective results of these studies and others indicate that known roosting sites, artificial or natural, should be protected in management plans for conservation of RBEB or SEM.

Some studies suggest that selection of roost trees may depend on landscape qualities than individual tree characteristics. Grindal (1999) while studying *Myotis spp*. in Newfoundland found that edges were important in roost site selection and that creation of corridors would increase accessibility to roosts. Implications of these findings and suggestions for bats indigenous to southeastern forests of the U.S. remain unclear. Radiotelemetry revealed that red bats (*Lasiurus borealis*) in east central Mississippi roosted in limited areas suggesting that landscape level features may have had greater influence on roost site selection than individual tree characteristics (Elmore et al. 2004). Other bat species may react to different factors. Mirowsky and Horner (1997) stated that individual roost tree characteristics may be more important than the microhabitat directly surrounding the roost tree for RBEB and SEM. However, this study did not quantify landscape level variables and measurements were taken within bottomland hardwood forests where bats were currently roosting. Therefore, it is unknown what landscape variables may have affected RBEB and SEM ability to find roost habitat. Certain physiographic features, such as topography, may determine microsite characteristics that bats require for roosting, foraging, and other activities. Considering research findings thus far, habitat conditions at both macro- and microhabitat scales potentially influence roost selection in southeastern bat species (Elmore et al. 2004, Mirowsky and Horner 1997).

Selection of roosting or foraging habitat by bats could be based on prey availability, varying habitat characteristics, or any combination of factors. Menzel et al. (2001) reported RBEBs foraging in upland pine (*Pinus spp*.) and Hurst and Lacki (1999) found RBEBs foraging in oak-hickory (*Quercus spp. – Carya spp.*) forests. Hurst and Lacki (1999) also stated a relationship between RBEB habitat use and occurrence of an important dietary item, a moth (*Catocala spp.*) which feeds on oaks and hickories during the larval stage. More research is needed to clarify relationships between habitat use and prey availability. However, other studies have suggested that roosting sites may be influenced by proximity to water or foraging sites (Grindal 1999). Other studies found that roost sites were close to alternate roosting sites such as other available cavity trees, bridges, or other man-made structures (Trousdale and Beckett 2005). Therefore, distribution of forest bats may be influenced by foraging habitat, prey availability, roost availability, and adjacent habitat types.

Justification

Wildlife management has historically concentrated on requirements for game species. With the increased interest in conservation of biodiversity and a more holistic approach to management, we are continually revealing habitat features and conditions that are important for maintenance and conservation of many other species. Cavity trees within forest stands are one such important habitat feature. Cavity trees used as roosting sites by bats are important sites for hibernating, mating, food digestion, young-rearing, and numerous social interactions (Kunz 1982). Use of cavity trees in bottomland hardwood forests by RBEB and SEM has been documented repeatedly (Cochran 1999, Hoffman 1999, Lance et al. 2001, Clark 2003). However, previous studies have not provided information on cavity tree species and availability within habitat areas or size classes, or provided morphological measurements of cavity trees or selection of cavity trees by bats.

Several authors have emphasized importance of forest and landscape level conditions for bats. Clark (2003) supported importance of surveying different habitat types due to the possibility that variability in hardwood forests can influence roosting structures for bats. Additionally, landscape characteristics such as distance to water or other roost structures, and canopy density may be significant to roost use or selection (Kalcounis-Ruppell et al. 2005). Limited information is available on influence of landscape characteristics and in-stand characteristics on roosting patterns of RBEB and SEM. Therefore, my study was designed to examine landscape features, microsite characteristics of roost sites, and forest stand conditions surrounding cavity trees used by bats and those not used by bats in bottomland hardwood forests of Noxubee National

Wildlife Refuge (NNWR). Implications of this study may provide managers with guidelines to consider in forest management to conserve habitat for RBEB and SEM at microsite levels, such as roost sites, and at forest stand levels.

This study also accounts for man-made structures that are used as roosts by these species. Clark (2003) stated that structures, such as bridges, cisterns, and wells play an important role in the population status assessment of these species. Preservation of these sites may be important to the conservation of RBEB and SEM. Furthermore, recommendations for habitat conservation and management for these species derived from this research will be incorporated into the wildlife and habitat management planning on NNWR and other public forest lands of Mississippi.

Objectives

1. Determine availability and use of tree cavities by RBEB and SEM within mature bottomland hardwood forests on NNWR.
2. Determine seasonal use of tree cavities by RBEB and SEM within mature bottomland hardwood forests on NNWR.
3. Examine cavity tree selection and describe tree characteristics used by RBEB and SEM within mature bottomland hardwood forests on NNWR.
4. Examine use of bridges and other artificial structures used as diurnal roosts by RBEB and SEM on NNWR.
5. Provide recommendations for forest management and sustainable production of cavities within bottomland hardwood forest types for protection and production of diurnal roosts for RBEB and SEM at NNWR.

CHAPTER II

RESEARCH DESCRIPTION AND METHODOLOGY

Study Area

My study was conducted on Noxubee National Wildlife Refuge (NNWR) in Oktibbeha, Noxubee, and Winston Counties, MS, USA. (Figure 2.1) The refuge was located in the Upper East Gulf Coastal Plain (Brady and Weil 2002). Average annual precipitation at NNWR was 143.18 cm based on readings obtained from 1971-2000 at an on-site weather center. The refuge consisted of 19,425 ha with 6,227 ha of bottomland hardwood forest (U.S. Fish and Wildlife Service 2005). Noxubee NWR was devoid of caves as is much of Mississippi. Study sites selected for this research covered 1,253 ha of bottomland hardwood forest type. Bottomland hardwood stands at NNWR typically had an overstory of sweetgum *(Liquidambar styraciflua)*, black tupelo *(N. sylvatica)*, baldcypress *(Taxodium distichum)*, American beech *(Fagus grandifolia)*, mockernut and pignut hickory *(Carya tomentosa, C. glauca)*, and several species of white oaks (*Quercus michauxii, Q. lyrata)* and red oaks *(Q. pagoda, Q. nigra, Q. phellos)*. Understory vegetation typically consisted of American hornbeam *(Carpinus caroliniana)*, American holly *(Ilex opaca)*, and winged elm *(Ulmus alata*). Bottomland hardwood forests were transected by the Noxubee River and associated tributaries. Periodic inundations generally occurred annually within the Noxubee River floodplain and duration of each flood event was typically 3 -5 days, primarily during January - April (D. Richardson, U.S

Fish and Wildlife Service, personal communication). Five main tributaries were located in the Noxubee River watershed including Chinchahoma Creek, Hollis Creek, Jones Creek, Loakfoma Creek, and Oktoc Creek (U.S. Fish and Wildlife Service 2005). Four study sites were selected within NNWR based on accessibility, composition of hardwood forests, and historical harvest information (Figure 2.2). The following habitat descriptions for each site were obtained through unpublished records and personal communication with NNWR staff. Study site 1 was 445 ha of proposed wilderness area that had not undergone silvicultural treatment in 70 years. Most of this area was a >100 year old oak-hickory forest with an overstory co-dominance of American beech in the western portion. Baldcypress was the primary dominant tree species in hydric sites of streams and backwater sloughs.

Study site 2 was located on Green-tree reservoir (GTR) #1. This GTR was 142 ha located south of Noxubee River and north of Oktoc Creek. About 50 -60 ha of this area was flooded annually from late November to mid February. Estimated age of the overstory was 70-110 years and was characterized by a dominance of oaks (*Q. michauxii, Q. lyrata,* and *Q. pagoda*), mockernut and pignut hickory, and sweetgum. Riparian habitat contained baldcypress trees with >150 cm diameter at breast height.

Study site 3 was approximately 385 ha and was located north of Oktoc Creek and south of Noxubee River. This site contained numerous sloughs and other wetland habitat with significant amount of oak senescence, producing a high number of snags. Forest composition differed from previously described sites with white oak *(Quercus alba)*, red hickory *(Carya glabra var. odorata)*, and sugarberry *(Celtis laevigata)* included in the overstory, and water plantain *(Alisma subcordatum)*, wild azalea *(Rhododendron spp.)*, American elm *(Ulmus americana)*, and sweetbay magnolia *(Magnolia virginiana)* composing the understory. This site also contained numerous sloughs and other wetland habitat. Openings created by tree die-off exhibited dense coverage of vines such as greenbriar (*Smilax spp*.), blackberries (*Rubus spp*.), kudzu (*Pueraria montana*), and climbing hempvine (*Mikania scandens*). Overstory was estimated at 25-30 years in disturbed areas, whereas, more pristine areas contained overstory trees that were ≥100 years of age.

Study site 4 was located in the Jones Creek bottomland hardwood area and was approximately 281 ha. The site was bordered by Oktoc Creek to the north and moist soil impoundments with intermittent drains to the south. Various secondary and tertiary streams transected this area and baldcypress was typically growing along these stream banks. Forest stand composition in this area has been influenced historically by over bank flooding from streams and inundation caused by North American beaver (*Castor canadensis*). Red maple and sweetgum dominated areas that were previously flooded. The eastern portion of the study area contained Nuttall Oak (*Quercus nuttallii*), which was not found in other study areas.

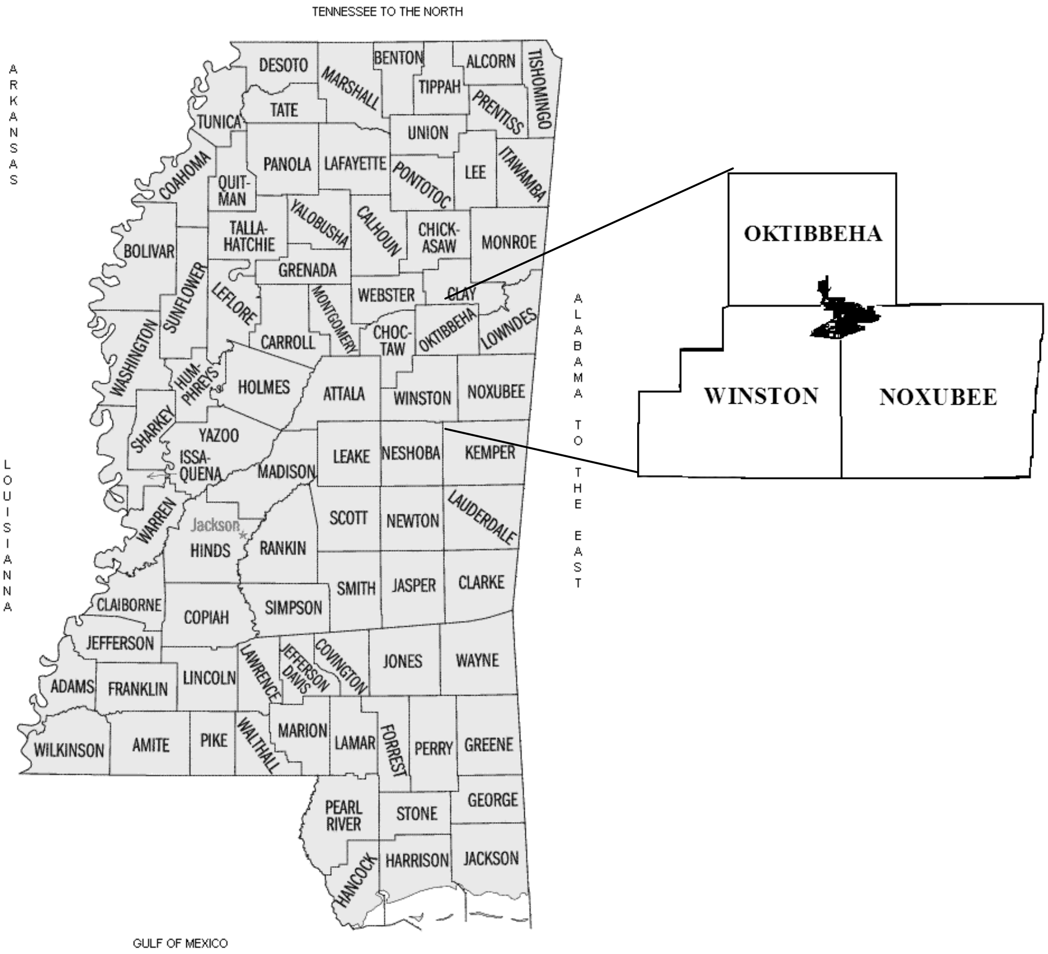

Figure 2.1 Noxubee National Wildlife Refuge located in Oktibbeha, Winston, and Noxubee counties in Mississippi in 2007.

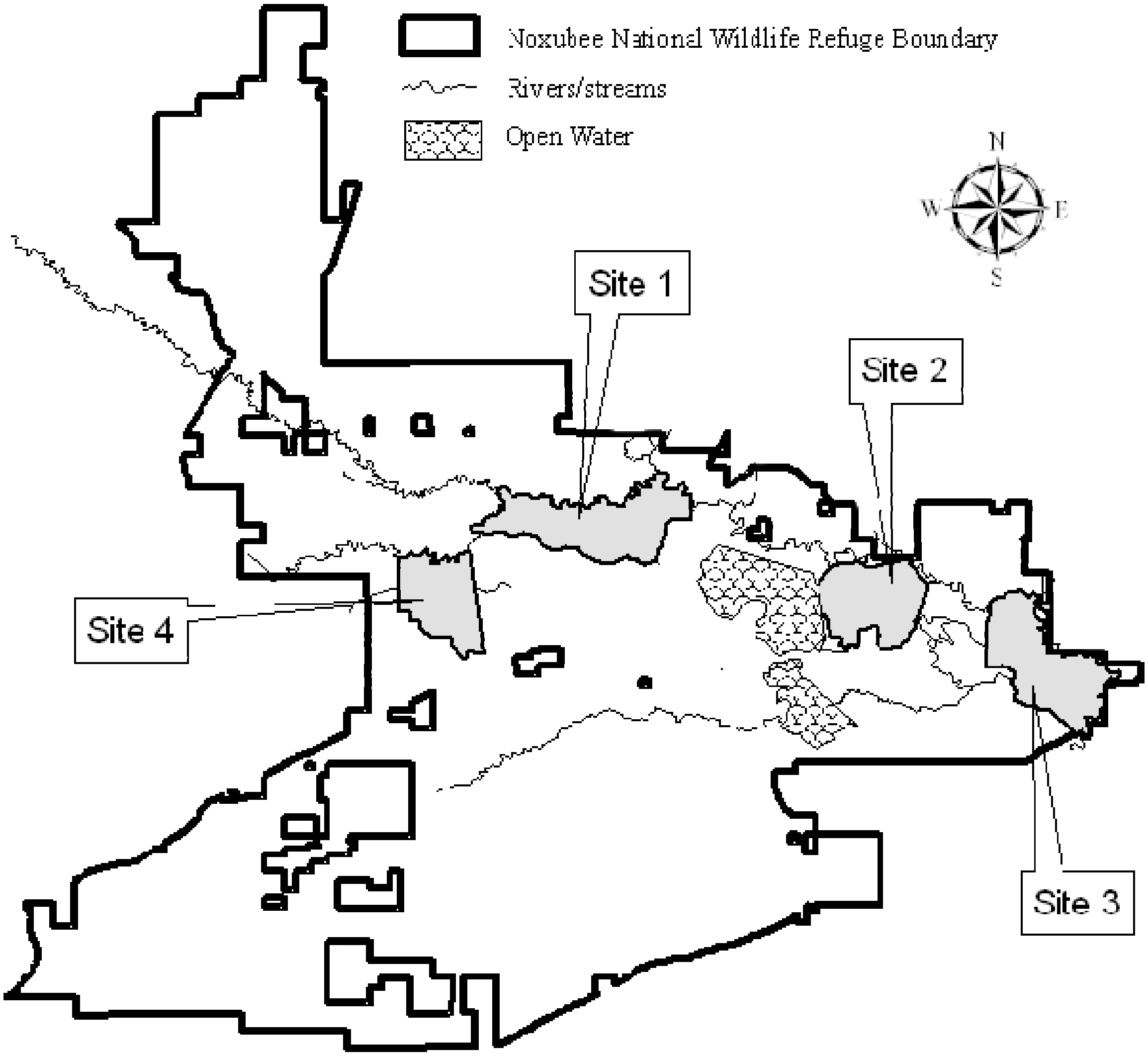

Figure 2.2 Study sites for cavity tree surveys conducted on Noxubee National Wildlife Refuge in northeast Mississippi. The four study sites were located within bottomland hardwood forested areas during 2005-2007.

Methods

Sampling design. - To determine availability and abundance of cavity trees in bottomland hardwood sites at NNWR, I surveyed the forest stand composition and recorded cavity trees found on 10% of each study site. Pre-sampling surveys were conducted in site 2 and bottomland hardwood areas not included as study sites during 2005. Cavity trees near easily accessible roads and trails were located and surveyed to determine presence of target bat species. Sampling intensity and study site locations were developed from these preliminary surveys. Using GIS (Geographic Information System) software and aerial photographs, a systematic grid was placed across the study areas (Figure 2.3). I configured grid points to equal 10% of the area (i.e. 1 point/4 ha = 10%) to ensure uniform coverage of the site (Oosting 1956). A 100% survey of the plot area began at each grid point. Each plot was 40 m ×100 m (0.4 ha). After analyzing estimated cavity tree density found within Site 2, the plot area was increased to 40 m × 200 m (0.8 ha, Figure 2.4) to improve precision and accuracy. Grid points were then placed at 1 point/8 ha for subsequent surveys in the remaining 3 sites maintaining a 10% survey of the sites. Direction of survey was established in one of 4 randomly selected cardinal directions from the grid point. A team of 3 people surveyed each plot. The center person stood at the grid point, as the other two members walked 20 m away from the center. The team walked in the previously randomly chosen direction for 200 m and searched for cavity trees (Figure 2.4). The plots did not cross forest type boundaries and direction was sometimes impeded by water features or tree blow downs. In the event that an area could not be traversed, either another direction was chosen randomly, or the plot was offset to accommodate mobility.

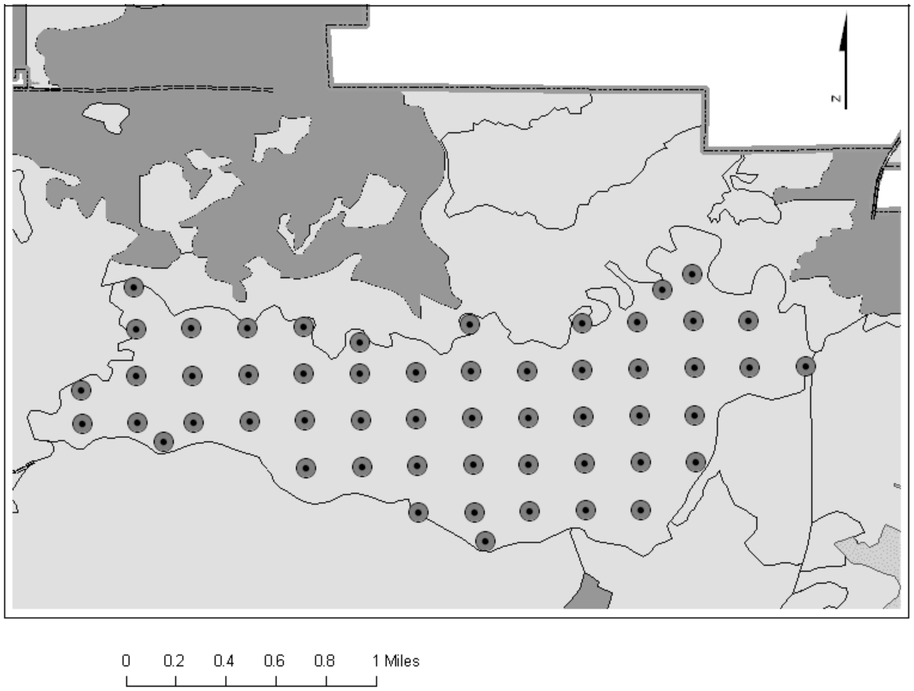

Figure 2.3 Site 1 overlaid with systematic grid generated using ArcView® in 2005 to locate starting point of plot surveys with a handheld GPS unit. Four study sites were located at Noxubee National Wildlife Refuge in Mississippi.

