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Summer Roosting by Adult Male Seminole Bats in the Ouachita Mountains, Arkansas

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ABSTRACT.—We used radiotelemetry to locate 51 diurnal roosts for 17 male Seminole bats (*Lasiurus seminolus*) during late spring and early summer, 2000–2005. We quantified characteristics of roost trees and sites surrounding roosts and compared those measurements with random trees and random locations. All but two roosts were located in the foliage of large overstory pines (*Pinus* sp.). All roosts were in trees ≥21.7 cm dbh and roost trees were taller and greater in diameter than random trees. A conditional logistic regression model differentiating roost sites from random locations indicated Seminole bats were more likely to roost at sites with more pines 25.0–49.9 cm dbh, fewer pines 10.0–24.9 cm dbh, lower overstory hardwood basal areas (BA) and more recently cut stumps than random; bats selected open forest sites dominated by large (>20.0 cm dbh) pines. Eighty-four percent of roosts were located in stands that were recently partially harvested or thinned but retained large overstory pines. Relatively open pine forest, with abundant large overstory pines, is important roosting habitat for male Seminole bats during summer on the western edge of their range.

INTRODUCTION

To implement conservation measures for any species, information on its natural history, behavior and habitat requirements is needed. Roost sites are a necessary habitat component for bats. Because roost sites play an important role in thermoregulation and protection from predators, roost site characteristics undoubtedly influence bat fitness and survival (Kunz and Lumsden, 2003).

The range of the Seminole bat, *Lasiurus seminolus* (Rhoads) is restricted to the southeastern U.S.; central Arkansas represents the northwestern edge of its range (Wilhide *et al.*, 1998; Bat Conservation International, 2001). Although a recent increase in roosting studies has provided substantial information on roosting by other lasurine bats such as the eastern red bat (*Lasiurus borealis*; *e.g.*, Hutchinson and Lacki, 2000; Elmore *et al.*, 2004), limited information is available on roosting ecology of Seminole bats.

Bats of the genus *Lasiurus* roost primarily in the foliage of trees (Constantine, 1958). Early observational studies suggested Seminole bats roosted primarily in Spanish moss (*Tillandsia usneoides*) and its distribution was believed to coincide with the range of this plant (Constantine, 1958; Barbour and Davis, 1969; Wilkins, 1987). However, those studies were limited because roost locations were documented only for easily accessible bats (*i.e.*, those roosting low enough to the ground to be easily observed) and those studies typically concentrated on only one type of roost substrate (*e.g.*, Spanish moss). Studies using radiotelemetry to locate roosts give less biased information on roosting and only recently

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have studies used radiotelemetry to quantify roost selection by Seminole bats (Menzel *et al.*, 1998, 1999, 2000; Hein *et al.*, 2005). Those studies found Seminole bats roosting primarily in the foliage of pines during summer, but limited information was provided on habitat associations for this species. In addition, those studies were on the eastern edge of the range of Seminole bats; thus, it is not known if roosting ecology of this species is similar throughout its distribution. Herein, we characterize summer roosts and roosting habitats of males and compare roost trees and sites surrounding roosts with random trees and sites to determine habitat features important to the roosting ecology of this species.

METHODS

STUDY AREA

The study was conducted in the 6545-ha Upper Lake Winona Basin (approximately 34°48′N, 92°58′W), situated in the Ouachita Mountains of central Arkansas. The Ouachita Mountains are a series of east-west oriented ridges and valleys that extend from central Arkansas into east-central Oklahoma. Elevations in this region range from 152 to 853 m, mean annual precipitation ranges from 1120 to 1370 mm and mean annual temperature ranges from 13.9 to 16.1 C (Skiles, 1981).

Most of the basin consisted of mixed shortleaf pine (*Pinus echinata*)-hardwood forest managed by the Forest Service, U.S. Department of Agriculture (Ouachita National Forest; ONF). The basin also contained a mix of other forest types including oak (*Quercus* sp.)-hickory (*Carya* sp.) and riparian hardwood forests. Approximately 12% (778 ha) of the study area was intensively managed industrial timberlands consisting primarily of closed canopy and older thinned plantations of loblolly pine (*P. taeda*) that were generally thinned and pruned at about 12–15 y of age.