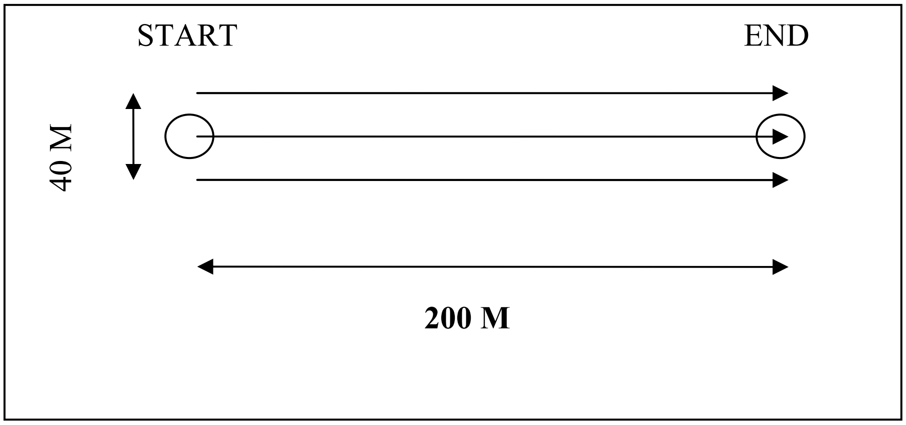

Figure 2.4 Diagram of plot survey design for locating cavity trees at Noxubee National Wildlife Refuge, Mississippi during 2005-2007. Lines represent path of surveyors and circles represent plot center of two 10-factor prism cruises conducted. Surveyors looked for cavity trees within the two outside lines.

Cavity tree measurements. - To ascertain morphology and characteristics of cavity trees, the following information was recorded for each cavity tree: species, diameter at breast height (DBH, cm), cavity type (basal, side, or top broken), and cavity measurements including opening height, opening width, chamber height, chamber width and wall width (cm). I also indicated when cavity trees were dead. All cavity measurements were taken with retractable measuring tape except chamber width and wall width. Chamber width was determined by drilling a hole into the cavity tree at breast height with a 9 mm drill bit and inserting a dowel rod delineated in inches. A reading was taken upon reaching the far wall of the chamber. This reading was the total of the chamber and the wall width. A notch was located at the tip of the dowel rod to determine the wall width. As the rod was drawn out of the hole, the notch would catch the side and the measurement was recorded. Wall width was subtracted from the first reading resulting in chamber width. Measurements were converted to centimeters for summary and analysis. Tree DBH was recorded in 5 cm diameter classes so that recommendations from this study would reflect forest habitat monitoring and inventory at NNWR. Stand cruises performed at NNWR typically record tree diameters in 5 cm diameter classes; therefore, results from this study would be easier to interpret and apply to management plans using the same classification (Noxubee National Wildlife Refuge staff, personal communication).

Cavity openings were classified as basal openings if they existed below breast height (1.4 m) higher openings were recorded as side openings. If there was evidence of breakage, researchers looked for broken trunks and branches at the tops of trees and recorded these types of openings as top openings. Also, top and side openings were found while examining trees with basal or low side openings for bats and noticing light from other openings.

Each tree cavity was inspected using a flashlight to determine presence of bats. In many cases where cavities were too small to be observed directly, a mirror was used in combination with a flashlight to reflect the chamber onto the mirror. Refuge staff created "windows" in 12 cavity trees to examine bat use of trees with inaccessible openings. This was achieved by cutting a rectangular opening with a chainsaw at approximately breast height. The extracted piece was replaced after each examination and the edges were sealed with foam to prevent a temperature change or wind current inside the chamber. Bats were identified based on characteristics and illustrations published by Menzel et al. (2002) and Harvey et al. (1999). A waypoint was taken at each cavity tree using a Global Positioning System (GPS) handheld unit and a unique numbered tag was placed on each tree to locate it for future examinations. I painted trees with a white band using tree-marking paint to facilitate relocation at later dates.

All GIS information and GPS locations were recorded as unprojected (geographic) Lat/Lon coordinates using NAD 1927 datum (Ormsby et al. 2001). This insured overall compatibility of coverage information. Aerial photographs taken in 2006 and digitized water body shapefiles provided by the Mississippi Automated Resource Information System were used to assess landscape measurements using ArcMap® 9.0 GIS software. These measurements were subjected to the possible error of the GPS unit at the time the waypoint was taken, which was typically <6 m. Landscape measurements included the following metrics (m): distance from the cavity tree to permanent water, winter available water, habitat edge, and distance to the next known cavity tree. Winter available water included low-lying areas that were typically flooded during winter. Habitat edge was defined by the place where study sites joined with areas that were different in vegetative composition from the study site. All measurements were taken for each cavity tree for comparative purposes.

This study included inspection of ancillary cavity trees to improve chances of encountering roosting bats and gain more information on cavity tree use. Ancillary cavity trees were defined as cavity trees that were found outside of the established plots or the 4 primary study areas. Characteristics for the selection criteria of ancillary trees were based on findings from previous studies which characterized cavity trees used by RBEB and SEM including large diameter, large basal cavities, or top broken trees that were hollow to the base (Clark 2003, Cochran 1999, Gooding and Langford 2004, Hoffman 1999, Trousdale and Beckett 2005). These attributes were assessed visually while performing cavity tree searches and examining cavities. The same measurements were recorded for ancillary cavity trees as cavity trees found within plots.

Forest stand composition. - Forest stand characteristics were determined within each plot to estimate species composition of forest overstory in each site. A prism cruise was performed at both ends of the plot (Figure 2.4) using a 10-factor prism. Species and DBH were recorded, measured in 5 cm diameter classes, for all trees $\geq$15 cm DBH within the plot. Snags also were noted.

Understory characteristics. - Understory vegetation characteristics were measured for comparison between bat use and non-use cavity trees within the same study site. I chose non-use trees that were similar to use trees in terms of DBH, cavity measurements, species, and location. These data were gathered during growing season from early May through mid-June 2007.

Four 1 m × 10 m transects were established at the base of each selected cavity tree. One transect began in the direction of the cavity, all other transects began 90 degrees from the cavity. In trees with only top-open cavities, transects were established at each cardinal direction, radiating outward from the tree. If water was present on one or more sides of the cavity tree, data was collected along transects that were accessible by walking. To discern influence of vegetation conditions relative to distance from the cavity tree, transects were disaggregated into 4 horizontal categories as follows: 0-2.5 m, 2.5-5 m, 5-7.5 m, 7.5-10 m. Horizontal categories were chosen by equally dividing the transect. Three vertical categories were established for vegetation height assessment as follows: ≤0.6 m, 0.6 m – 1.4 m, ≥1.4 m. Vertical categories were chosen based on forest characteristics and levels in which bats may fly when seeking roosts (Hunter 1990). To assess density of vegetation that might influence bat use of cavities, stems were counted within each of the 4 1 m × 2.5 m quadrats within the transect and recorded within the appropriate vertical categories. Bonham (1989) recommended using small quadrats (1 m × 2.5 m) to obtain densities of small plants. All stems that were <15 cm DBH were recorded in 6 growth form categories: woody, vine, herbaceous, grass, tree, or shrub (Miller and Miller 1999).

I used the line intercept method to determine percent coverage of vegetation (Hays et al. 1981). I recorded genus of every plant that intercepted each 10 m long transect and distance (cm) the plant covered within each of the aforementioned vertical categories.

Overstory characteristics. - Crown cover was measured using the GRS densitometer™ (Geographic Resource Solutions, Arcata, CA). Ten readings were recorded in each transect approximately 1 m apart beginning at the base of each cavity tree. This yielded 40 crown coverage readings per cavity tree. If water or major tree blow-downs impeded safe access, 30 readings were recorded within accessible transects. To describe the overstory composition, I performed a prism cruise 5 m from the cavity using a 10-factor prism (Higgins et al. 1996). I recorded species and DBH, measured in 5 cm diameter class of all trees ≥15 cm DBH within the plot (Duncan and Duncan 1988).

Surveys for cavity tree use by bats. - Cavity trees were examined at least once each season for bat use to determine relationships between cavity tree characteristics and seasonal use. The following time periods were used to determine season of surveys: winter- late November – early March; spring -late March – May; summer -June – early September; and fall -late September – early November.

Within the NNWR there were several artificial structures available for bat use including abandoned houses, bridges, and wells. Artificial roosts were inspected 4 times annually within each seasonal time period used for cavity tree surveys. There were 41 bridges traversing bottomland hardwood forest on or directly adjacent to NNWR. These bridges, as well as 7 abandoned buildings and 2 wells, were inspected by use of a flashlight during daylight hours typically between 0800 and 1600 (Trousdale and Beckett 2005). Bridge type (concrete, wood, or metal) and measurements (length and width) were recorded to determine any correlation between construction material or size and bat use.

Refuge staff constructed roosting habitat out of a metal culvert in winter 2005. The culvert was 90 cm wide and 10 m long and topped with plywood for a ceiling. Cypress boards were placed inside to provide texture for hanging bats. The culvert was placed along the edge of bottomland hardwood habitat about 200 m from the edge of site 1 near a road accessed only by refuge staff. Use of these structures is reported in Chapter IV and discussed qualitatively in Chapter V.

Radiotelemetry. - To assist in locating cavity trees used by bats, US Fish and Wildlife Service employees placed 0.6 g radiotransmitters (Blackburn Transmitters, Nacodoches, TX) on RBEBs and tracked them to roost sites. Radiotransmitters were attached with Skinbond® between the scapulae after shaving or cutting hair at the site of attachment. Bats were wrapped in cloth and held from 5 – 20 minutes so that refuge staff could assess health of the bat and ensure radiotransmitter attachment before releasing at the capture site. Radiotransmitters were usually 6% of the bat's weight which exceeded the ≤5% suggested by Aldridge and Brigham (1988). However, no adverse effects from radiotransmitter attachment were observed. The USFWS biologists gathered data on each captured bat including, weight (g), gender, species, and reproductive stage (pregnant or lactating). This information is discussed qualitatively in Chapter IV with regard to roost fidelity. These data were used to supplement information discerned from searches of cavity trees to identify trees used as roosts by bats. Roost trees discovered using this method were inspected throughout this study and collection of data on tree and forest stand characteristics was conducted. All USFWS employees conducting animal research adhered to the protocol as described by the American Society of Mammalogists.

Hypothesis Testing and Analysis

The following null hypotheses were evaluated:

H1 Availability and abundance of cavity trees are similar among tree species and size classes

Test: Simple linear regression and relative frequency and density comparisons

H2 The number of cavity trees used by bats is similar among tree species and size class (a separate hypothesis was developed for each bat species).

Test: Manly's alpha selectivity index and Kolmogorov-Smirnov test

H3 Presence/absence of bats is not related to site characteristics (a separate hypothesis was developed for each bat species).

Test: Logistic regression and Mann-Whitney 2-sample test

H4 Presence/absence of RBEB or SEM during winter is not influenced by cavity tree characteristics, proximity to water, and distance to habitat edge or other cavity tree.

Test: Logistic regression

H5 Seasonal use of cavity trees by SEM or RBEB is not influenced by cavity morphology or tree characteristics.

Test: one-way Analysis of variance (ANOVA)

H6 Presence/absence of SEM or RBEB in cavity trees is not influenced by cavity morphology, tree characteristics, proximity to water, or distance to habitat edge or other available cavity tree.

Test: Logistic regression

I calculated relative frequency of cavity trees within species and size classes to determine abundance of cavity trees in the 4 study sites. I calculated density (trees/ha) of cavity trees and density of trees found in prism cruises within tree species and size class. I compared these densities in a simple linear regression to assess availability in size classes.

Site characteristics were evaluated for differences between use and non-use trees by bats. I wanted to determine if vegetation density or structure prevented bat use of cavity trees. Percent coverage of woody and herbaceous plants and stem densities of vegetation surrounding cavity trees were analyzed to determine if vegetation characteristics influence bat use of cavity trees. Logistic regresssion analyses were used to assess the relationship between these vegetation measurements and bat use. Mann-Whitney 2-sample tests were used to determine if there was a difference between bat use and non-use trees with regard to basal area and canopy cover.

I used logistic regression analyses to determine relationships between bat use and cavity tree characteristics (DBH, cavity tree height and width, chamber height and width and wall width). Based on previous studies, I expected that bats used large diameter trees with large internal chambers. Trees with smaller openings or thicker walls were expected to be used in winter due to these characteristics possibly providing stable internal temperatures inside the cavity tree. Separate regression analyses were performed to determine relationships between use trees and landscape measurements (distance to water, other known cavity trees, and edge). I expected bats would use trees close to water courses to be closer to a source for feeding, drinking, or movement. Bats may use cavity trees close to habitat edge for similar reasons, foraging sites and corridors. These analyses were conducted separately from the cavity tree metrics due to difference in sample populations from two data sets. Cavity tree mseasurements were acquired in the field and landscape measurements were acquired using computer programs. There were missing data values for some tree characteristics due to morphology of trees. For example, I could not measure cavity openings in a tree with a top opening. I obtained all landscape measurements for trees in which a waypoint was obtained. Therefore, the two data sets were variable with regards to sample sizes. Conducting two different regression analyses increased number of samples used in each model.

I wanted to ascertain what cavity tree characteristics contributed to a tree being more suitable for roosting by bats among different seasons. Seasonal use of cavity trees was analyzed using one-way ANOVA after transforming data to meet the normality assumption (Dowdy and Wearden 1991). Cavity trees were the experimental units, treatment effects were seasons, and response variables were cavity tree characteristics. I checked these data for normality using the Shapiro-Wilk test (STATISTIX 2000). No assumptions of normality were required for logistic regression analyses; therefore, data did not need to be transformed (Morrison 2005). For the ANOVA, I used Fisher's F test to determine equality of variances (Dowdy and Wearden 1991, SAS Institute Inc. 2004).

To determine if bats used certain tree species and provide management guidelines accordingly, Manly's selectivity index was used to determine bat roost selection of tree species (Heisey 1985, Manly 1974). I used a Kolmogorov-Smirnov test to find out if bats were using tree species and size classes randomly. Non-parametric Mann-Whitney 2-sample test was used to determine differences in the stand characteristics between use and non-use cavity trees (Dowdy and Wearden 1991). I used one-way ANOVA to determine differences in stand composition among the four study sites. Experimental units were study plots, treatment effects were study sites and the response variable was basal area calculated from prism cruises. Normality and equality of variances assumptions were met.

CHAPTER III

CAVITY TREE AVAILABILITY WITHIN FORESTED STUDY SITES

Measurements of forest stand composition within bottomland hardwood study sites were used to determine cavity tree availability on the study sites. This inventory conducted during the same study period as surveys to determine bat use of cavity trees allowed assessment of roost site availability in conjunction with bat use of cavity trees. This approach allowed evaluation of forest stand characteristics of roost sites for RBEB and SEM. Furthermore, this information will provide a baseline for management guidelines to increase or sustain cavity trees at NNWR.

Methods

Forest stand measurements. - To determine cavity tree availability, I obtained and calculated forest stand measurements to describe the overstory vegetation present in the 4 study sites at NNWR. I completed 100 prism cruises with a basal area 10-factor prism in site 1, 68 cruises in site 2, 82 in site 3, and 56 in site 4 according to methods described by Oosting (1956). I calculated basal area (ft^2/ac) for each plot by summing total trees in each plot and multiplying by ten. I then converted to m^2/ha by multiplying the resulting basal area by 0.0929 m, then by 2.47 ha. Basal area metrics calculated for each plot were arranged according to site and used in an analysis of variance (ANOVA) to discern potential differences in mean basal area among the 4 study sites (Dowdy and Wearden

1991). Least squares difference (LSD) tests were used to compare sites to each other. Complete description of study sites and sampling methodology are discussed in detail in Chapter II.

I estimated tree density (trees/ha) from prism cruise data for each 5 cm diameter class and tree species. I assumed tree diameter was distributed evenly within each 5cm size class (B. Parker, Mississippi State University, personal communication). The computation (A. Ezell and B. Parker, Mississippi State University, personal communication) used was as follows:

$$(N_t /pt) \times Ft$$

where:

Nt = number of trees in each diameter class (t)

pt = number of cruise points

Ft = tree factor for BAF 10 prism cruise calculated as: diameter at breast height (DBH) × 2.75 = Plot Radius Factor (PRF); Area(A) $= \pi(PRF)^2$; $Ft = 43560ft^2/A$

The plot radius factor for a 10-factor prism indicates that for every inch of DBH a tree can be 2.75 feet from the point and be included in the tally (Avery and Burkhart 2002). The result of these computations was trees per acre (TPA) which I then converted to trees /ha (TPA × 2.47).

Calculations were derived for each site independently to detect differences in stand composition among the 4 study sites. The number of cruise points used in the formula was the number performed for that site in which calculations were made. The same computation was used to calculate trees/ha for each tree species. Individual tree densities were summed across size classes to obtain total trees/ha for each tree species. Tree species were identified according to Duncan and Duncan (1988).

Cavity tree availability. - I summed cavity trees found in plot surveys by species and size class in each site and calculated density (trees/ha) in the aforementioned categories. Plots in sites 1, 3, and 4 were 0.8 ha and in site 2 plots were 0.4 ha. I calculated density of trees in each site accordingly. To determine if effort to increase size of plots resulted in an increase in precision, I calculated coefficient of variation for the number of cavity trees found in each site. I calculated a ratio to determine propensity of a tree species or size class to exhibit cavities. This ratio was based on number of cavity trees of each species within a specified size class relative to all trees found within the same species and size class in prism cruises. This ratio was calculated as: density of cavity trees/density of trees found in prism cruises. The greater the ratio, the greater the likelihood for cavity occurrence in that species or size class. A simple linear regression was used to indicate the relationship between this ratio as a response variable with diameter classes. The ratio gives an estimation of cavity tree availability of a particular tree species or size class in the study sites at NNWR. Using density for the ratio calculation standardized the unit of measurement to compare two sample populations obtained by 2 different methods, prism cruises and plot surveys. Cavity trees were located using designated plot sizes and prism cruises were variable plot sizes.

To estimate abundance, I calculated relative frequency of cavity trees and trees located by prism cruises categorized by tree species and size classes. These data are discussed qualitatively regarding tree species and size classes. Also, and simple linear regression was used to determine if the incidence of cavities increased with DBH. The number of cavities in each diameter class was the response variable used in the regression with DBH as the predictor variable.

I summarized counts of ancillary cavity trees by species and sites. Ancillary cavity tree data could not be used in density calculations or comparisons with prism cruise data because of the method used to locate them. Ancillary cavity trees were not found in established plots and were located outside of designated plots or outside study site boundaries. Some of these trees were found during pre-sampling surveys while evaluating potential study sites. Others were found while conducting bat surveys, radiotracking bats to roost sites, or walking between designated study plots.

Cavity placement was recorded according to the location of cavity opening: basal opening, top opening, or side opening. This feature was discussed qualitatively relative to cavity tree availability. Refer to Chapter II for definitions of cavity placement terms.

Results

Forest stand composition. - Prism cruises conducted in the 4 study sites yielded 2,700 individual trees representing 36 tree species that were measured for the evaluation of forest stand characteristics in the 4 study sites at NNWR (Table A.1). Approximately 2-5% of trees located in prism cruises in the 4 study sites were snags. Sweetgum (*Liquidambar styraciflua*) was the most abundant species (n=506) overall and was the prevalent species in sites 1 and 4 comprising 24% (n=211) and 19% (n=97) of the stand composition respectively (Table A.1). Cherrybark oak (*Quercus pagoda*) was the second most abundant species over all sites (n=471) and was the most frequent species in sites 2 and 3 comprising 22% (n=143) and 20% (n=132) of the overall stand composition, respectively (Table A.1). However, density of sweetgum was greater in sites 2 and 3 showing that more sweetgums were in smaller class sizes compared to cherrybark oak. For example, 72% (82/113) of sweetgums in site 2 were in the <40 cm DBH size classes and only 1 sweetgum was found to be ≥70 cm DBH. By comparison, only13% (18/143) of cherrybark oaks were <40 cm DBH and 68 were found in the ≥70 cm DBH size classes in site 2. Size class distribution had an affect on densities where trees that were found in low numbers could have a high density and vice versa. Red maple (*Acer rubrum*) had the greatest recorded density for a tree species in site 4 (56.3 trees/ha) with >80% (61/72) of red maples being detected in the <40 cm DBH size classes (Table A.1). American hornbeam (*Carpinus caroliniana*) had the greatest density (22.6 trees/ha) in site 3; however, comprised <4% (n=23) of the tree species in that site (Table A.1).

Alternatively, frequency of swamp chestnut oak (*Quercus michauxii*) contributed >6% (n=44) to stand composition in site 3 but had a lesser density (8.9 trees/ha) than American hornbeam (Table A.1). All American hornbeams found in prism cruises in site 3 were <25 cm DBH. Swamp chestnut oak ranged in DBH from 20 to 105 cm with only 6 trees out of 44 in the <25 cm DBH classes. Larger trees such as, cherrybark oak, water oak (*Quercus nigra*), overcup oak (*Quercus lyrata*), and some sweetgum were the most frequent in terms of number of trees in all sites; however, smaller trees such as red maple and American hornbeam had greater densities.

Tree density decreased as DBH increased in all sites. Tree density was greatest in site 4 (222 trees/ha) compared to other sites, with >50% of trees found in <40 cm DBH size classes (Table 3.1). By comparison, only 34% of trees were found in the <40 cm

DBH size classes in the remaining sites. Site 3 had the least density (160.2 trees/ha) followed by site 1 (179.1 trees/ha) and site 2 (183.5 trees/ha; Table 3.1).

Basal area differed among the 4 study sites ($F_{3,302}$=2.59, P=0.053). Site 2 had the greatest basal area at 21.4 m^2/ha ± 0.89 and site 3 had the least basal area at 18.5 m^2/ha ± 0.7 (Table 3.2). The LSD test showed that site 3 was different from the other sites (Table 3.2). Data from prism cruises showed that there was a greater number of trees/ha in smaller size classes (<40 cm DBH). Graphically, densities of trees found in prism cruises relative to DBH, declined and began leveling off nearing zero at 50 cm DBH (Figure 3.1). Site 4 had the greatest tree densities in size classes ranging from 20 to 40 cm DBH; however this site had the least density of trees in the 15 cm DBH size class. All other sites had nearly the same density of trees in the 15 cm size class and all sites had peak densities at 15 to 20 cm DBH (Figure 3.1).

Table 3.1 Density of trees categorized in 5 cm diameter at breast height (DBH) size classes located by 10-factor prism cruises performed in four study sites at Noxubee National Wildlife Refuge, Mississippi during 2005-2007.

	Density (trees/ha)					
DBH (cm)	Site 1	Site 2	Site 3	Site 4	Mean	SE
15	35	33	28	14	27.5	4.9
20	35	34	27	59	38.9	7.0
25	18	25	23	40	26.5	4.9
30	15	17	18	26	19.2	2.5
35	16	14	15	24	17.0	2.4
40	13	14	8	20	13.8	2.4
45	11	12	10	13	11.3	0.7
50	10	8	6	9	8.0	0.9
55	7	7	7	5	6.5	0.5
60	5	5	6	3	4.5	0.6
65	4	4	5	4	4.2	0.3
70	4	3	3	2	2.9	0.4
75	3	3	2	1	2.3	0.3
80	2	2	1	<1	1.4	0.3
85	1	1	1	<1	1.0	0.2
90+	1	2	1	1	1.4	0.2
Total	179	183	160	222	186.2	

Table 3.2 Study site comparison of basal area (m^2/ha) calculated from prism cruises conducted in four study sites at Noxubee National Wildlife Refuge, Mississippi during 2005-2007.

Groups	n	$\bar{x}$	SE	t-Grouping
Site 1	100	20.6	0.71	BA
Site 2	68	21.4	0.89	AA
Site 3	82	18.5	0.70	BB
Site 4	56	20.8	0.83	AA

Cavity tree availability. - I located 622 cavity trees at NNWR, of which 144 were ancillary cavity trees. I found 478 cavity trees within designated boundaries of plot surveys. Of the total cavity trees found (n=622), 13% (n=81) were snags. The coefficient of variation (CV) decreased when plots were increased in size from the preliminary 0.4 ha plots to the subsequent 0.8 ha plots. In site 2 with the 0.4 ha plots, the CV was calculated as 1.32 and decreased to 0.74 in site 1 with 0.8 ha plots. The CV was 1.11 and 1.18 on sites 3 and 4, respectively. Most (558/622) cavity trees found exhibited basal openings. Approximately 10% (62/622) of cavity trees had more than one type of opening. Twenty-three tree species exhibited cavities at NNWR and these cavity trees ranged in size from 15 to 210 cm DBH. Densities of cavity trees peaked at around 35 cm DBH on each site (Table 3.3, Figure 3.2).

The number of cavity trees found decreases with increasing diameter ($R = 0.39$, $P = 0.002$). Cavity tree density also decreases as size class increases; however, when compared to trees within the prism cruise data, cavity tree densities were greater than what was available in forest stands in the >50 cm DBH size classes (Table 3.3, Figures 3.1, 3.2). The ratio of cavity tree density to prism cruise tree density showed that there was a greater prevalence of cavity trees in the large diameter size classes when compared to trees from the cruise data (Figure 3.3). The prism cruise data represented a sample of what type of trees are available within the forest stands of the 4 study sites. The greatest differentiation between the 2 groups was at 105 cm DBH showing that cavity development may be relatively high at this size class (Figure 3.3). Overall, this ratio and the tendency for cavities to be present increased as DBH increased ($R = 0.5$, $P \leq 0.001$).

Abundances compared between cavity trees and prism cruise trees revealed similar results. Relative frequency calculated for each size class showed that most cavity trees (55%) ranged in size from 25-50 cm DBH. The sample population of trees from prism cruises revealed that 55% of trees on these sites ranged in size from 35–60 cm DBH. Although this was a slightly greater size class range for most prism cruise trees compared to cavity trees, abundance of trees in larger size classes revealed the opposite. For example, relative frequency for size classes ≥100 cm DBH revealed that 6% of cavity trees compared to only 2.6% of prism cruise trees were found in this size class.

Some tree species did not exhibit cavity development until reaching a specific DBH, although prism cruise data shows that the tree species were present in small size classes (≤25 cm DBH) on the 4 study sites. Unlike sweetgum which exhibited cavities in trees ranging from 15 to 105 cm DBH (n=293), the least size classes in which cavities were found in baldcypress (*Taxodium distichum*) was ≥35 cm DBH (n=23). Similarly, American beech (*Fagus grandifolia*; n=55) and overcup oak (n=24) were only found with cavities in size classes ≥40 cm DBH.

Sweetgum was the most abundant cavity tree in all sites comprising 54% (260/478) of the overall cavity availability in plot surveys (Table A.2). Sweetgum cavity trees also were the greatest in density in all sites compared to other cavity tree species (Table A.2). Other species that commonly exhibited cavities included American beech, American holly (*Ilex opaca*), black tupelo (*Nyssa sylvatica*), and green ash (*Fraxinus pennsylvanica*). American beech cavity trees were detected most often in Site 1 and had the second highest density at 3.1 cavity trees/ha. Only sweetgum surpassed beech with 8.9 cavity trees/ha on that site (Table A.2). American beech was not as prevalent in other study sites. A comparison of cavity tree species to prism cruise trees showed that American beech was the species most likely to produce cavities in the bottomland hardwood sites at NNWR (Table 3.4). According to the ratio of cavity trees to prism cruise trees, an American beech from these study sites exhibited about a 93% chance of having a cavity (Table 3.4). The second greatest percentage of cavity presence in a tree species was 25.8% for American holly (Table 3.4). There were 13 tree species found in prism cruises that were not found in plot surveys for cavity trees; therefore, these species received 0% for cavity production in study sites at NNWR (Table 3.4).

Some of the least common tree species exhibited cavity production. For example, mean density of American sycamore (*Platanus occidentalis*) in prism cruise data was 0.7 ± 0.4 trees/ha; however, this species exhibited the third greatest occurrence of cavities in a tree species (Table 3.4). A similar situation occurred with black tupelo with an average density of 3.2 ± 0.5 trees/ha and it was the fourth greatest cavity producer in this study (Table 3.4). In contrast, some of the dominant species in prism cruise data did not commonly exhibit cavity development. Cherrybark oak had an average density of 15.4 ± 2.0 trees/ha; however, only 0.3% were found with cavities (Table 3.4). Red maple was more common than cherrybark oak with an average density of 30.5 ± 9.5 trees/ha; however, only 1.4% contained cavities (Table 3.4).

Three tree species that were not discovered in plot surveys were found as ancillary cavity trees. These species included post oak (*Quercus stellata*), southern red oak (*Quercus falcata*) and eastern cottonwood (*Populus deltoides*). Sweetgum was the most prevalent ancillary cavity tree species with 33 trees recorded. Sweetgum was followed by baldcypress and black tupelo both of which yielded 19 out of 144 total ancillary cavity trees (Table A.3). Only 4 baldcypress cavity trees were found within survey plot boundaries compared to 19 that were found as ancillary. Site 1 contained the greatest number of American beech (n=16) that were ancillary cavity trees; whereas more baldcypress and sweetgum ancillary trees were found on the remaining sites (Table A.3).

Mean DBH for ancillary cavity trees was 73 ± 3.4 cm compared with 44 ± 0.8 cm for plot trees. This is a conservative estimate because 13 ancillary trees were not measured to obtain DBH. These trees were either immersed in water and DBH could not be accurately or safely measured or they fell before measurements were taken. Five of these were large baldcypress located in streams estimated at $\geq$150 cm DBH.

Table 3.3 Density (trees/ha) and number (n) of cavity trees categorized by 5 cm diameter at breast height (DBH) size classes on four study sites at Noxubee National Wildlife Refuge, Mississippi during 2005-2007.

DBH	Site 1		Site 2		Site 3		Site 4		Mean Density	SE
	n	Density	n	Density	n	Density	n	Density		
15	2	0.2	0	0.0	0	0.0	0	0.0	0.0	0.05
20	10	1.0	4	0.3	11	1.2	2	0.3	0.7	0.22
25	18	1.7	16	1.2	16	1.7	4	0.7	1.3	0.25
30	10	1.0	18	1.3	18	1.9	3	0.5	1.2	0.29
35	17	1.6	16	1.2	22	2.3	10	1.6	1.7	0.24
40	10	1.0	25	1.8	20	2.1	5	0.8	1.4	0.31
45	16	1.5	14	1.0	13	1.4	7	1.2	1.3	0.12
50	13	1.3	6	0.4	9	0.9	8	1.3	1.0	0.20
55	8	0.8	2	0.1	10	1.1	2	0.3	0.6	0.21
60	12	1.2	4	0.3	6	0.6	5	0.8	0.7	0.18
65	16	1.5	6	0.4	6	0.6	2	0.3	0.7	0.28
70	10	1.0	0	0.0	3	0.3	1	0.2	0.4	0.21
75	6	0.6	6	0.4	2	0.2	3	0.5	0.4	0.08
80	4	0.4	1	0.1	0	0.0	0	0.0	0.1	0.09
85	4	0.4	0	0.0	0	0.0	0	0.0	0.1	0.10
90	3	0.3	0	0.0	3	0.3	1	0.2	0.2	0.07
95	1	0.1	0	0.0	0	0.0	0	0.0	0.0	0.02
100	1	0.1	1	0.1	0	0.0	0	0.0	0.0	0.02
105	4	0.4	0	0.0	0	0.0	0	0.0	0.1	0.10
110	1	0.1	0	0.0	0	0.0	0	0.0	0.0	0.02
115+	0	0.0	0	0.0	1	0.1	0	0.0	0.0	0.03
Total	166	16.1	119	8.6	140	14.7	53	8.7	12.0	1.96

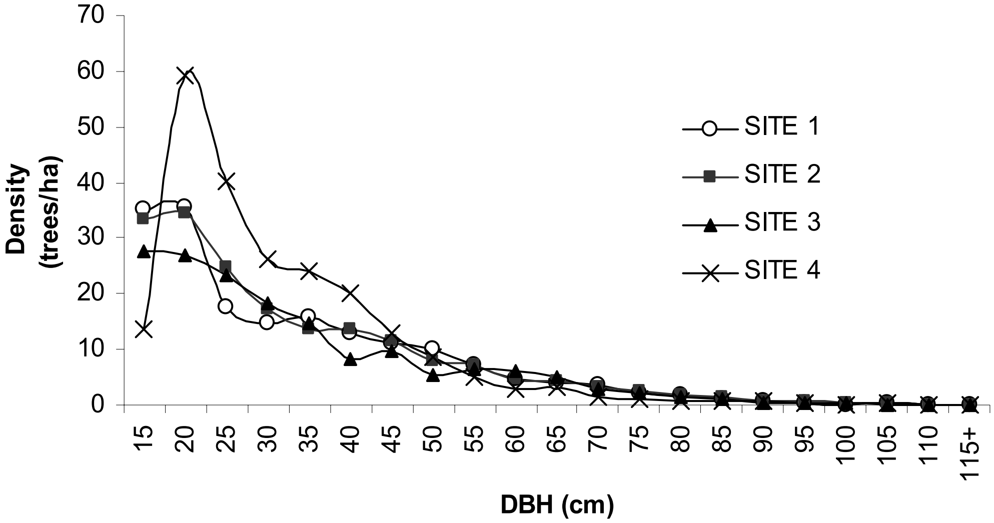

Figure 3.1 Average density (trees/ha) of all trees found in prism cruises conducted in four bottomland hardwood forest habitat sites at Noxubee National Wildlife Refuge, Mississippi during 2005-2007. Data were recorded in 5 cm diameter at breast height (DBH) size classes.

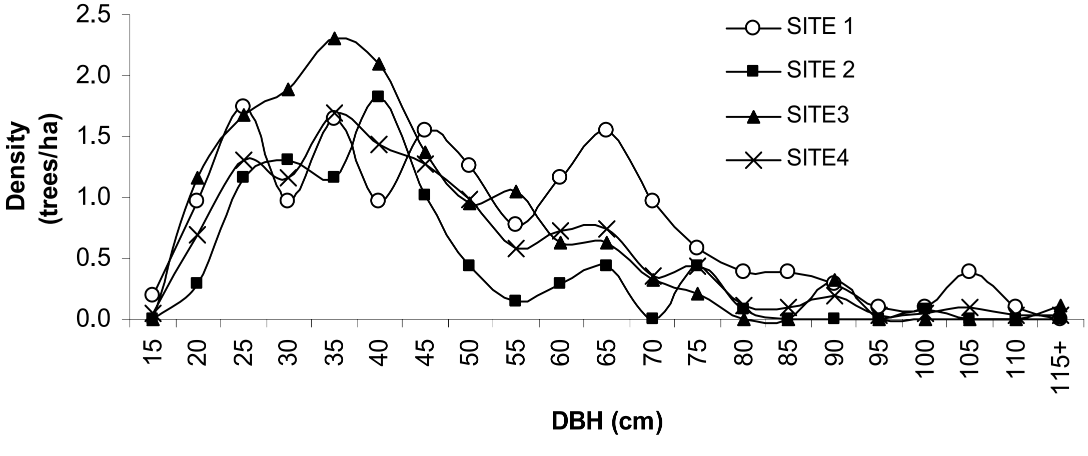

Figure 3.2 Average density (trees/ha) of cavity trees found in fixed plot surveys conducted at Noxubee National Wildlife Refuge, Mississippi during 2005-2007. Four study sites were surveyed in bottomland hardwood forest habitat. Data were recorded in 5 cm diameter at breast height (DBH) size classes.