National forest lands within the basin were divided into 4 areas where different silvicultural treatments were implemented in 2000 as part of a multidisciplinary research project (Guldin, 2004). These four areas included the following management approaches: (1) partial harvesting and midstory removal (2096 ha) with overstory basal areas (BA) of 13.8 m^2/ha pine and 1.1–2.3 m^2/ha hardwood; (2) group selection (1044 ha) where groups or trees were removed in openings of 0.40–4.05 ha and the surrounding forest was thinned; (3) mix of treatments (1791 ha) including single-tree selection, group selection, seed-tree cuts and unharvested stands; and (4) unharvested forest (836 ha) consisting mostly of mature, second-growth pine-hardwood forest. Throughout the basin, unharvested stands were interspersed within those treatment units. Thus, the Winona Basin contained most of the predominant forest types, seral stages and forest management practices that existed in the Ouachita Mountains.

BAT CAPTURE AND TELEMETRY

From mid-May until late Jul. 2000–2005, we captured bats between 2100 and 0130 CST using 3–8 mist nets (2.6–12.0 m wide × 2.6 m tall with 25 mm mesh) at 21 trapping areas distributed throughout the basin. Trapping locations were primarily stream pools, but also included forest roads, culverts, bridges, ponds and dry creek beds. Age (juvenile or adult) was assessed based on the degree of ossification of the metacarpal-phalanx joints (Racey, 1974). We followed the guidelines of the American Society of Mammalogists for the capture, handling, and care of mammals (Animal Care and Use Committee, 1998).

We used radio transmitters to locate bats at their diurnal roost sites from mid-May until early Aug. Transmitters were bonded to the mid-scapular region with surgical adhesive following partial hair removal. Bats were instrumented with 0.32 or 0.70-g transmitters with

10 or 21-d batteries, respectively. Transmitter load was 2.6–8.4% of body mass and averaged 4.5% (±0.5 SE). All instrumented bats were adults. We radiotracked each bat to its roost site the morning following capture and for approximately 5 d/wk thereafter. After the approximate roost tree was determined, we visually located bats. When a bat could not be identified visually in the roost, we collected habitat data for the surrounding site (roost ''site'' hereafter), but did not collect data specific to the roost tree (*e.g.*, tree species).

ROOST AND SITE DATA COLLECTION

For visually confirmed roosts, we recorded tree species, diameter at breast height (dbh) and distance from roost tree to nearest overstory tree. We measured roost height, total tree height and height to base of tree canopy with a clinometer. An index of canopy volume was estimated by measuring canopy width in two dimensions (90° apart) on the ground; widths were then multiplied by total canopy height (total height minus height from ground to base of the tree canopy). Percent canopy closure from roost to 2 m above and from roost to 2 m below was estimated independently by two observers and averaged. Aspect of roost was measured in relation to the tree trunk.

To characterize habitat surrounding each roost, we collected data on site attributes within a 17.84-m radius (0.1 ha) plot centered on each roost tree. For roosts that lacked visual confirmation, this plot was centered on the general area indicated by radiotelemetry. At each plot, we determined pine and hardwood overstory heights by averaging heights for two dominant pines and two dominant hardwoods. Within the plot, all woody stems >1 m tall and <5 cm dbh were counted, all woody stems >1 m tall and ≥5 cm dbh were recorded by dbh and species and all stumps with ≥10-cm-diameter tops resulting from recent tree harvest were tallied. At four locations (90° apart) along the outer edge of the plot, we measured canopy cover using a spherical densiometer and pine and hardwood basal area using a 1-factor metric prism; data for each variable were then averaged for the plot.

To determine potential site characteristics that may have affected roost selection, we chose random trees and sites to compare with roost trees and roost sites. Identical habitat measurements were collected for random and roost plots. To ensure random trees were among those available to bats, we chose a random tree for each roost tree by choosing the first tree ≥5 cm dbh (hardwood or pine) and >40 m distance, at a random azimuth from the roost location. When adjacent roost locations were ≤20 m apart, we measured a single plot (centered between the 2 roosts) and a single corresponding random plot.

DATA ANALYSES

We treated each roost location as an independent sample although multiple roost locations from individual bats were included in the data set, which is the method of analysis most commonly used in studies of bat roost selection (*e.g.*, Menzel *et al.*, 1998; Hutchinson and Lacki, 2000; Mager and Nelson, 2001; Elmore *et al.*, 2004). We used Student's *t*-tests to determine if structural (*e.g.*, height, diameter) differences existed between randomly selected trees and roost trees. We compared roost aspect with random orientation using Rayleigh's test (Zar, 1999). We used alpha = 0.05 as the level of significance for hypothesis tests.