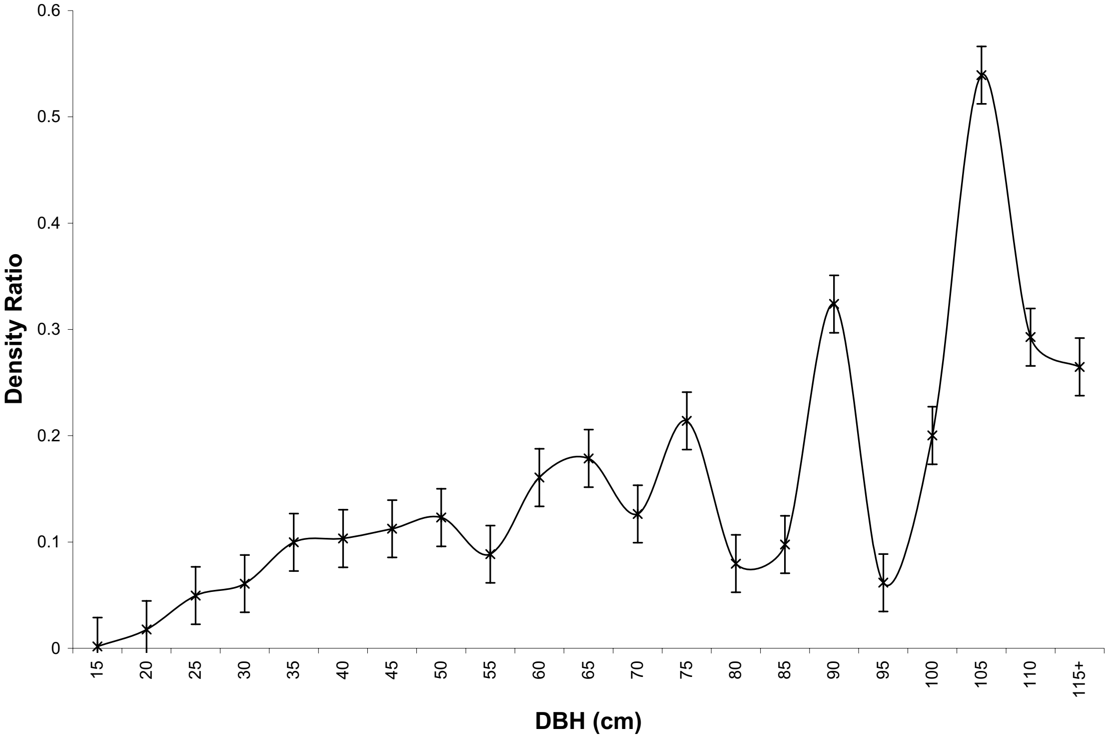

Figure 3.3 A ratio of the average density (trees/ha) of cavity trees found in fixed plot surveys to trees located in 10-factor prism cruises shown in 5 cm diameter at breast height (DBH) size class. Surveys were conducted in four bottomland hardwood forest study sites at Noxubee National Wildlife Refuge during 2005-2007. Ratio was calculated as follows: cavity tree density/cruise tree density. The ratio shows that the number of cavity trees increases in larger size classes in relation to trees found in prism cruises.

Table 3.4 Percentage of the densities of trees found with and without cavities at Noxubee National Wildlife Refuge, Mississippi. Percentage compares cavity trees located in plot surveys to trees found during prism cruises in four study sites during 2005-2007.

Tree species found to have cavities		Tree Species found to have no cavities	
Tree Species	Percentage with cavities	Tree Species	Percentage with cavities
American beech *Fagus grandifolia*	92.9	Black willow *Salix nigra*	0
American holly, *Ilex opaca*	25.8	Loblolly pine, *Pinus taeda*	0
American sycamore *Platanus occidentalis*	18.7	Red mulberry *Morus rubra*	0
Black tupelo *Nyssa sylvatica*	17.8	Nuttall oak *Quercus nuttallii*	0
Sweetgum *Liquidambar styraciflua*	15.6	Northern red oak *Quercus rubra*	0
Green ash *Fraxinus americana*	10.8	Red hickory *Carya glabra var. glabra*	0
Sugarberry *Celtis laevigata*	9.5	Scarlet oak *Quercus coccinea*	0
Pignut hickory *Carya glabra*	7.3	Sassafras *Sassafras albidum*	0
Shagbark hickory *Carya ovata*	5.9	Slippery elm *Ulmus rubra*	0
Persimmon *Diospyros virginiana*	4.0	Swamp laurel oak *Quercus laurifolia*	0
Overcup oak *Quercus lyrata*	3.4	Sugar maple *Acer saccharum*	0
White oak *Quercus alba*	3.3	Shumard oak *Quercus shumardii*	0
American elm *Ulmus americana*	2.6	Southern red oak *Quercus falcata*	0
Water oak *Quercus nigra*	2.1		
Mockernut hickory *Carya tomentosa*	2.1		
Swamp chestnut oak *Quercus michauxii*	2.0		
Winged elm, *Ulmus alata*	1.7		
Yellow-Poplar *Liriodendron tulipifera*	1.7		
Willow oak *Quercus phellos*	1.6		
Red maple, *Acer rubrum*	1.4		
Baldcypress *Taxodium distichum*	1.3		
American hornbeam *Carpinus caroliniana*	1.1		
Cherrybark oak *Quercus pagoda*	0.3		

Discussion

In my study, a greater number of cavity trees existed in larger (≥50 cm DBH) size classes relative to overall availability found in prism cruises. Trees exhibited an increase in relative cavity availability as diameter size increased (Figure 3.3). Other studies concur that incidence of cavity trees increases with increasing diameter (Allen and Corn 1990, Fan et al 2003*b*). According to Fan et al. (2003*b*), stand age and tree size were important indicators of cavity abundance in Missouri. Fan et al. (2003*b*) found a greater abundance of cavity-prone species in old-growth sites. In his study, individual forest stands of different age classes were compared. In this study; entire study sites were surveyed and not divided by age classes, topography, or composition. The possible variation in age class structure in the study sites prevents this type of comparison. However, older trees also are usually larger trees and thus, tree size is correlated (Fan et al. 2003*b*). Fan et al (2003*a*) found that increasing basal area also increased proportion of plots found with cavities. In my study, site 2 exhibited the greatest average basal area; however, it had the least density of cavity trees compared to the other 3 study sites. Variation in forest stand parameters over the large study sites likely prevented detection of a relationship between cavity tree density and basal area. If sites were categorized into forest stands with different age-class trees, basal area could be a predictor for cavity production at NNWR (Fan et al 2003*a*).

Tree species that were most likely to exhibit cavities were American beech, American holly, American sycamore, black tupelo, and sweetgum. For some species, cavity production may not be prevalent until the tree reaches a certain size or age class. Density of baldcypress was greater in prism cruises than in cavity trees found in plot surveys; however, the least size recorded for baldcypress cavity trees was $\geq$35 cm DBH. Baldcypress in lesser size classes were identified in prism cruises thereby producing a greater availability of this tree species in the sites than what was detected as cavity trees in plot surveys. American beech and overcup oak cavity trees also were found in larger $\geq$40 cm DBH size classes. Although cherrybark oak trees were found in large size classes in prism cruises, relatively few of them had cavities. Therefore, cherrybark oak may be less susceptible to cavity formation than other trees in the same size class. Cavity development has been associated with certain tree species and with age and size class of forest stands. However, more research is needed to determine a threshold size classes of cavity development for individual tree species (Allen and Corn 1990; Fan et al.2003*a,b*; McClelland 1979) .

Site conditions and location may be another reason that cavity prevalence of some tree species may be overlooked. Some species are more likely to grow near water or edge where they may be missed during plot surveys that are placed throughout the stand. Concentrating plot surveys along streams, wetlands, and edge may yield different tree species that are prevalent cavity producers in these microhabitats.

Several species that were found in prism cruises were not cavity producers. Some species were rarely found and were concentrated in certain areas. Nuttall oak (*Quercus nuttallii*), swamp laurel oak (*Q. laurifolia*) and scarlet oak (*Q. coccinea*) were rare occurrences at NNWR ($n < 10$), and. were concentrated in small areas of study sites. Allen and Corn (1990) found scarlet oak to be an important cavity producer in Missouri oak-hickory forests. A larger sample of these more rare species in bottomland hardwood forest at NNWR, could lend different results. In contrast, loblolly pine (*Pinus taeda*) and black willow (*Salix nigra*) were found much more frequently and never had cavities.

Inclusion of ancillary cavity trees was important in detecting cavity trees that were less common or localized in distribution across study sites. For example, American sycamore was detected as an important cavity tree due to inclusion of ancillary cavity trees. This species was only found along the edge of rivers and streams. Although some plots were located along streamsides, I found only 5 American sycamores within survey plots. Five additional sycamore trees were located as ancillaries while walking along streams searching for the next plot. Post oak, southern red oak, and eastern cottonwood cavity trees were found along road edges, but not located in plot surveys. American sycamore and eastern cottonwood were uncommon species at NNWR (David Richardson, personal communication). To find a greater number of less common species, surveys should be concentrated in microhabitats where these species occur. Oosting (1956) recommends rectangular shaped plots for surveying large vegetation. For evaluation of cavity tree availability, I recommend concentrating rectangular plots along streamsides and edges for effective detection of cavity trees as well as covering the interior of the study site. Detection of less common trees may require stratification of study sites into microhabitats, including rare habitats. For these bats, a rare tree may be important for roosting and these trees are worth finding despite sample size and study design. For example, Yarrow and Yarrow (1999) reported that sycamore is a valuable cavity tree for many wildlife species including bats, cavity nesting songbirds, wood ducks (*Aix sponsa*), and squirrels (*Sciurus spp.*).

American beech was a prevalent cavity species in Site 1 with the second greatest cavity tree density for the site based on plot surveys and another 16 were found as ancillary cavity trees. This species was often found in groups and had a high density percentage with an estimated 93% exhibiting cavities. Overall density of American beech was 3.4 trees/ha this was the eleventh greatest density out of 30 known species. This species was not found scattered evenly throughout the site, it was only located close to streams and in low-lying depressions. Lowney and Hill (1989) surveyed NNWR for cavity trees suitable for wood duck nesting. They stated that American beech and sycamore were the most important cavity-forming species for wood ducks. Fan et al. (2003*b*) had similar findings in mid-western forests; American beech and maple were the 2 species most likely to have cavities. I concur with both, according to percentages calculated to show the tree species most likely to develop cavities, American beech and American sycamore were important cavity producing species in my study.

To promote cavity trees and development of cavities in forest stands, managers should consider characteristics of each tree species and not rely on tree size alone. Allen and Corn (1990) stated that susceptibility and rate of decay varied among tree species. Lowney and Hill (1989) also suggested that cavity occurrence was related to species. To manage most effectively, encourage growth of cavity producing species in their most productive sites according to site indexes for that particular area. Based on my study, American beech, American sycamore, black tupelo, sweetgum, and baldcypress should be retained in forest stands for cavity production. For optimal cavity production, these species should be allowed to reach size classes of $\geq$50 cm DBH. To ensure cavity tree availability over time, forest monitoring should assess availability of young cavity trees in the stand. Silvicultural plans and management should include approaches to enhancing retention and recruitment of trees with existing cavities. Also, tree species that are likely to develop cavities should be allowed to reach older age and size classes. An ideal location to accomplish this measure is within protected streamside management zones and unharvested buffers of forested wetlands (Dickson and Sheffield 2001).

Future study recommendations. - Two different sampling methods were used for sampling trees in this study. Plot surveys were used to locate cavity trees, whereas prism cruises assessed composition of the stand where plot surveys were conducted. I recommend using plot surveys to evaluate cavity tree availability with the modification of recording and collecting data on every tree within the plot and noting those that are cavity trees. Use of one method of sampling trees would create compatible data sets in which to assess availability and abundance of cavity trees within the tree population of the plot. This method also may reduce the chance that an observer would miss seeing a cavity in a tree because every tree within the plot would be measured. Density calculations would be less intensive and comparisons between cavity trees and the total tree population would be derived from the same data set. Additionally, I recommend using the same sampling intensity throughout all study sites over the entire study period including using the same plot sizes. In my study, Site 2 was used as a preliminary study site and pre-sampling data collection began in February 2005. Based on analysis of data from site 2, plot sizes were increased for the remaining 3 sites to increase sampling intensity and decrease variability. Repeated sampling in Site 2 following changes in sampling methodology were not feasible due to time and budgetary constraints; therefore, plot size and sampling intensity was less in Site 2 as compared to Sites 1, 3, and 4. The longer plots used in this study decreased variation; however, future sampling designs should determine the sampling effort needed to further minimize variation for locating cavity trees at NNWR.

There were cavity trees located outside site boundaries or in other areas of NNWR that were not chosen as study sites. Due to the inclusion of counts of ancillary cavity trees in this study, there were species found with cavities that would not have otherwise been found. If I had used plot data only, cavity trees such as baldcypress and American sycamore would have been under-represented. My sampling methodology resulted in plots being systematically distributed across study sites to survey different microhabitats occurring within the sites. However, based on assessment of ancillary and within plot cavity trees, I conclude that sampling intensity using data from established plots alone was not adequate to detect number of cavity trees that occurred along streams, wetlands, and in low-lying areas. Therefore, I recommend that future studies use a stratified design in which microhabitat types within floodplains are identified and sampled. Using a stratified design, efforts can be increased in areas where cavity trees are likely to occur. Targeting these areas can increase incidence of finding cavity trees and assessing use by bats. Cavity trees can develop due to a number of factors and knowing the history of the sites and where cavity trees are most likely to develop can allow researchers and managers to concentrate in areas with the most likely presence of cavity trees. Identification of important habitat types can be based on forest stand composition but also may need to include consideration of topographic and hydrological characteristics that influence microsite conditions and biological communities (Jones and

Taylor 1999). Hodges and Switzer (1979) reported different habitat types within the floodplain that produce different forest stand composition as follows: terraces, flats, oxbows, backwater swamps, and streamside fronts and bars. These habitat types typically exhibit different tree composition and site indices due to differences in elevation, soil texture, and drainage (Hodges and Switzer 1979). Also, tree protection in streamside management zones, effects of foraging beaver (*Castor canadensis*) on basal cavity development, and species-specific site adaptations may cause varying tree composition, growth form, and cavity development within different microsites of floodplains (Hodges and Switzer 1979, Muller Schwarze and Sun 2003). Therefore, a more concentrated approach for locating cavity trees in future studies would be to stratify floodplain forest types and allocate sample plots within these types, if feasible. Sampling variability may be reduced using this method due to the stratification by stand characteristics. However, at the time of this study, information on forest stand composition was not available for determining stratification of study sites at NNWR. Iinformation gained by these surveys can provide baseline data to guide future surveys conducted in these bottomland hardwood sites.

The plot surveys located within study sites excluded cavity tree species that were found outside of transect boundaries, study sites, and forest types. Because only bottomland hardwood forests were surveyed, this study did not include assessment of cavity trees in any other forest type. For example, my study sites did not encompass upland hardwood or mixed hardwood pine forests; therefore, post oak, southern red oak, and eastern cottonwood were typically not found. Although these species were not included in calculations of forest stand composition or cavity tree density, they were found to exhibit cavities. Therefore, future studies could be designed to assess cavity tree availability across forested landscapes that include upland forest types, ravine and cove hardwood forests, and riparian forests (Dickson and Sheffield 2001). Inclusion of forest types with bottomland hardwood forests within a landscape level might also elucidate the influence of hydrologic and topographic conditions on cavity tree abundance and distribution as well as use of cavity trees by bats (Ford et al. 2006).

CHAPTER IV

ROOST CHARACTERISTICS AND USE

I quantitatively assessed relationships between forest stand measurements and use of cavity trees as roosting habitat for RBEB and SEM. I also evaluated roost tree characteristics for each bat species. For these analyses, use trees are defined as those cavity trees in which at least one bat was detected roosting at least once during the study. I will refer to cavity trees in which no bats were found roosting during time of check as non-use trees.

Methods

Cavity tree measurements. - All cavity tree metrics, described in Chapter II, were tested statistically to determine potential relationships with bat use. All statistical operations were performed at $\alpha = 0.05$. Data collection methods are described in detail in Chapter II.

I used logistic regression to determine which tree characteristics influenced use of cavity trees by bats (PROC LOGISTIC, SAS Institute Inc. 2004). The dependent variable was a binary use or non-use and explanatory variables for the model were diameter at breast height (DBH), cavity width, cavity height, and chamber height. This model was used for both bat species. Of the 622 cavity trees found, 562 were used in this analysis because some trees (n=60) were not inspected for bat use. These 60 cavity trees could not be inspected for bat use due to inaccessibility of the cavity or the cavity was too small for examination. Software used for statistical analyses only used observations in which all data points were recorded (SAS Institute Inc. 2004). The variables chamber width and wall width were excluded from these analyses due to the number of missing data points. There were 193/562 examined cavity trees in which these data were not collected. Collection of these measurements required the cavity tree to have an internal chamber at breast height; therefore, data were not gathered on trees where a chamber did not extend to breast height. I tested for significant relationships between these explanatory variables using the Pearson correlation coefficient (STATISTIX 2000).

Vegetation characteristics. - All vegetation measurements discussed herein were described more thoroughly in Chapter II in the section entitled, Vegetation Characteristics. These measurements describe habitat conditions surrounding both use and non-use cavity trees to assess vegetation characteristics that could possibly influence roost tree use by RBEB or SEM. Because of this focus, non-use trees selected for comparisons were chosen based on similarity of morphological characteristics, such as DBH or chamber height, to use trees to control variation created by other possible explanations for lack of use by bats. At the time surveys were conducted, there were 50 known use trees with recorded cavity tree measurements and suitability for these vegetation surveys. Suitability refers to those cavity trees that were still standing and not top broken as to possibly discourage bat use. I found 46 non-use trees that were similar in characteristics and comparable to use trees in which to gather surrounding vegetation measurements. Cavity trees from all 4 study sites were used in gathering these data. I performed line intercepts, stem counts, prism cruises and took densitometer readings around all selected trees in each site. The test variables gathered from these methods were percent coverage, stem density, basal area, and canopy cover respectively (Higgins et al. 1996).

Understory sampling. - Line intercept data were summarized into the following growth form categories for analysis: herbaceous, grass, tree, shrub, vine, water, and debris (Miller and Miller 1999). I calculated percent coverage of each form by dividing distance that each form covered by total distance of the transect line. I summed distance values of each form category for the 4 10 m transects around each tree. I calculated percent coverage for each form at each tree to be used as the explanatory variable for a comparison between use trees and non-use trees using logistic regression (PROC LOGISITIC, SAS Institute Inc. 2004). I conducted separate regression analyses for each of the 3 vertical categories ($\leq$ 0.6m, 0.6 - 1.4m, $\geq$ 1.4m). No assumptions of normal distribution or data transformation were required (Morrison 2005).

Stem counts were conducted in 4 1 m × 10 m transects radiating from the base of the cavity tree. These transects were divided into 4 quadrats in the following horizontal categories: 0.0-2.5, 2.5-5.0, 5.0-7.5, and 7.5-10.0 m. Counts were initially recorded in 6 form categories: woody, vine, herbaceous, grass, tree, or shrub (Miller and Miller 1999). I grouped woody, vine, tree, and shrub categories into woody category and herbaceous and grass categories into herbaceous for analyses. I calculated density for each form category in each horizontal and vertical categories ($\leq$0.6 m, 0.6 m – 1.4 m, $\geq$1.4 m) for each tree. I calculated density by dividing number of stems by the area (2.5 m^2).

Logistic regression analyses were used to discern important relationships between the vegetation categories and bat use of a cavity tree within each horizontal and vertical category. Separate regression analyses were performed on the 2 growth form categories and explanatory variables were the stem densities recorded within each of the horizontal and vertical categories. There were 12 explanatory variables used in the analysis for woody growth form (4 horizontal categories × 3 vertical categories). Only 8 explanatory variables were used in the herb growth form analysis because there were not enough herbaceous data within vertical category 3 ($\geq$1.4 m) to include in analyses.

Forest stand measurements - I measured canopy cover around selected use and non-use cavity trees during spring from 15 May 2007 to 8 June 2007, using a GRS™ densitometer (Stumpf 1993). Percentage of canopy closed was calculated for each tree by counting number of zeroes (zero = closed) recorded and dividing by number of readings. I used Mann-Whitney 2-sample test to determine if there was a difference in samples of canopy cover between use and non-use trees (Dowdy and Wearden 1991).

Prism cruises were performed using a 10-factor prism at 5 m from the cavity. I calculated basal area (BA) for each plot (BA = number of trees in the plot × 10; Higgins et al. 1996). I used Mann-Whitney 2-sample test to determine a difference in the basal area sample populations of use and non-use cavity trees (Dowdy and Wearden 1991).

Landscape measurements of cavity trees. - I successfully recorded location of 605 cavity trees with a Global Positioning System (GPS) and loaded the points into ArcMap® (ESRI, Redlands, CA). For landscape measurements, I measured distance to permanent water, winter available water, habitat edge, and distance to nearest known cavity tree using measuring tools in ArcMap® (Ormsby et al. 2001). I conducted logistic regression analyses to determine relationships between response variables of bat use or non-use of a cavity tree for both bat species and the aforementioned explanatory variables. Of the cavity trees successfully recorded into ArcMap®, 548 were included in evaluation for bat use. I included only those trees that were successfully examined for bat use. Those that could not be examined had cavities that were inaccessible, too small, or the chamber was not suitably visible. I conducted separate analyses for each species of bat to determine which landscape factors might have influenced whether a certain bat species uses a cavity tree as a diurnal roost.

Cavity tree use. - I used Manly's alpha selectivity index to determine if a relationship exists between tree species and use by RBEB and SEM (Heisey 1985). This selectivity index is based on availability of the resource. However, I modified the approach to reflect detectability of bats by the sampling effort in this study (Heisey 1985). Due to unequal sampling, I standardized the data to account for the variable number of times a tree was inspected for bat use. I could not inspect every tree every day. Therefore, number of times a bat could be detected depended on number of times I was able to inspect the cavity tree. For these calculations, I defined available cavity trees as those with characteristics that bats used in this study. I attempted to reduce variability in analysis by eliminating cavity trees that bats may not use because of unfavorable characteristics. I counted number of cavity inspections performed on each cavity tree to reflect availability of finding a bat using the cavity tree. I counted number of detections of a bat per cavity tree to reflect use. I pooled these counts across species of available cavity trees and cavity trees used by bats to examine sample sizes. I eliminated cavity trees that were inspected <4 times, and cavity tree species in which <4 were found (Manly 1974). I assessed resource selectivity based on detectability of a bat and number of cavity inspections. This method replaced using number of all available cavity trees found as would be calculated if sampling intensity was equal among cavity trees (Heisey 1985). I used number of cavity inspections and number of times a bat was detected for each tree species in the Manly's alpha selection model to derive a selection indicator value for each tree species. The selection indicator was calculated as follows:

$$\log p_i / \Sigma \log p_i$$

Where p_i was the proportion of non-detections of a bat out of the number of inspections of each cavity tree (p_i = number of non-detections/number of inspections).

The selectivity index used to compare the selection indicator for each species was based on the number of tree species used in the procedure and was calculated by raising the number of species to -1 power. Separate selection indices were calculated for each bat species**.** All cavity tree species were pooled across sites because bats are capable of flying in and out of study areas (Menzel et al. 2001). To determine if use of tree species differed from what was expected based on cavity tree availability, I used a Kolmogorov–Smirnov test. The observed values for the number of bat use trees in each species were tested against the expected use. The percentage of expected use was calculated by dividing number of use trees by number of available cavity trees. Expected use was generated by multiplying the number of available cavity trees in each species by the percentage.

To describe tree use by size class, I compiled a summary of all trees used as roosts into intervals of size classes for each bat species and calculated relative frequency of use. I also summarized relative frequencies of use by size class in colonial ($n \geq 5$) and solitary ($n \leq 4$) use categories for both bat species. I used Kolmogorov-Smirnov to determine if bats used trees randomly with regard to size class. The observed values were tested against the expected values in each 5 cm size class as described above.

I summarized trees used as colony roosts into 3 categories: maternal, winter, and summer. Maternal colonies were found May – June and were characterized by presence of lactating females or pups. Winter colonies occurred during cooler months (October – March) and summer colonies were found during warmer months (typically May – September) and pups were not present. Bats were counted individually whenever possible. However, counts were estimated for large colonies or where the entire colony could not be seen.

Seasonal use of cavity trees. - I grouped tree characteristics among seasons for an analysis of variance one-way ANOVA to determine if bat use changed among seasons regarding cavity tree characteristics. All use trees were included in the ANOVA and dependent variables included: DBH, cavity width, cavity height, chamber height, chamber width, and wall width. The data were square-root transformed to meet the normality assumption (Dowdy and Wearden 1991). Twelve separate ANOVAs were performed, one for each dependent variable with season being the independent and separate analyses for each bat species.

Logistic regression analyses were used to determine if characteristics of non-use cavity trees differed from trees used by bats in winter. All use trees that were inspected in winter were included in the analysis (n=60). Use trees that were not used by a bat during the winter sampling period were considered winter non-use trees for these analyses. Thirteen use trees were not checked during winter due to flooding because basal openings could not be examined while under water. Cavity trees with missing data values were excluded by SAS in the logistic regression analyses (SAS Institute Inc. 2004). To increase number of data points used in the model, I performed 2 separate analyses for each bat species. I divided explanatory variables for each analysis according to methods used to obtain these data. Therefore, one analysis incorporated cavity tree characteristics obtained in the field as the explanatory variables (DBH, cavity width, cavity height, chamber height, chamber width, wall width) and another used landscape measurements which were obtained using a computer program (distance to permanent water, winter available water, habitat edge. and the next known cavity tree).

Results

Eighty-two cavity trees were used by bats. Seventy-four of those were used by RBEB or SEM and 8 trees were used by other bat species, mainly eastern pipistrelle (*Perimyotis subflavus*). Rafinesque's big-eared bat were found in 49 different trees and SEM were detected in 47 trees. Twenty-two cavity trees were used by both RBEB and SEM. Only 5 bat use trees were snags, and RBEB were found in 4 of these while SEM used 2 of them. One snag was a swamp chestnut oak (*Quercus michauxii*) used as a summer roost by RBEB.

Cavity tree measurements. - Pearson's correlation coefficient showed a strong positive correlation (R = 0.94, 0.89 in RBEB and SEM, respectively) between the explanatory variables chamber width and DBH. Chamber width was excluded from the logistic regression model because of missing data and high collinearity with DBH.

The concordance of the logistic regression model showed that 90% of use trees could be predicted based on associations with cavity tree measurements and RBEB use. There was a positive relationship in tree DBH (χ_1^2= 30.4, P <0.001) and chamber height (χ_1^2= 6.1, P =0.01) for cavity trees used as roosts by RBEB (Table 4.1). Means of all cavity tree variables were greater in RBEB use trees than non-use trees (Table 4.1). Use trees averaged approximately 50 cm DBH larger than non-use trees and mean chamber height was >300 cm greater in use trees than non-use trees (Table 4.1). Trees used by RBEB ranged in size from 40 – 210 cm DBH and chamber height ranged from approximately 195 – 1200 cm.

Comparable to RBEB results, DBH (χ_1^2= 16.0, P<0.001) and chamber height (χ_1^2= 10.0, P =0.002) were predictors of cavity tree use by SEM (Table 4.2). Additionally, analysis revealed a correlation with SEM use and cavity height (χ_1^2= 5.5, P =0.018; Table 4.2). The concordance value in this model showed that 86% of cavity trees used by SEM could be predicted by cavity tree measurements. Chamber height and DBH were correlated positively; however, cavity height had a negative relationship with SEM use. Cavity height averaged 5 cm less in SEM use trees, but cavity width averaged 10 cm larger for use trees compared to non-use cavity trees. Tree size ranged from 40-155 cm DBH, chamber height ranged from 105-1200 cm, and cavity height ranged from 10 - 122 cm in cavity trees used as roosts by SEM.

Table 4.1 Results of logistic regression analysis used to compare use and non-use cavity tree characteristics for roosting Rafinesque's big-eared bat at Noxubee National Wildlife Refuge during 2005-2007.

Cavity Tree Measurements (cm)	Use		Non-use		Logistic Regression Statistics		
	$\bar{x}$	SE	$\bar{x}$	SE	SE	χ^2	*P*-value
DBH	99.6	5.45	48.8	0.92	0.02	30.42	<0.001
Cavity width	40	4.52	22.9	0.76	0.03	2.06	0.1517
Cavity height	70.2	9.38	57.2	1.96	0.01	0.71	0.3990
Chamber height	574.4	45.55	264.7	9.53	0.01	6.13	0.0133

Table 4.2 Results of logistic regression analysis used to compare use and non-use cavity tree characteristics for roosting southeastern myotis at Noxubee National Wildlife Refuge during 2005-2007.

Cavity Tree Measurements (cm)	Use		Non-use		Logistic Regression Statistics		
	$\bar{x}$	SE	$\bar{x}$	SE	SE	χ^2	*P*-value
DBH	78.5	3.92	50.6	1.11	0.02	16.01	<0.001
Cavity width	33.1	2.53	23.1	0.81	0.02	2.45	0.1172
Cavity height	53.7	4.68	58.2	2.06	0.01	5.56	0.0184
Chamber height	543.6	38.11	264.3	9.80	0.01	10.07	0.0015

Understory characteristics surrounding cavity trees. –Statistical analyses showed no significant differences ($P > 0.05$) in ground vegetation characteristics that surrounded use and non-use cavity trees. Logistic regression analyses of the percent vegetation coverage calculated for each of 7 form categories (herbaceous, grass, tree, shrub, vine, water, and debris) in designated vertical categories (< 0.6 m, 0.6 m – 1.4 m, > 1.4 m) did not explain bat use or non-use of cavity trees at $\alpha = 0.05$. I summarized mean percent coverage for use and non-use trees in each vertical and form category (Table 4.3).

The logistic regression model did not detect a significant relationship between woody ($\chi_1^2 = 0.69$, $P = 0.41$) or herbaceous ($\chi_1^2 = 0.29$, $P = 0.59$) vegetation density surrounding cavity trees used bats compared to cavity trees not used. The mean density of woody plants was 7.5 and 8.2 stems/m^2 for use and non-use cavity trees respectively. Woody stem density ranged from <1 to 65 stems/m^2 around cavity trees including all vertical categories. Typical tree species included Oaks (*Quercus spp.*), American hornbeam (*Carpinus caroliniana*), green ash (*Fraxinus pennsylvanica*), sweetgum (*Liquidambar styraciflua*) and elms (*Ulmus spp.*). Common woody shrubs included *Vaccinium spp.*, and *Rhododendron canescens* and woody vines present were *Smilax spp.*, *Toxicodendron radicans*, *Lonicera japonica*, and *Berchemia scandens*.

Stem densities of herbaceous plants averaged 28.2 and 30.7 stems/m^2 for use and non-use trees, respectively. Densities ranged from <1 to >250 stems/m^2 with greater stem densities typically surrounding use trees. The maximum stem density recorded at a non-use cavity tree was 170 stems/m^2. Herbaceous species occurring most often were *Eupatorium spp., Saururus cernuus., Viola spp., Justicia spp., and Commelina spp.*

Forest stand measurements. - Canopy cover for non-use trees averaged 95% closed canopy and use trees averaged 93% closed canopy. No significant difference in tree canopy cover existed between use and non-use cavity trees ($P = 0.11$). Mean basal area was 23.7 m^2/ha for non-use trees and was 22 m^2/ha for use trees. No significant difference in mean basal area between use and non-use trees was detected ($P = 0.29$).

Landscape characteristics. - Cavity tree distance to permanent water ranged from 0 m to 729 m for trees used by either or both bat species. Maximum cavity tree distance to winter available water was approximately 450 m for trees used by either or both bat species. Distance to nearest known cavity trees from known use trees ranged from <2 m to >500 m. Both bat species occupied trees that were within 1 m to >800 m of forest edge. The only explanatory variable found significant for RBEB use was distance to the nearest known cavity tree ($\chi_1^2 = 7.8$, $P = 0.01$; Table 4.4). RBEB use trees were farther from other cavity trees than non-use trees. According to the concordance value for the model, cavity tree use by RBEB can be predicted 70% of the time using these metrics. Average distance to the nearest cavity tree was 180 m for use trees and 44 m for non-use trees. For SEM the only significant landscape variable was distance to winter available surface water ($\chi_1^2 = 6.9$, $P = 0.009$; Table 4.4). Non-use trees were on average 60 m closer to winter surface water than SEM use trees. The concordance value was only 60% for this model; therefore, the predictability of these metrics regarding use by SEM is close to random.

Table 4.3 Average percent coverage calculated from line intercepts performed around cavity trees used by Rafinesque's big-eared bats and southeastern myotis at Noxubee National Wildlife Refuge during 2005-2007.

Vertical Categories[a]		$\bar{x}$ ± SE						
		Debris	Grass	Herb	Shrub	Tree	Vine	Water
Use	1	45.4 ± 3.1	19.9 ± 3.2	8.1 ± 2.2	3.3 ± 1.2	5.5 ± 0.8	34.8 ± 5.1	6.2 ± 2.8
	2	-	1.3 ± 0.8	0.9 ± 0.4	4.1 ± 1.5	11.3 ± 2.7	5.6 ± 2.2	-
	3	-	-	0.1 ± 0.1	1.2 ± 0.7	175.8 ± 8.4	6.9 ± 1.7	-
Non use	1	56.3 ± 4.1	14.0 ± 2.2	3.4 ± 0.9	1.0 ± 0.3	4.3 ± 0.8	36.4 ± 5.6	2.2 ± 1.7
	2	0.5 ± 0.5	0.05 ± 0.1	0.3 ± 0.1	1.1 ± 0.4	6.9 ± 1.1	2.7 ± 0.7	-
	3	-	-	-	1.3 ± 0.8	185.4 ± 8.5	3.2 ± 1.0	-

[a] Vertical categories are: 1 = < 0.6 m, 2 = 0.6 m – 1.4 m, and 3 = > 1.4 m.

Table 4.4 Summary of statistics from logistic regression analysis of measured landscape characteristics and their relation to cavity tree use by Rafinesque's big-eared bat and southeastern myotis at Noxubee National Wildlife Refuge during 2005-2007.

Landscape Measurements[a]	Rafinesque's big-eared bat			Southeastern myotis		
	P-value	Slope	χ^2	*P*-value	Slope	χ^2
Permanent water	0.6507	< -0.01	0.21	0.7056	< -0.01	0.14
Winter available water	0.7298	< -0.01	0.12	0.0087	< 0.01	6.87
Nearest known cavity tree	0.0051	< 0.01	7.84	0.9080	< 0.01	0.01
Edge	0.0578	< -0.01	3.60	0.3544	< -0.01	0.86

[a] Landscape measurements are distances (m) to the feature from cavity trees measured using ArcMap®

Cavity tree use. - Twelve tree species were used in the Manly's alpha procedure to determine selection of cavity trees by RBEB and SEM. This yielded 0.083 as the selection index for both bat species. Seven tree species were excluded from analysis because of lack of observations or small sample size. An indicator value was calculated for each tree and those greater than the selectivity index were selected by bats. This analysis showed that RBEB most often selected roosting cavities in baldcypress (*Taxodium distichum*), American Sycamore (*Platanus occidentalis),* black tupelo (*Nyssa sylvatica*), pignut hickory (*Carya glabra*), swamp chestnut oak (*Quercus michauxii*), and water oak (*Q. nigra*; Table 4.5). There were 49 cavity trees of 14 species used as roosts by RBEB (Table B.1). The Kolmogorov-Smirnov test showed that RBEB did not choose tree species randomly as roosts (P<0.001). The expected use of baldcypress by RBEB was 2 trees; however, I observed RBEB in 10 baldcypress. By comparison, RBEB were observed (O) in half of the expected (E) number of trees for American beech (E = 7, O = 4; *Fagus grandifolia*) and sweetgum (E = 20, O = 9).

The selectivity index for SEM revealed that both bat species selected to roost in similar tree species. Tree species most often selected by SEM included American sycamore, black tupelo, water oak, and sweetgum (Table 4.6). The selection indicator for American beech (0.079) cavity trees used by SEM was close to the selectivity index value (0.083). I found that with only 1 additional cavity tree inspection resulting in a positive detection of a SEM in American beech, it would have been a selected cavity tree species for SEM. Cavity tree species used as roosts by SEM were selected randomly according to Kolmogorov-Smirnov test (P = 0.82). Southeastern myotis roosted in slightly fewer cavity tree species than RBEB (n=10); however, the same species were used by RBEB (Table B.1).

Simultaneous roosting between these species of bats may account for similarities among the tree species that were most often used as roost sites. Many (22/74) use trees were used by both bat species representing 10 different tree species with sweetgum, black tupelo and baldcypress being the most commonly used simultaneously. There were 2 species that had large enough sample sizes and were inspected individually >4 times; therefore, were included in the analysis, but not used by bats (Tables 4.5, 4.6). Green ash (*Fraxinus pennsylvanica*) and red maple (*Acer rubrum*) were found with characteristics conducive to bat use; however, no bats were found in these tree species.

Noxubee NWR staff attached radiotransmitters to 15 RBEBs from 2005-2006 to find additional roosting sites to increase information about roost use and fidelity. However, only 4 additional cavity trees were located using this method, and most bats returned to the place of capture. Transmitters were attached to 10 males and 4 females, gender was not recorded for one capture. Eight captures were solitary roosting males. Most bats (n=12) were captured in cavity trees; few (n=3) were captured in artificial roosts. Bats were detected an average of 9 times before the transmitter was recovered or no longer detected. The longest time period of telemetry observation was 49 days and the shortest time to recovery was 3 days. Bats changed roosts an average of 3 times ranging from 1-9 times. Seven bats used 3 different roosts during telemetry observations, often coming back to the same locations repeatedly. Most bats (n=11) changed locations after the initial capture, 4 of these returned to the initial capture site within a few days.

Table 4.5 Manly's alpha selectivity index for cavity tree species used by Rafinesque's big-eared bat as roosting habitat at Noxubee National Wildlife Refuge in Mississippi during 2005-2007.

Cavity Tree Species	n	No. of Checks	No. of Bat Detections	Selectivity Indicator[a]	
Green Ash	7	33	0	0	N[b]
Red Maple	4	24	0	0	N
Sweetgum	105	627	16	0.012	U[c]
Shagbark Hickory	5	31	1	0.015	U
American Beech	37	182	7	0.018	U
Overcup Oak	16	93	7	0.035	U
Water Oak	4	57	13	0.117	S[d]
Swamp chsestnut Oak	9	100	23	0.118	S
Pignut Hickory	4	58	14	0.125	S
Black Tupelo	19	228	66	0.155	S
American Sycamore	6	38	11	0.155	S
Baldcypress	10	182	77	0.249	S

[a] Selectivity index is 0.083; tree species with a selectivity indicator > 0.083 are more often selected

[b] N = Non-use

[c] U = Use

[d] S = Selected

Table 4.6 Manly's alpha selectivity index for cavity tree species used by southeastern myotis as roosting habitat at Noxubee National Wildlife Refuge in Mississippi during 2005-2007.