To determine how forest attributes affected roost selection, we used matched-pairs (each roost matched with its random location) conditional logistic regression (Hosmer and Lemeshow, 2000) to create models that related habitat parameters with an increased likelihood of bat roosting. After removing highly correlated ($r \geq 0.70$) variables, we included 12 habitat parameters (Table 1) derived from 0.1-ha plots surrounding roost and random trees. Number of hardwoods 5.0–9.9, 10.0–24.9 and 25.0–49.9 cm dbh correlated

TABLE 1.—Site characteristics from 0.1-ha plots entered into logistic regression models comparing roost sites of male Seminole bats (*Lasiurus seminolus*) with random locations in the Ouachita Mountains of Arkansas, 2000–2005

Variable	Description
PTH	Average tree height of pines (m)
HTH	Average tree height of hardwoods (m)
BAp	Average overstory basal area of pines (m^2/ha)
BAh	Average overstory basal area of hardwoods (m^2/ha)
COV	Average overstory canopy cover (%)
Stumps	Number of recently cut tree stumps >10 cm (total number in plot)
DisTree	Distance to nearest tree (m)
Under5	Number of stems <5.0 cm dbh (total number in plot)
P5to10	Number of pines 5.0–9.9 cm dbh (total number in plot)
P10to25	Number of pines 10.0–24.9 cm dbh (total number in plot)
P25to50	Number of pines 25.0–49.9 cm dbh (total number in plot)
Pover50	Number of pines ≥50 cm dbh (total number in plot)

highly ($P > 0.70$) with hardwood BA and were removed from analyses. We determined a set of candidate models using a best subsets procedure, which selected the best 1-variable model, best 2-variable model and so forth based on values of the chi-square statistic (SAS Institute Inc., 2000). We then determined the most parsimonious model among all candidate models based on the value of Akaike's Information Criterion (AIC; Burnham and Anderson, 2002) modified for small samples (AIC_c; Anderson *et al.*, 2000). We assessed model fit using generalized maximum-rescaled R^2 (Nagelkerke, 1991; SAS Institute Inc., 2000). We used multimodel inference by averaging parameter estimates of models within 2 units of AIC_{min} (Burnham and Anderson, 2002); we used weights (ω_i) calculated among models within two units of AIC_{min} for averaging and we calculated odds ratios (odds roost/odds random) from averaged parameters. We computed unconditional SEs for each parameter (Burnham and Anderson, 2002).

We compared proportions of used habitats with proportions of available habitats with a chi-square goodness-of-fit test. We defined available habitat based on locations of roosts. We created a 1000-m buffer around each roost location and created a polygon that encompassed all buffers; that polygon subsequently was considered the area of available habitat. Although little information is available on home ranges or movements by Seminole bats, the 1000-m buffer corresponded roughly with the average maximum distance traveled by eastern red bats during foraging in forested environments of the Southeast (Elmore *et al.*, 2005). Forest habitat classes were derived from digital forest stand maps of the study area obtained from the ONF. Those maps were updated and corrected using a 10-m digital color orthoquad (DOQ) and ground-truthing. We collected global positioning system (GPS) coordinates for each roost location and overlaid those locations on vegetation maps in a geographic information system (GIS) to determine the proportion of roosts in each habitat type.

RESULTS

We captured 35 Seminole bats over 107 nights (494 net nights) during six summers. Male Seminole bats comprised 4.6% of all captures but no females were captured during summer. Twenty-one adult males were instrumented, but four of those were never detected after release. For the remaining 17 bats, we located 51 roosts, 44 (86.3%) of which were visually confirmed. The number of roosts per bat was 1–6 and averaged 3.0 (±0.4 SE).