Cavity Tree Species	n	No. of Checks	No. of Bat Detections	Selectivity indicator[a]	
Green Ash	7	33	0	0	N[b]
Red Maple	4	24	0	0	N
Shagbark Hickory	5	31	0	0	N
Overcup Oak	16	93	2	0.023	U[c]
Swamp Chestnut Oak	9	100	4	0.043	U
Pignut Hickory	4	58	3	0.056	U
Baldcypress	10	182	12	0.072	U
American Beech	37	182	13	0.079	U
Sweetgum	105	627	57	0.101	S[d]
Water Oak	4	57	6	0.118	S
Black Tupelo	19	228	36	0.182	S
American Sycamore	6	38	10	0.324	S

[a] Selectivity index is 0.083; tree species with a selectivity indicator > 0.083 are more often selected

[b] N = Non-use

[c] U = Use

[d] S = Selected

Sizes of cavity trees used as roosts ranged from 40 cm to 210 cm DBH for RBEB and from 40 cm to 155 cm DBH for SEM (Table B.1). The Kolomogorov-Smirnov test revealed that RBEB did not choose cavity trees randomly with regards to size class ($P < 0.001$). However, SEM did use cavity tree size classes randomly ($P = 0.053$). RBEB typically used trees $\geq$80 cm DBH more frequently than expected. Many use trees were used by both bats (n=22, 30%). However, there were some differences in the size classes of cavity trees used by the 2 species. A compilation of all cavity trees used by each bat species with tree groupings according to size yielded a comparison of 47 trees used by SEM and 47 trees used by RBEB. Two trees used by RBEB did not have DBH recorded. Over half (55%; 26/47) of cavity trees used by SEM ranged from 40-70 cm DBH and only 19% (9/47) of used trees were in the $\geq$100 cm DBH size class (Figure 4.1). RBEB more often used larger trees, with nearly half (43%; 20/47) of these roost trees being $\geq$ 100 cm DBH and approximately 28% (13/47) of roost trees in the smallest size class interval (Figure 4.1). Both species used the medium size class (75-95 cm DBH) nearly the same frequency. Number of trees used in the medium size class was 14 and 12 for RBEB and SEM, respectively.

Both bat species often used large trees for colony roosting (Figure 4.2). Determination of frequency of cavity tree use within DBH size classes according to solitary and colony bat use included consideration of 32 solitary roost trees for RBEB and 31 for SEM. Colony use trees included in this evaluation totaled 13 for RBEB and 15 for SEM. Tree species used by RBEB for colony roosts were 7 baldcypress, 4 black tupelo, 1 swamp chestnut oak, and 1 American sycamore. Cavity trees used by SEM as colony roosts were 6 black tupelo, 6 sweetgum, 1 eastern cottonwood, 1 baldcypress, and 1

American sycamore. Five cavity trees were used as colony roosts simultaneously by both bat species. These were composed of 3 black tupelo, 1 baldcypress, and 1 American sycamore ranging in size from 50 – 155 cm DBH. Southeastern myotis tended to use smaller size class trees (40-70 cm DBH) for solitary roosting whereas many switched to larger size class trees (≥100 cm DBH) for colony roosting (Figure 4.2). Rafinesque's big-eared bat used trees in all size classes at nearly the same frequency for solitary roosting; however, use frequency shifted to larger size class trees (≥100 cm DBH) for colony roosting (Figure 4.2).

The small sample size of cavity trees used as colony roosts prevented statistical analysis. Of roost trees evaluated, 8 were used as maternal colony roost trees, 9 were used as winter colony roost sites, and 16 were used during summer. Some trees were used more than one season and by both bat species. A summary of counts at these roosts show that RBEB congregated in large numbers (200+) during winter (Table 4.7). Southeastern myotis tended to roost in colonies ≤ 50 individuals during all times of the year (Table 4.7). I observed these smaller colonies with larger colonies of RBEB in the same trees. Both bat species roosted together in summer and winter; however, they segregated for maternal roosting.

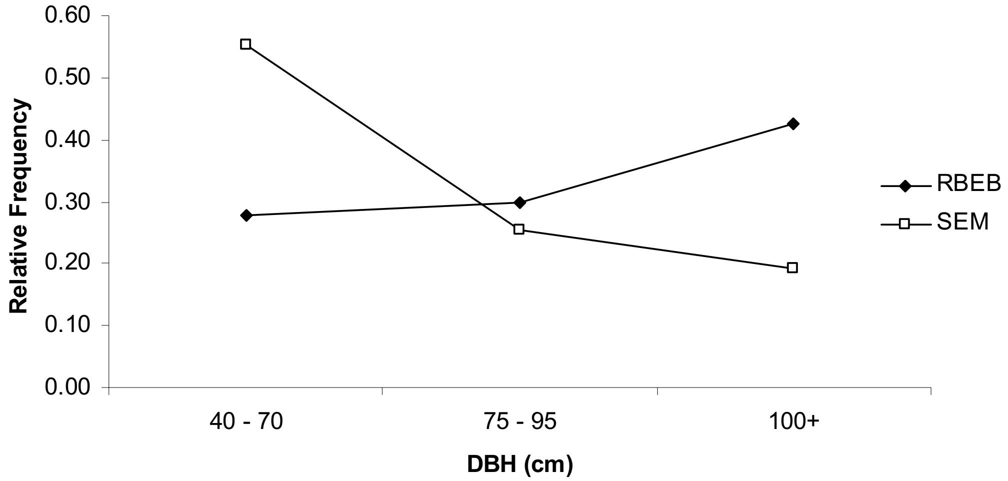

Figure 4.1 Relative frequency of cavity tree use per size class (DBH) for Rafinesque's big-eared bat (RBEB) and southeastern myotis (SEM) at Noxubee National Wildlife Refuge during 2005-2007.

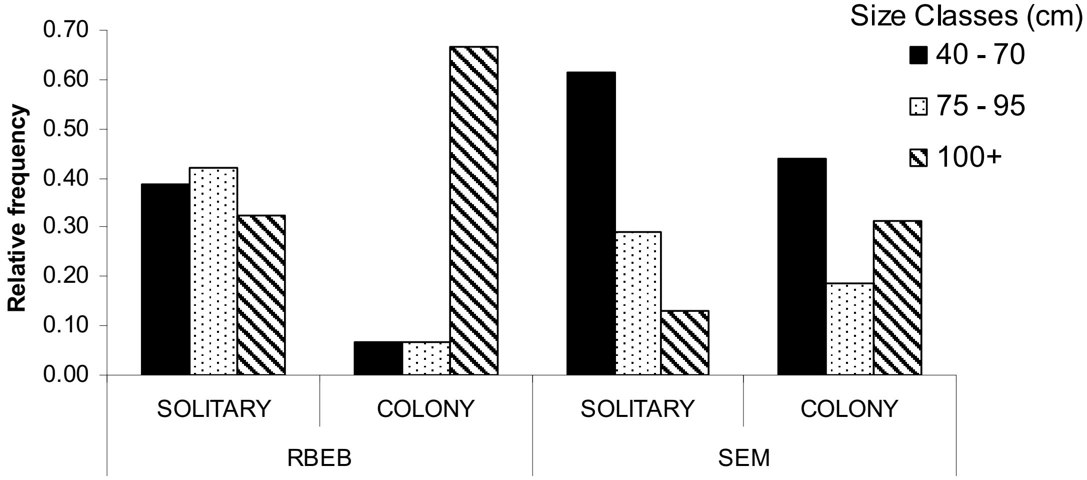

Figure 4.2 Cavity tree use within different size classes grouped according to use (solitary, n < 4 and colony, n $\geq$5) by Rafinesque's big-eared bat (RBEB) and southeastern myotis (SEM) at Noxubee National Wildlife Refuge in Mississippi during 2005-2007.

Table 4.7 Cavity trees used for colony roosting by Rafinesque's big-eared bat (RBEB) and southeastern myotis (SEM) at Noxubee National Wildlife Refuge (2005-2007).

Bat species	Colony type	n	Range in DBH of Roost Tree (cm)	Range in Number of Bats Counted
RBEB	Maternal	6	115-175	10-50
	Winter	6	50-155	5-200+
	Summer	8	50-185	5-100+
SEM	Maternal	2	60-95	50
	Winter	8	50-155	5-50
	Summer	9	50-115	5-50

Seasonal use of cavity trees. - Cavity tree measurements tested in the ANOVA revealed no difference (P>0.05) in cavity trees used by RBEB among seasons. The analysis revealed a significant difference in the DBH of cavity trees used by SEM during different seasons. Cavity trees used by SEM during winter were typically larger than those used in other seasons ($F_{3,80}$=2.99, P=0.04). Winter use cavity trees ranged in size from 50 - 155 cm DBH; whereas those used in summer, the season when the smallest size classes were used, ranged from 40 – 105 cm DBH.

Of the 74 identified use trees for RBEB and SEM, 19 were used in winter. RBEB used 14 different cavity trees in winter and SEM used 15 different cavity trees as winter roosts. Ten roost trees were used simultaneously by both species during winter comprising 6 different tree species including baldcypress, black tupelo, eastern cottonwood (*Populus deltoides*), pignut hickory, sweetgum, and American sycamore.

Of the 49 cavity trees used by RBEB in this study, 38 of them were inspected during winter and these were included in the logistic regression analysis. Of the 47 cavity trees used by SEM, 42 were checked during winter. Eighteen winter use trees were ancillary cavity trees. The 3 most prevalent winter roost tree species were baldcypress, sweetgum, and black tupelo. The logistic regression analyses revealed no difference between cavity trees used in winter compared to non-use cavity trees that were examined for bats in winter.

Bat use of artificial structures. - Possible artificial roosts at Noxubee NWR included bridges, old homes, sheds, wells, cisterns, and culverts. The section entitled, Surveys for Cavity Tree Use by Bats in Chapter II explains methods of inspection and further details regarding artificial structures. Some old buildings and wells were known RBEB roosts before the study began in February 2005. Seven houses or sheds were documented as RBEB roosts by July 2007. Most observations of the houses showed solitary uses; however, one house occasionally had 3 to 5 bats roosting together.

Three types of bridges were located at NNWR including concrete (flat bottom, I-beam, or metal I-beam), wood, and metal grate. Of the 41 bridges surveyed, most (n=26) were concrete with I-beam supports. The only documented use of a bridge was a concrete I-beam on a paved road where I found 2 SEM roosting on a support beam in May 2005. The bats were banded by a refuge biologist, but were not seen again under the bridge. No other bridges were used by bats during this study.

Within a few months the modified culvert that was placed by refuge staff to serve as an artificial tree was being used by a RBEB. Refuge biologists captured the bat and placed a band on the wing for identification. The culvert was observed >25 times and the bat was consistently (10/25 observations) using the culvert from January 2005 to May

2006. Other RBEBs were observed using the culvert and a maximum of four bats was observed at one time.

Discussion

Cavity tree characteristics. - Both bat species roosted in cavity trees that were typically larger sized trees with larger internal measurements when compared to non-use cavity trees. Chamber height and DBH were found to be important cavity tree characteristics that influenced use of cavity trees by both bat species. Similar results were found in east Texas where RBEB bats and SEM roosted in larger (99.8 ± 22.3 cm DBH) cavity trees with taller internal chambers (8.9 ± 5.3 m) compared to unoccupied trees (Mirowsky 1998). Average tree diameter of cavity trees used by RBEB in this study was comparable (99.6 ± 5.5 cm DBH) and trees used by SEM were slightly smaller (78.5 ± 3.9 cm DBH). Carver and Ashley (2008) also found that trees occupied by RBEB were larger (124.5 ± 5.1 cm DBH) than those used by SEM (76.4 ± 10.8 cm DBH). Southeastern may use roost trees opportunistically. Internal chamber height averaged approximately 5.5 m for both bat species in this study. Use of large diameter cavity trees by RBEB has been documented repeatedly (Cochran 1999, Hoffman 1999, Gooding and Langford 2004, Trousdale and Beckett 2005, Carver and Ashley 2008).

The measurement of internal chamber width was not used in statistical analysis because of small sample size and the high correlation between chamber width and DBH. Tree diameter is a relatively easy measurement to obtain and this metric is used by foresters at NNWR for stand assessments. Recommendations for cavity tree retention based on DBH would be more applicable and functional to forest managers due to the standard use of DBH in forest stand surveys than internal cavity measurements which would require special equipment and more time to obtain.

Cavity trees used by SEM had smaller than average cavity height compared to non-use trees. Studies have shown that rate of decay and susceptibility of trees to form cavities varied among tree species (Allen and Corn 1990). Therefore, one possible explanation for the difference in the average cavity heights between cavity trees used by RBEB and SEM may be due to a difference in tree species used as roosts and their rate of decay. More research is needed to determine if this is a factor of the bats choosing different size cavities or an inherent variable in development of tree cavities within different stands or tree species.

Cavity tree use by bats. - Although bats may not distinguish the difference in one tree species over another, it is important to provide recommendations regarding which tree species are best suitable for cavity production and use by bats. Forest managers may not have the resources to obtain metrics on individual cavity trees within forest stands. Therefore, finding associations between bat use and tree species is needed to assist managers in making forest management decisions for the benefit of these species of concern.

Based on analysis of cavity tree measurements and their association with bat use, the modification of the Manly's alpha procedure used in this study served to control variability in tree characteristics. For example, bats only used trees that were $\geq$ 40 cm DBH. However, I measured all known cavity trees that were $\geq$15 cm DBH (Table B.1).

If I used all available cavity trees to compare with use trees, I would have included trees that bats did not use perhaps because of unfavorable tree characteristics. Instead, only trees that met the criteria of bat use trees, as found in this study were used in the analysis.

The Manly's alpha procedure was sensitive to sample sizes. For example, the American beech indicator value for cavity trees used by SEM was so close to the selection index that only 1 additional inspection with SEM detected in an American beech would have yielded a selection of American beech as roosts by SEM. I attempted to control bias within this analysis by eliminating trees that were not checked for presence of bats at least 4 times during the study (Manly 1974). If trees inspected <4 times were included in the analysis, the procedure would have predicted that bats selected a tree species based on a small number of observations and detections. For example, a tree that was checked twice with a bat being detected once would be considered used 50% of the time; therefore, garnishing a large selection indicator value. I observed only 1 white oak, 1 willow oak, and 1 cherrybark oak (*Quercus pagoda*) that was used by RBEB. Additionally, there were 2 eastern cottonwoods that met the criteria of tree characteristics used by bats as roosts, and 1 was used by both bat species. This was a small sample size in which to draw conclusions and they were not used in analysis. However, use of these tree species was noteworthy.

The Manly's alpha procedure may be more useful and reliable for predicting outcomes in data with large sample sizes and more evenly distributed availability and use. However, this procedure highlighted species where they may have otherwise been ignored. It is important to note white oak, willow oak, cherrybark oak and eastern cottonwood as use trees and require further investigation before dismissing them as unimportant roost trees for bats.

There were an uneven number of times that trees were inspected during the study. It is reasonable to assume that a greater number of inspections increase the chance of detecting a bat. To reduce this bias, number of tree inspections was summed across tree species and number of detections was compared to number of inspections. I recommend that bat use be sampled evenly by conducting an equal number of inspections per tree to allow researchers to compare rate of detection among individual trees and to reduce variation in analysis.

There were numerous considerations in this study regarding calculating Manly's alpha selectivity index for tree species selected as roosts by bats. Caution should be used in interpretation of selection indices. For example, pignut hickory was a selected roost tree by RBEB according to Manly's alpha selection index. However, there was only 1 pignut hickory used by bats in this study (Table B.1). This tree was not excluded from the sample because there were enough detections of a bat in that tree to meet sample sizes required by the procedure. I suggest interpreting selection values conservatively and use other methods of analysis for stronger assessments. The Kolmogorov-Smirnov test gave an indication of whether bats used cavity trees randomly. The test revealed that SEM used cavity trees randomly with regard to tree species and size class. The manly's alpha gives an ordered selectivity of trees used by bats. Southeastern myotis were using trees randomly, thus indicating that they are more of a generalist when choosing roost trees compared to RBEB. This is evident in the sweetgum cavity trees that SEM used as roosts. The Manly's alpha revealed that SEM selected to roost in sweetgum and it was the most prevalent cavity tree species in this study. The use of sweetgum by SEM may be an effect of the number of sweetgum cavity trees available. The Manly's alpha selection may not be as informative for SEM as it was for RBEB. The Kolmogorov-Smirnov test helps in making management decisions for these bat species. Managers may want to focus efforts on retaining certain cavity tree species for RBEB, while maintaining a general population of cavity trees that are large enough (≥40 cm DBH) to be used as roosts by SEM.

Sweetgums were frequent producers of cavities; almost half of all cavity trees found in this study were sweetgum. Additionally, approximately 35% of use trees were sweetgums and they were more commonly used by SEM than RBEB according to Manly's alpha procedure. This analysis revealed a distinction between the 2 bat species and use of this tree species as a roost. Carver and Ashley (2008) suggested that although RBEB and SEM used the same tree species on occasion, the 2 species may prefer different roost tree characteristics. In this study, sweetgum was used by SEM 43% of the time, whereas RBEB was found in only 18% of sweetgums (Table B.1). Although sweetgum cavity trees were the most highly available and encompassed a wide variety of cavity metrics in this study, RBEB used other tree species more frequently.

Southeastern myotis commonly roosted in smaller sized trees than RBEB. This is especially indicated by cavity trees used by colonies of SEM as opposed to those used by colonies of RBEB. In this study, I found a nearly equal use of trees in medium size classes by solitary bats of both species. However, RBEB shifted to larger (>100 cm DBH) size class trees for colony use whereas SEM continued to use smaller (40 – 70 cm DBH) size class trees as colony roosts. This may indicate that SEM exhibit a more generalist behavior when selecting roost trees than RBEB, or that cavity trees exhibiting the characteristics required by SEM are more abundant. Cochran (1999) theorized that SEM may have a competitive advantage over RBEB due to the seemingly less accessible roost sites chosen by RBEB in his study. Due to the forest stand composition on the study sites, there was a greater number of cavity trees in smaller size classes. Therefore, a greater number of cavity trees at NNWR may be more suitable for SEM roosts than for RBEB. This indicates the importance of preserving large diameter relic trees for possible roost sites by bats.

Baldcypress, black tupelo, and sweetgum were the tree species that most often contained a bat based on counts of individual trees used (Table B.1). According to sample sizes, it is understandable that sweetgum be used more often because it was the most prevalent cavity tree in the sample (Table B.1). On the contrary, baldcypress, American sycamore and black tupelo represented 4%, 2% and 7% of cavity trees respectively. These tree species were used more often than expected by both bat species. These also were the tree species that were used simultaneously by colonies of RBEB and SEM. Mirowsky (1998) also documented use of black tupelo by RBEB and SEM. If management goals are to manage for both bat species, these are very desirable tree species for roosting habitat. Because of their contribution to overall cavity tree availability, sweetgums should be retained for all cavity roosting species. Habitat management plans for bottomland hardwood forests should consider all potential cavity using species rather than focusing on a few select species. Priority can be given to species of concern such as RBEB and SEM. However, providing enough cavity trees to sustain all cavity-user populations may prevent limiting this resource for these sensitive bat species. Therefore, I submit that management for these bats prioritize protecting large relic baldcypress, American sycamore, and black tupelo while also retaining sweetgum and other tree species that frequently contain cavities.