TABLE 2.—Attributes of 44 trees used by Seminole bats (*Lasiurus seminolus*) for roosting and comparisons of these attributes with random trees (n = 44) in the Ouachita Mountains, Arkansas during summer, 2000–2005

	Roost		Random			
Attributes	Mean	SE	Mean	SE	*t*	P
Tree characteristics						
Tree height (m)	21.5	0.7	18.7	0.9	−2.42	0.018
Tree diameter (dbh, cm)	36.1	1.4	29.4	1.9	−2.81	0.006
Height to base of canopy (m)	11.4	0.5	9.2	0.6	−2.76	0.007
Canopy volume (m^3)	710	87	637	110	−0.52	0.603

All roosts were in canopies of live trees and all roosts trees were ≥21.7 cm dbh (range 21.7–58.5 cm; Table 2). For visually confirmed roosts, 95.4% of roosts were in pines; however, in random plots, pines ≥21.0 cm comprised only 33.0% of available trees ≥5 cm dbh. In pines, Seminole bats roosted by hanging on pine needles, cones, small twigs and limbs. Of pines used, 88.61% were shortleaf (84.4% of available pines >21.0 cm dbh) and 11.4% were loblolly (15.6% of available pines >21.0 cm dbh). Only two visually confirmed roosts were in hardwoods: one white oak (*Quercus alba*) and one mockernut hickory (*Carya tomentosa*). These two non-pine roosts were used by two different bats; their other roosts were in pines. Average height to roost was 16.5±0.8 m, average distance from roost of edge of tree canopy was 69.3±10.1 cm, average canopy closure above roosts was 61.6±4.2% and average canopy closure below roosts was 20.8 ±4.8%. Aspect of roosts did not differ from random orientation ($z = 0.04$, n = 44, $P > 0.50$). Roost trees used by Seminole bats were taller, greater in diameter and higher to the base of crown than random trees (Table 2).

Logistic regression analyses differentiating roost sites from random sites included three models within two units of AIC_{min} (Table 3). The parameter-averaged model included the following variables: BAh (estimate = −0.327 ± 0.205 SE; odds ratio = 0.721), Stumps (estimate = 0.110 ± 0.043; odds ratio = 1.117), P25to50 (estimate = 0.223 ± 0.096; odds ratio = 1.249) and P10to25 (estimate = −0.008 ± 0.012; odds ratio = 0.992). Male Seminole bats were more likely to roost at sites with more large pines in the overstory (P25to50), more recently cut stumps (Stumps), fewer small overstory pines (P10to25) and lower overstory hardwood BA (BAh) than random.

The majority (60.8%) of roosts were in partially harvested, mixed pine-hardwood stands that had undergone midstory removal (Table 4). Proportions of habitats used differed from proportions of available habitats ($\chi^2 = 51.55$, df = 6, $P < 0.001$). Six roosts each were in group selection stands, thinned loblolly pine plantations and unmanaged (no silvicultural treatments other than infrequent prescribed burning) mixed pine-hardwood forest ≥100 y old.

TABLE 3.—Values of AIC_c, difference from AIC_{min} (Δ_i), model weights (ω_i), and maximum-rescaled R^2 for models within 2 units of AIC_{min} (48.773) comparing roost sites of male Seminole bats (*Lasiurus seminolus*; n = 44) and random locations in the Ouachita Mountains of Arkansas, 2000–2005. Model parameters are defined in Table 1

Model	AIC_c	Δ_i	ω_i	R^2
+[a] Stumps + P25to50	50.367	1.594	0.241	0.31
+ Stumps + P25to50 − BAh	48.773	0.000	0.534	0.39
+ Stumps + P25to50 − BAh − P10to25	50.503	1.730	0.225	0.40

[a] + = positive association with roost location in model, − = negative association with roost location in model

TABLE 4.—Proportions (number of roosts in parentheses) of 51 roosts of Seminole bats (*Lasiurus seminolus*) from 17 males in 7 forest habitat classes and proportional availability of those habitats in the study area in the Ouachita Mountains of Arkansas, 2000–2005

Forest habitat	Used	Available
Even-aged pines 30–49.9 y old	2.0(1)	5.0
Mixed pine-hardwood 50–99.9 y old	2.0(1)	20.6
Mixed pine-hardwood ≥100 y old	11.8(6)	5.2
Mixed pine-hardwood, group selection	11.8(6)	10.4
Mixed pine-hardwood, partially harvested	60.8(31)	23.4
Thinned loblolly pine plantation	11.8(6)	13.2
Other forest habitats	0.0(0)	22.2