Out of 82 use trees, 19 were used in winter which may indicate the rarity of cavity trees with characteristics that are suitable as winter roosts for RBEB and SEM. Some (n=10) winter use trees were found to be inhabited by both bat species simultaneously. Mirowsky and Horner (1997) located 14 roosts in east Texas and documented only one incidence of sympatric roosting by RBEB and SEM. In my study, these 2 bat species were not only found roosting in the same tree together but were observed clustered together in the chamber on occasion. Tree species used by both bats during winter in this study were baldcypress, black tupelo, eastern cottonwood, pignut hickory, sweetgum, and American sycamore. Further investigation is needed to detect significant differences between cavity trees used as winter or maternal roosts and those used as solitary roosts. There were not enough maternal or winter use observations to perform statistical operations for this data set. However, I determined that trees used by both bat species as winter or maternal roosts were larger $\geq$80 cm DBH size classes. Colony use trees ranged from 50 cm to 185 cm DBH. These large size class trees may not be highly available, 63% of cavity trees located in this study were <50cm DBH and <6% were $\geq$80 cm DBH. The above listed tree species may possess certain internal or external factors that promote use during winter or as maternal colony roosts. Protecting these winter use trees and those used as maternal roosts may help provide bats with the requirements needed to survive through these sensitive times.

Mean number of times a use tree was examined for bat use in this study was 13, number of tree inspections ranged from 1 to 50, with trees more easily accessible inspected more frequently. Mean number of inspections until a bat was detected in a tree was 3. More research is needed to confirm sampling intensity needed to detect bat use of cavity trees. However, Ferrara and Leberg (2005) recommended at least 3 surveys to detect use of bridges by bats. I attempted to inspect each cavity tree at least once per season. If sampling efforts were concentrated on cavity trees with characteristics that were important to bats such as, large diameter and chamber height, the number of cavity trees to inspect would be reduced by half. Thus, allowing researchers to increase rate of inspection while maintaining the same sampling intensity. This study provided baseline data on cavity tree metrics so that future studies can concentrate efforts and continue to increase knowledge about these bats at NNWR.

Vegetation characteristics. - Basal area surrounding use and non-use trees was 21.8 and 23.7 m^2/ha, respectively. Fan et al. (2003*a*) found that cavity tree density increased in stands where basal area was >18.3 m^2/ha and that basal area was one of the best predictors of cavity availability. Therefore, I recommend maintaining basal areas in bottomland hardwood forests at current levels to provide possible roosting habitat for RBEB and SEM on NNWR. Further research is needed to determine an upper limit of basal area for management of these species because no significant difference was found between use and non-use trees. There were no areas where cavity trees were concentrated except along water courses. However, there were many non-use trees and use trees along stream banks. Similar soils, tree species, and surrounding habitat characteristics may explain why no differences existed between use and non-use trees regarding surrounding vegetation characteristics.

Trees are ephemeral housing for cavity dwelling species and are constantly changing. Hurricanes in 2005 spurred tornadoes that sliced through NNWR including study site areas. Approximately 25 known cavity trees were found on the ground after the storms. Some cavity trees were standing, but damaged from the storm. This damage may have adversely affected bats from using these trees as roosts. Although several cavity trees were lost, only one known use tree was destroyed during the storms.

CHAPTER V

CONCLUSIONS

Cavity Producing Tree Species and Use by Bats

Tree species prone to produce cavities were American beech (*Fagus grandifolia*), followed by American holly (*Ilex opaca*), American sycamore (*Platanus occidentalis*), black tupelo (*Nyssa sylvatica*) and sweetgum (*Liquidambar styraciflua*). In an earlier study on NNWR, Lowney and Hill (1989) found that American sycamore and American beech were the most important cavity tree species for wood ducks. American beech trees with cavities were the second most available cavity tree species (55/622); however, RBEB and SEM used them sparingly as roosts (Table B.1). Mirowsky and Horner (1997) documented use of one American beech by RBEB in Texas. It remains unclear why beech trees were not used more often when considering that there were an abundance of these trees that exhibited large diameters and large internal chamber measurements.

Observations and recommendations for cavity producing tree species with regard to bat use is discussed below. Of the tree characteristics measured, DBH and internal chamber height were found to be the most important characteristics for bat roost trees in this study. The smallest cavity tree used by bats in this study was 40 cm DBH , and all American beeches with cavities located in this study were $\geq$ 40 cm DBH (Table B.1). Rafinesque’s big-eared bat used cavity trees with $\geq$ 195 cm chamber height, and SEM used trees with > 187 cm chamber height. Most (76%, 42/55) American beech cavity trees had chamber heights that were > 195 cm. There could be a microclimate effect within the chamber of cavity trees that was preventing a greater use of this tree species. For example, 18% (10/55) of American Beech had top openings with no ceiling and only one tree with an open top was used as a roost tree in this study. Hoffman (1999) also found that SEM did not roost in cavity trees without a ceiling. Lack of a ceiling could be a deterrent to consistent use because of microclimate variation within the chamber due to air drafting through the chimney-like structure of a cavity with upper level openings. Internal microclimate within the cavity chamber related to air movement and temperature stability could possibly render these trees less suitable for roosting bats compared to cavity trees with a ceiling. However, microclimate effects were not measured in this study and scarcity of use of American beech cavity trees with ceilings remains unclear. Future studies at NNWR should be designed to include measurement of microclimate conditions in cavity trees with different structure, such as trees with ceilings above internal chambers versus trees with openings above the internal chambers.

Both bat species used baldcypress, but this species was not common in forest stands comprising only 4.5% (124/2700) of trees found in prism cruises (Table B.1). By comparison, < 4% (23/622) of cavity trees were baldcypress, but almost half (43%, 10/23) of these were used by bats (Table B.1). In this study, both bat species used baldcypress frequently as a roost tree and 70% of the 10 baldcypress used by bats were either winter or maternal colony roosts. Baldcypress trees were used frequently despite the low availability of these trees on the landscape and bats appeared to select these trees for roost sites during different seasons. Baldcypress cavity trees found in this study ranged in size from 35 – 210 cm DBH (Table B.1). Baldcypress that were used by bats were > 100 cm DBH and by comparison, maternal use of baldcypress cavity trees occurred in trees that ranged from 125 – 185 cm DBH. Four of the 5 maternal roost trees identified in this study were baldcypress. Therefore, I strongly recommend conserving baldcypress, particularly cavity trees, within the range of RBEB and SEM for possible roosting sites. These trees should be allowed to grow large to have the opportunity to develop cavities that support colonies of RBEB and SEM at NNWR. Retention of baldcypress on long rotations (>100 years) may benefit other wildlife species such as, chimney swifts *(Chatura pelagica)*, prothonotary warblers *(Protonotaria citrea)*, and black bear *(Ursus americanus*; Yarrow and Yarrow 1999).

Black tupelo comprised 7% (43/622) of cavity trees found and 35% (15/43) of these were used by bats with half (7/15) of these containing colonies (Table B.1). Black tupelo cavity trees supporting bat colonies were large size class trees (50 – 115 cm DBH: Table B.1). Black tupelo was less abundant, according to prism cruise data, than baldcypress comprising only 2% (54/2700) of trees species found in the 4 study areas (Table B.1). Similarly, American sycamore represented <1% (10/2700) of overall stand composition and <2% (10/622) of cavity trees. Additional research is recommended to determine use of these tree species in other geographic locations within the range of RBEB and SEM. I recommend that future research on roost trees for these bats where black tupelo or American sycamore occurs should examine these species as possible preferred roost sites as well as important winter or maternal colony roost trees.

Sweetgum contributed to nearly half of available cavity trees in this study and was used as a roost tree by RBEB and SEM. Sweetgum cavity trees used by bats ranged in size from 40 - 105 cm DBH. One sweetgum (95 cm DBH) was used as a maternal colony roost by SEM. Lowney and Hill (1989) reported sweetgum as a suitable cavity tree species for wood ducks at NNWR. Considering contribution of sweetgum as a cavity producer, this species should be retained in management plans for cavity-roosting species.

American holly frequently exhibited cavities, but mean DBH was only 30 cm. Bats of both species roosted in trees that were ≥40 cm DBH, and no bats were found roosting in American holly in this study. American holly trees that were 40 cm DBH were documented in this study on NNWR within prism cruises; however, they did not exhibit cavities at this size. American holly is not a recommended species for bat roost sites according to results of this study, but they may provide cavity nesting opportunities for songbirds and other mammals (Yarrow and Yarrow 1999).

There were 13 cavity tree species that were not used by bats at NNWR. Some of these trees are relatively small trees (≤25 cm DBH), such as American hornbeam (*Carpinus caroliniana*) and therefore, might not achieve sizes large enough for these bats to use them as roosts. However, others were within the size range of bat use trees, but were not used due to other factors. An example of this is willow oak (*Quercus phellos*). Other non-use tree species may have such a small sample size that it is unclear as to the bat use of these species. Some of these with favorable cavity tree characteristics included winged elm (*Ulmus alata*), yellow-poplar (*Liriodendron tulipifera*), and post oak (*Quercus stellata*). Further investigation of these tree species is required to assess bat use.

Further investigation is needed to determine contribution of eastern cottonwood as a bat-roosting tree species. Only 2 were found as ancillary cavity trees and one was used by RBEB and SEM (Table B.1). Eastern cottonwood is rare at NNWR (Noxubee National Wildlife Refuge staff, personal communication), and I would recommend retaining all eastern cottonwoods at NNWR, especially those with cavities, until further investigation is more conclusive.

To conserve species like eastern cottonwood that may be found only along streamsides, I suggest conserving microhabitats that support preferred species. For example, baldcypress was only located along streams, low-lying depressions, and ephemeral wetlands. Protection of trees within forested wetlands and streamside management zones could allow trees to reach older age classes (Yarrow and Yarrow 1999, Dickson and Sheffield 2001). Conserving the aforementioned habitat types may promote this species and provide bats with more of these roost tree species.

Habitat Management Recommendations

The most often used roost tree species for both bat species were baldcypress, black tupelo, and American sycamore. These are all less common species in Mississippi due to the decline of bottomland hardwood forests in which these species occur (Frederickson et al. 2005). Due to their known value as cavity trees for black bears (*Ursus americanus*), cavity nesting songbirds, and raptors, baldcypress are often conserved in management plans. Protective measures for retention of mature trees, as well as recruitment of young trees into older age classes can also benefit RBEB and SEM. Bottomland hardwood forest types also support a plethora of hard mast producing species, such as oaks and American beech, as well as soft mast and browse that are eaten by popular game species in the southeastern U.S. (Yarrow and Yarrow 1999). Some preferred mast-producing species may not be as conducive to cavity production as sweetgum, baldcypress, black tupelo, and American beech. However, American beech and black tupelo serve a double purpose being producers of mast eaten by many species (Yarrow and Yarrow1999). The recommendations in this study can lead to a balance between game and non-game management and create more incentive for retention of cavity-producing trees and mast-producing trees. Several species including prothonotary warblers, gray squirrels *(Sciurus carolinensis)*, wood ducks *(Aix sponsa)*, raccoons *(Procyon lotor)*, black bear and many raptors might benefit from this research based on previous knowledge of cavity use (Yarrow and Yarrow 1999; Dickson and Sheffield 2001).

Noxubee National Wildlife Refuge manages for waterfowl by providing food sources in managed impoundments and winter flooded green timber reservoirs (GTR). Study sites chosen for this research were either in or adjacent to GTRs. The purpose of GTRs is to provide mast-producing trees for duck food. Baldcypress typically occurred along naturally flooded areas such as streambanks and depressional wetlands at NNWR. An integrated management for GTRs at NNWR could increase bat-roosting sites. Green timber reservoirs could be managed to allow more area to remain flooded for longer periods to encourage baldcypress growth where bat-roost trees were found (Yarrow and Yarrow 1999). Cavities created in baldcypress can also be used by wood ducks, thereby accomplishing components of waterfowl management goals (Lowney and Hill 1989).

This research considered smaller cavity trees by including cavity trees that were 15 cm DBH and above to assess overall cavity availability within study sites at NNWR. Consideration of these smaller trees (15 < 40 cm DBH) can provide an indication of recruitment of cavity trees into the forest stand in the future. Potential future bat roost trees are those that are < 40 cm DBH and data from this study showed that 32% (202/622) of cavity trees have the potential to become bat roost trees. This study identified several tree species that were conducive to cavity formation, such as sweetgum, American beech, black tupelo, and American sycamore. These also were frequently used by bats. Retention of these potential roost trees is more cost and time effective than replanting. Determination of important species, microhabitat, and landscape characteristics of these potential roost trees can assist managers in making more proactive decisions that are effective in retaining forest biodiversity with emphasis on cavity-using fauna.

During this study, 4 bottomland hardwood sites were surveyed from February 2005 to November 2006. These sites were chosen because they were different in forest stand composition, understory vegetation, and current and past management practices. Sites were specifically chosen based on these differences to gather a more comprehensive representation of forests in the southeastern floodplains. In general, forests of NNWR were older age classes than surrounding lands. Thus, this study provides baseline information on more mature deciduous forests, associated habitat structure, and use by rare species. Furthermore, results from site comparisons of landscape characteristics may explain absence of bats in some bottomland hardwoods. Jaberg and Guisan (2001) used general linear models to predict presence of bat species based on landscape structure.

Their results showed that presence or absence of certain bat species were correlated with elevation and vegetation cover. Future research at NNWR could investigate associations with bat use of microhabitats by stratifying study sites by these categories.

Considerations for Landscape Characteristics

Bats use different vegetation types across landscapes for many purposes. Bats may use openings for corridors and upland forests for foraging. Red bats (*Lasiurus borealis*) have been documented using intensively managed pine forests for foraging and roosting (Elmore et al 2004). Although red bats exhibit a completely different roosting behavior than cavity roosting species and associations cannot be garnered based on roost habitat, it is important to note that studies are finding that bats are foraging or otherwise using areas where they were previously not associated. For example, Hurst and Lacki (1999) documented RBEB foraging in upland oak-hickory forests (Hurst and Lacki 1999). I recommend that future studies consider habitat surrounding the roosting habitat of RBEB and SEM within bottomland hardwood forests on a landscape scale to determine habitat selection of these species.

It is often stated that RBEB are declining due to loss of roosting habitat which has been associated with bottomland hardwood forests (Clark 2003, O'Shea et al. 2003, Sherman 2004). Despite the decline of species, RBEB are not likely found in all bottomland hardwood forests within their range. Therefore, there may be other factors that cause them to inhabit certain forests or areas. Mirowsky and Horner (1997) found an abundance of cavity trees in bottomland hardwoods of East Texas and stated that roosting habitat did not seem to be a limiting factor for RBEB or SEM. Disturbance or pollution could keep bats out of an area due to their sensitivity to these factors (Hickey et al. 2001, Medellin et al. 2000). Bats also may key in on certain landscape characteristics that provide other survival needs that are just as important as roost sites.

Elmore et al. (2004) reported that stand level characteristics were more important than individual roost tree characteristics for red bats. This study found the opposite for RBEB and SEM probably due to the more generalist roosting habitats of red bats as opposed to RBEB and SEM which seem to require specific roost trees. Fan et al. (2003*a, b*) found that stand age and/or tree size was the most important predictor of cavity availability, as trees grew larger or older, cavity availability increased. This study had similar results although stand age was not measured, a larger proportion of large (≥75 cm DBH) trees had cavities when compared to the available trees in those size classes. Stand characteristics such as basal area and canopy cover were not significant when comparing habitat characteristics that surrounded use and non-use trees. However, homogeneity of the stands may have influenced these results. More research is needed to determine effects of other stand characteristics on roost trees of these bats.

Distance to habitat edge has been found to be a significant landscape characteristic that influences red bats (Elmore et al 2004). In this study, distance to edge was not a significant landscape variable for RBEB or SEM. Ford et al (2006) reported a link between presences of various bat species to riparian habitat. In this study, research areas were bordered by streams or rivers, so that a large proportion of surveyed area was located in riparian habitat. Bat roost trees were found along streams, but distance to permanent water was not significant. These results may have been influenced by the selection or size of study sites close to permanent water sources and habitat edge. Cavity tree distance to winter available surface water was statistically significant for SEM. However, the mean distance differed only 50 m between use and non-use cavity trees. This may not be biologically significant due to the long distances that bats fly to locate foraging sites (Menzel et al. 2001). Studies conducted in larger contiguous bottomland hardwood forests may produce different results regarding roost tree use and habitat associations with landscape characteristics.

Cavity Formation

The tendency for trees to form cavities was not similar across all tree species. The tendency for cavity formation could be related to inherent tree characteristics, such as softer cambium, prevalence for easy breakage, or susceptibility to fungal infections. Other factors can influence cavity formation including exposure to damage by feeding animals, fire, flooding or other forms of injury to bark or cambium (Hunter 1990). The natural feeding habits of beaver can injure tree bases and allow colonization of tree pathogens which promote development of basal openings for cavity formation and roosting sites (Muller-Schwarze and Sun 2003). Roosting sites also can be created in beaver impoundments when trees begin to decay or die due to flooding. Certain tree species, such as baldcypress, are prevalent in these hydric habitat types and could be more susceptible to cavity formation due to their location. Fire also can cause cavity formation. Boyles and Aubrey (2006) stated that fire can create fire scars providing a conduit for fungal infection and subsequent cavity formation. However, bottomland hardwood stands are generally not burned, so use of prescribed fire may not be applicable in most areas for increasing cavity tree abundance for roosting sites for RBEB and SEM.

Fan et al (2003*a*) found that a reduction in basal area would decrease cavity tree resources and recommended longer rotations to increase cavity tree abundance. Carver and Ashley (2008) suggested that opening the stand would likely increase ground cover and possibly adversely affect bat use of ground level cavities. Therefore, forest management practices must assess habitat requirements for individual bat species or at least group bats according to roosting and foraging habits. Similar management practices will not have the same outcome for bats roosting in leaf litter and bark as opposed to cavity tree dwellers. Also, diversity of forest stands where bats live limit forest management actions to those that can be effective within the habitat. More research is needed to determine limiting factors for RBEB and SEM. It is not yet known if cavity tree availability or other factors are limiting population numbers at NNWR. For now, managers should attempt to retain tree species that have susceptibility to cavity formation and allow these trees to grow >40 cm DBH for these rare bats.

Cavity Tree Characteristics

Tree DBH and internal chamber height were the most influential characteristics in roost trees used by RBEB and SEM. I examined use tree data and found that 82% of trees used by RBEB had a DBH of ≥ 70 cm. Most (81%) of trees used by SEM exhibited diameters of ≥ 60 cm. SEM used cavity trees with slightly smaller DBH than RBEB. The smallest tree used by bats exhibited a diameter of 40 cm. RBEB and SEM used trees with similar chamber heights, with 92% of RBEB and 93% of SEM roosting in trees with internal chamber heights of ≥ 300 cm. The smallest chamber height in a roost tree was 187 cm. I recommend that future surveys for these bat species focus on cavity trees that are ≥ 40 cm DBH and approximately ≥ 187 cm chamber height. Also, I recommend measuring DBH and chamber height in future studies to define characteristics of use trees of these bat species in other forest types or geographic locations.

I measured wall width to determine if thickness of the trunk's wall influenced use by roosting bats. This parameter was theorized to be of importance in maintaining microclimate stability, particularly during winter when a thicker wall might be needed for retention of suitable internal temperatures. I found that wall width was highly correlated with tree diameter and not an easy measurement for managers to obtain. Therefore, recommendations from this study include the assumption that tree species retained for RBEB and SEM use will typically exhibit a large internal chamber width if tree diameter is large. I did not measure temperatures inside cavity trees; thus, wall width effects on internal chamber temperatures remains unknown. I would recommend measuring temperatures in relation to wall width and other cavity tree measurements to determine what characteristics may correlate with inside chamber temperature and to ascertain temperature variants that may influence cavity tree use by bats.

Roost Site Use between Rafinesque's big-eared bat and southeastern myotis

While both bat species roost in bottomland hardwood forests, there were differences in roost tree selection and use. The most noticeable differences between these 2 species were the location of the bats inside the chamber and their behavior during inspections. RBEBs typically roosted along the sides of the chamber and would arouse readily when the tree was examined with a flashlight. SEMs were usually found roosting on the "ceiling" of the chamber or very close to the top and they did not typically arouse during cavity examination. A few cavity trees contained eastern pipistrelles *(Perimyotis subflavus)* that were difficult to distinguish from SEM except that they were typically found along the sides of the chamber instead of near the ceiling. Other studies also have noted this difference in locations of SEM and RBEB within tree chambers stating that SEM were found near the top and RBEB were along the sides of the chamber (Mirowsky and Horner 1997, Carver and Ashley 2008). Some colonies of SEM were heard; however, SEM were not usually seen flying within the chamber of the tree. In contrast, some individuals in the large colonies of RBEB would take flight when trees were inspected even before a flashlight illuminated the tree's chamber.

Both bat species roosted together and were most often found doing so during winter. Ten of the 19 trees used in winter contained both bat species roosting simultaneously. Southeastern myotis roosted in cavity trees with a smaller average DBH than those used by RBEB; however, both species more often used large DBH trees in winter. Maternity roosts for RBEB (N=6) ranged from 115-175 cm DBH, whereas only 2 SEM maternity roosts were found and they were 60 - 95 cm DBH. Maternity roosts were not used sumultaneously by the two bat species.

The Manly's alpha procedure showed similarities in selection of roost trees regarding tree species. However, some differences worth noting were that SEM roosted in sweetgum and American Beech more often than RBEB, and RBEB roosted in baldcypress more often than SEM. Forest managers can consider preferences of individual bat species to optimize habitat management for either or both bat species.

Habitat Destruction

Frederickson et al (2005) stated that 80% of bottomland hardwood forest habitat in the southeastern U.S. has been eliminated due to agriculture and urbanization. A suspected decline in RBEB and SEM populations has been attributed to loss of habitat; however, population status is unknown (Clark 2003, O'Shea et al 2003). More research is needed to determine what other habitat types are needed to provide foraging, resting, or other life-sustaining activities. Associations with landscape characteristics such as distance to water or foraging areas are not understood fully. Providing open corridors for reaching foraging areas may be a factor in recruitment, leading to an increase in population numbers. Other landscape characteristics such as distance to cropland or urbanized areas have not yet been investigated. Pollution may be the cause of population decline in some areas. Bats are sensitive to pollution and contaminants (Hickey et al. 2001), and with the increase of agriculture and urbanized areas comes an increase in water and air pollutants. Additionally, insecticides used on agricultural land may have a significant detrimental impact on the prey base of these bat species, possibly forcing bats to find alternative roosting or foraging areas.

Use of Artificial Roosts

This research agrees with other studies documenting use of large diameter cavity trees (Cochran 1999, Hoffman 1999, Gooding and Langford 2004, Carver and Ashley 2008). However, I did not find as many bats using bridges as others have (Lance et al 2001, Ferrara and Leberg 2005, Trousdale and Beckett 2005). Only one examination during summer yielded finding a bat under a bridge. Of 41 bridges surveyed, one was used by two SEM. Abandoned houses and other structures at NNWR were typically occupied by only one RBEB during inspection. The general lack of use of artificial structures may imply that available natural roosts were sufficient for the bat populations at Noxubee NWR. However, more research is needed to assess population numbers and requirements. Studies have documented use of various artificial structures as roosts for RBEB and SEM (Harvey and Saugey 2001, Sherman 2004). Future surveys should examine use of artificial structures as possible roosting sites. Proactive management should seek to protect these roosts from disturbance and deterioration. The culvert erected to provide additional roosting habitat for bats, was a simple way to provide tree-like roosting habitat for RBEB and possibly SEM. Rafinesque's big-eared bats were observed roosting in the culvert, but no SEM were observed inside during examinations at the time of this study. I encourage other managers and conservationists to use similar resources to create bat roosting habitat where needed.

Research Recommendations

Many studies have concentrated on one or 2 tree species for searching for these bats. Valuable use information may be missed this way. Because, tree species differ across the region, I do not recommend only concentrating on certain species for bat surveys. Instead, I suggest surveying all cavity trees with > 40 cm DBH and chamber height >187 cm. I found no significant differences in seasonal use by RBEB, but SEM noticeably switched to larger trees for winter roosts. Southeastern myotis used trees averaging 75 – 80 cm DBH in all seasons except winter in which roost trees averaged 106 ± 33 cm DBH. Winters in Mississippi are typically mild with temperatures rarely causing freezing conditions (Carpenter and Provorse 1996). Research conducted in more northern regions may yield different results in seasonal use. It has also been suggested that cavity tree numbers may increase in areas where limb breakage from ice storms may frequently occur (Lowney and Hill 1989). Therefore, cavity use by bats in different regions can yield different results due to environmental and regional climate effects.

Microclimate parameters were not measured in this study, and these factors could influence cavity tree use. Researchers may find that these bats use different areas of their range differently. I have suggested that future studies examine use of certain tree species, but some of the preferred species found in this study do not occur across the entire range of these bats. Therefore, RBEB and SEM may choose different species of trees as roosts depending on tree availability and regional effects. Furthermore, multiple sampling methods may be needed to increase chances of finding roost sites.

Nearly 90% of cavity trees found in this study contained basal openings. This trend is most likely influenced by sampling methods. Basal openings are closer to eye level than those that are located along sides of trees or are top openings. Important roost trees could have been missed using plot surveys alone. Some baldcypress roost trees had noticeable top-broken or side-openings and refuge staff cut holes into the side of the tree to observe bats. These "windows" were replaced after observation and measures were taken to seal the opening to prevent unwanted air flow into the chamber. It is uncertain how many bat use trees were not discovered due to searching techniques in this study. Every attempt was made to increase sample size of use trees. Refuge staff placed raddiotransmitters on some bats to find additional roosting sites. Because bats that were fitted with radiotransmitters led researchers to cavity trees in my study, I recommend radiotracking of bats to increase potential for locating roost sites in combination with tree survey methods. I also recommend searching for ancillary cavity trees in addition to plot survey methods. Large diameter trees were targeted when searching for ancillary trees to increase chances of finding bat roost trees. Including ancillary trees, creating windows in hollow trees, and radiotracking bats improved the sample size of bat use trees and contributed greatly to the knowledge of colony use of cavity trees by RBEB and SEM at NNWR.

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APPENDIX A

DENSITY TABLES FOR PRISM CRUISES AND CAVITY TREE SURVEYS

Table A.1 Number (n) and density (trees/ha) of trees categorized by species found from prism cruises conducted in four study sites at Noxubee National Wildlife Refuge during 2006-2007.

	Site 1		Site 2		Site 3		Site 4	
Tree Species	n	Density	n	Density	n	Density	n	Density
American beech *Fagus grandifolia*	34	3.4	0	-	2	0.3	5	0.7
American elm *Ulmus americana*	2	2.0	0	-	7	4.5	10	5.7
American holly *Ilex opaca*	1	0.5	0	-	20	8.0	0	-
American hornbeam *Carpinus caroliniana*	17	16.2	6	8.7	23	22.6	4	4.7
American sycamore *Platanus occidentalis*	3	0.2	1	0.5	2	0.3	4	1.7
Baldcypress *Taxodium distichum*	20	2.4	44	9.7	9	0.9	51	16.5
Black tupelo *Nyssa sylvatica*	25	3.0	8	1.8	10	4.3	11	3.7
Black willow *Salix nigra*	4	0.9	0	-	0	-	1	0.6
Cherrybark oak *Quercus pagoda*	126	12.5	143	21.1	132	13.2	70	14.6
Green ash *Fraxinus americana*	9	1.4	9	4.5	29	8.5	11	8.6
Loblolly pine *Pinus taeda*	18	1.8	9	1.0	6	0.5	2	0.5
Mockernut hickory *Carya tomentosa*	25	9.5	0	-	16	3.2	10	4.9
Nuttall oak *Quercus nuttallii*	0	-	0	-	0	-	8	2.7
Northern red oak *Quercus rubra*	0	-	6	0.6	0	-	0	-
Overcup oak *Quercus lyrata*	72	9.5	101	14.1	54	9.4	30	10.0
Persimmon *Diospyros virginiana*	2	1.0	2	1.1	1	0.3	0	-
Pignut hickory *Carya glabra*	19	5.4	0	-	8	4.8	1	0.1
Red hickory *Carya glabra var. glabra*	1	0.0	0	-	2	0.4	0	-
Red maple *Acer rubrum*	79	27.1	40	28.0	13	10.5	72	56.3
Red mulberry *Morus rubra*	0	-	0	-	1	0.6	1	0.8
Scarlet oak *Quercus coccinea*	4	0.2	0	-	0	-	0	-

Table A.1 Continued

	Site 1		Site 2		Site 3		Site 4	
Tree Species	n	Density	n	Density	n	Density	n	Density
Sassafras *Sassafras albidum*	0	-	0	-	0	-	2	0.6
Sugarberry *Celtis laevigata*	0	-	3	0.7	10	3.7	0	-
Swamp chestnut oak *Quercus michauxii*	64	11.0	16	4.0	44	9.1	40	13.8
Slippery elm *Ulmus rubra*	6	2.7	1	0.5	2	0.9	5	2.5
Sweetgum *Liquidambar styraciflua*	211	45.5	113	53.5	85	22.3	97	47.8
Shagbark hickory *Carya ovata*	11	2.4	12	4.3	21	5.1	10	4.3
Swamp laurel oak *Quercus laurifolia*	0	-	5	0.6	1	0.2	0	-
Sugar maple *Acer saccharum*	1	0.7	0	-	0	-	0	-
Shumard oak *Quercus shumardii*	0	-	0	-	2	0.2	4	0.6
Southern red oak *Quercus falcata*	0	-	2	0.2	0	-	0	-
Unknown	7	1.1	9	2.4	7	1.7	5	1.0
Winged elm *Ulmus alata*	7	2.9	7	5.2	4	2.3	3	1.8
Willow oak *Quercus phellos*	28	1.9	34	5.1	69	7.7	22	7.1
White oak *Quercus alba*	2	0.2	15	2.2	4	0.6	2	0.2
Water oak *Quercus nigra*	73	9.7	47	12.5	73	13.9	14	3.7
Yellow-poplar *Liriodendron tulipifera*	26	4.0	1	1.0	5	0.4	12	6.4
TOTAL	897	179.1	634	183.5	662	160.2	507	222.0

Table A.2 Number of cavity trees and density (trees/hectare) by tree species from survey plots in four study sites at Noxubee National Wildlife Refuge, Mississippi during 2005-2007.

Tree Species	Site 1		Site 2		Site 3		Site 4	
	n	Density	n	Density	n	Density	n	Density
American Beech *Fagus grandifolia*	32	3.1	0	-	1	0.1	5	0.8
American Elm *Ulmus americana*	0	-	0	-	3	0.3	0	-
American Holly *Ilex opaca*	4	0.4	0	-	17	1.8	0	-
American Hornbeam *Carpinus caroliniana*	1	0.1	1	0.1	4	0.4	0	-
American sycamore *Platanus occidentalis*	4	0.4	0	-	1	0.1	0	-
Baldcypress *Taxodium distichum*	0	-	3	0.2	0	-	1	0.2
Black Tupelo *Nyssa sylvatica*	12	1.2	8	0.6	2	0.2	2	0.3
Cherrybark Oak *Quercus pagoda*	0	-	1	0.1	1	0.1	0	-
Green Ash *Fraxinus pennsylvanica*	4	0.4	7	0.5	15	1.6	0	-
Mockernut Hickory *Carya glabra*	1	0.1	0	-	1	0.1	1	0.2
Overcup Oak *Quercus lyrata*	2	0.2	6	0.4	8	0.8	0	-
Persimmon *Diospyros virginiana*	1	0.1	0	-	0	-	0	-
Pignut Hickory *Carya glabra*	1	0.1	1	0.1	4	0.4	1	0.2
Red Maple, *Acer rubrum*	4	0.4	5	0.4	9	0.9	0	-
Sugarberry *Celtis laevigata*	0	-	0	-	4	0.4	0	-
Swamp Chestnut Oak *Quercus michauxii*	4	0.4	0	-	2	0.2	1	0.2
Sweetgum *Liquidambar styraciflua*	92	8.9	76	5.5	54	5.7	38	6.3
Shagbark Hickory *Carya ovata*	0	-	2	0.1	3	0.3	3	0.5
Unknown	3	0.3	2	0.1	2	0.2	0	-
Winged Elm, *Ulmus alata*	0	-	0	-	2	0.2	0	-
Willow Oak *Quercus phellos*	0	-	2	0.1	2	0.2	0	-
White Oak, *Quercus alba*	0	-	0	-	1	0.1	0	-
Water Oak *Quercus nigra*	0	-	5	0.4	3	0.3	1	0.2
Yellow-Poplar *Liriodendron tulipifera*	1	0.1	0	-	1	0.1	0	-
TOTAL	166	16.1	119	8.6	140	14.7	53	8.7

Table A.3 Species and number of ancillary[a] cavity trees found in or around four designated study sites in bottomland hardwood forest habitat at Noxubee National Wildlife Refuge, Mississippi during 2005-2007

	Count					
Tree Species	Site 1	Site 2	Site 3	Site 4	Other Areas	Total
American Beech, *Fagus grandifolia*	16	1	0	0	0	17
American sycamore *Platanus occidentalis*	2	2	1	0	0	5
Baldcypress, *Taxodium distichum*	0	11	5	3	0	19
Black tupelo, *Nyssa sylvatica*	6	9	3	1	0	19
Cherrybark Oak, *Quercus pagoda*	0	1	2	0	2	5
Eastern cottonwood *Populus deltoides*	0	2	0	0	0	2
Green ash, *Fraxinus pennsylvanica*	0	1	0	0	0	1
Overcup oak, *Quercus lyrata*	1	6	1	0	0	8
Pignut hickory, *Carya glabra*	0	2	1	0	0	3
Post oak, *Quercus stellata*	0	0	0	0	1	1
Red maple, *Acer rubrum*	0	3	0	0	0	3
Shagbark hickory, *Carya ovata*	0	2	0	0	1	3
Southern red oak, *Quercus falcata*	0	0	0	0	2	2
Swamp chestnut oak *Quercus michauxii*	2	5	0	0	0	7
Sweetgum, *Liquidambar styraciflua*	10	15	2	1	5	33
Unknown	0	2	0	0	1	3
Water oak, *Quercus nigra*	0	4	0	0	2	6
White oak, *Quercus alba*	0	0	0	0	2	2
Willow oak, *Quercus phellos*	0	2	1	0	0	3
Winged Elm, *Ulmus alata*	0	0	0	1	0	1
Yellow-poplar *Liriodendron tulipifera*	1	0	0	0	0	1
Total	38	68	16	6	16	144

[a] Ancillary cavity trees are those found outside the survey plots within designated study sites or in other areas outside the study site boundary.

APPENDIX B

STAND COMPOSITION, CAVITY TREE AVAILABILITY, AND BAT USE

Table B.1 Comparison of cavity tree species used by Rafinesque’s big-eared bat (RBEB) and southeastern myotis (SEM) as roosts to the availability of cavity trees found by plot surveys, and the overall stand composition measured by 10-factor prism cruise surveys conducted on four bottomland hardwood study sites at Noxubee National Wildlife Refuge, Mississippi during 2005 – 2007.

	Trees detected in Prism Cruise Surveys			Trees detected in Cavity Tree Surveys			RBEB Use Trees			SEM Use Trees		
Tree Species	n	%[a]	DBH	n	%	DBH	n	%	DBH	n	%	DBH
American Beech (Fagus grandifolia)	41	1.5	25-95	55	8.8	40-105	4	8.2	65-90	7	14.9	50-80
Baldcypress (Taxodium distichum)	124	4.6	20-140	23	3.7	35-210	10	20.4	100-210	3	6.4	100-155
Black Tupelo (Nyssa sylvatica)	54	2.0	15-95	43	6.9	20-150	9	18.4	50-115	9	19.1	50-115
Cherrybark Oak (Quercus pagoda)	471	17.4	15-135	7	1.1	60-100	1	2.0	70			
Eastern Cottonwood (Populus deltoides)	0	0	-	2	0.3	60-95	1	2.0	95	1	2.1	95
Overcup Oak (Quercus lyrata)	257	9.5	15-130	24	3.9	40-120	2	4.1	85-120	1	2.1	85
Pignut Hickory (Carya glabra)	28	1.0	15-80	10	1.6	25-80	1	2.0	70	1	2.1	70
Swamp Chestnut Oak (Quercus michauxii)	164	6.1	15-125	14	2.3	50-120	5	10.2	70-110	2	4.3	100

Table B.1 Continued

Tree Species	Trees detected in Prism Cruise Surveys			Trees detected in Cavity Tree Surveys			RBEB Use Trees			SEM Use Trees		
	n	%	DBH	n	%	DBH	n	%	DBH	n	%	DBH
Sweetgum (Liquidambar styraciflua)	506	18.7	15-105	293	47.1	15-105	9	18.4	40-105	20	42.6	40-95
Shagbark Hickory (Carya ovata)	52	1.9	15-75	11	1.8	35-75	1	2.0	75			
American Sycamore (Platanus occidentalis)	10	0.4	20-150	10	1.6	50-150	3	6.1	70-140	2	4.3	70-140
Willow Oak (Quercus phellos)	154	5.7	20-110	7	1.1	25-105	1	2.0	105			
White Oak (Quercus alba)	23	0.9	30-110	3	0.5	90-115	1	2.0				
Water Oak (Quercus nigra)	207	7.7	15-105	15	2.4	25-105	1	2.0	105	1	2.1	105

[a] Percentages are the proportion of each tree species represented within each sample population.