DISCUSSION

Roosts of male Seminole bats were primarily (95.4%) in the foliage of large (>21.0 cm dbh) overstory pines in pine-dominated stands. Although Constantine (1958) observed Seminole bats roosting in Spanish moss during winter and early spring, our results and those of Menzel *et al.* (1998, 1999, 2000) do not support assertions that Seminole bats are closely associated with Spanish moss during summer. In this study, no roosts were located in Spanish moss, which is rare (or nonexistent) in the Ouachita Mountains (Garth, 1964). However, the geographic distribution of Seminole bats coincides rather closely with the pine belt of the southeastern U.S. (Garth, 1964; Burns and Honkala, 1990; Bat Conservation International, 2001). Given the reliance on pines for roosting by this species and its distribution, we suggest that the Seminole bat is an obligate of pine forests in the southeastern U.S., although it will roost occasionally in hardwoods.

Mean heights and diameters of trees used for roosting were smaller than those reported in Georgia, Florida and South Carolina (Menzel *et al.*, 1998, 1999, 2000), likely a result of regional differences in site, management and climate that affected overall tree sizes. Nonetheless, we found Seminole bats selected trees that were taller and larger in diameter than random trees. Studies indicate many forest bats, including foliage-roosting species, usually roost in the larger trees within their environment (*e.g.*, Hutchinson and Lacki, 2000; Menzel *et al.*, 2000; Mager and Nelson, 2001). The ecological reason for this behavior is unknown. Avoiding terrestrial predators by roosting high in large trees has been proposed (*e.g.*, Morrison, 1980; Vonhof, 1996), but this explanation is only valid if terrestrial predators pose a greater risk to roosting bats than avian predators. However, little is known about predation rates on tree-roosting bats. Others suggest that larger trees extending above the surrounding canopy receive greater solar radiation, which may speed fetal growth and development (Racey and Swift, 1981; Vonhof, 1996). However, our study was limited to adult males; thus, thermal effects on fetal development could not explain selection of large trees. Male Seminole bats simply may select overstory trees to avoid the more cluttered conditions closer to the ground (*e.g.*, midstory and shrub layers) that can impede flight and visual identification of predators.

Seminole bats generally selected residual overstory trees at sites where overall tree densities had been reduced through recent harvesting. Sites where Seminole bats roosted were more likely to have greater numbers of large overstory pines, fewer midstory pines and lower hardwood densities than random sites. Further, roost sites were more likely to have greater numbers of recently cut stumps than random locations, indicating areas selected for roosting were thinned or partially harvested recently. Based on microhabitat analyses presented here, Seminole roost sites could be characterized as relatively open forest sites, with abundant mature pines and few hardwoods. Roosts sites of the Seminole bat in eastern portions of its range had higher overstory BAs and lower richness of understory woody vegetation than random sites (Menzel *et al.*, 2000).

Seminole bats used partially harvested or thinned stands considerably for roosting. Most of these stands were harvested in 2000 and prescribe burned in 2001. Although 11.8% of Seminole bat roosts in our study were in unmanaged, old-growth (≥100 y old) forests of mixed pine-hardwood, 84.4% were in stands that had undergone some type of thinning or partial harvesting but retained overstory pines. A more comprehensive analysis of forest stand preferences found Seminole bats preferred to roost in (or close to) mature stands that had undergone partial harvesting and midstory removal; they avoided mature, relatively unmanaged second-growth forests of mixed pine-hardwood or hardwood and dense young (15–29 y old) stands of pine (Perry *et al.*, 2007). Furthermore, Seminole bats rarely roosted in unharvested buffers retained around stream drains in partially harvested stands; instead, they typically roosted in the harvested portions (Perry *et al.*, 2007). Based on our site- and stand-level analyses, this species appears to favor roosting in open woodlands of mature pine or habitats with similar structure. Menzel *et al.* (1998) also found Seminole bats were closely associated with pine-dominated communities managed with prescribed fire that created open understories. Historically, much of the southeastern U.S. was open pine woodlands maintained by frequent fire (Sharitz *et al.*, 1992; Lorimer, 2001; Frost, 2006). These habitats were dominated by large-diameter pines; understories were open and dominated by grasses and other herbaceous vegetation. Habitats structurally similar to these once abundant ecosystems, including stands with retained overstory pines that have undergone recent thinning, midstory removal and burning, appear to be favored for roosting by male Seminole bats.

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