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Roost Characteristics of Hoary Bats in Arkansas

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Abstract.—We radiotracked nine hoary bats (*Lasiurus cinereus*) and characterized 12 roosts during late spring and early summer in the Ouachita Mountains of central Arkansas. Hoary bats generally roosted on the easterly sides of tree canopies in the foliage of white oaks (*Quercus alba*), post oaks (*Q. stellata*) and shortleaf pines (*Pinus echinata*). Roost heights averaged 16.5 ± 2.2 m and all roost trees were >21 cm dbh and were taller and greater in diameter than random trees. Roost sites averaged 7.7 m^2/ha basal area (BA) of overstory pines, 4.4 m^2/ha BA of overstory hardwoods and 80% canopy cover. Roost sites had a greater number of understory stems than random sites. All roosts were located in stands dominated by mature (overstory >50 y old) overstory trees. Seven roosts were in relatively unmanaged mixed pine-hardwood and hardwood stands >50 y old and four roosts were in mature mixed pine-hardwoods stands that recently had been thinned and subjected to prescribed burning; one additional roost was located outside the study area in a mature shortleaf pine stand that was thinned approximately 10 y previously. Although not abundant during early summer in Arkansas (only 3% of our captures), hoary bats were confirmed to reproduce in the region.

Introduction

Species conservation requires ecological and life history information that is largely lacking for hoary bats (*Lasiurus cinereus*). The hoary bat is the most widespread of all American bats and ranges from southern South America to northern Canada and from Hawaii to the Caribbean islands (Shump and Shump, 1982). Despite its broad distribution, little is known about its ecology, especially in the eastern United States. To date, only one comprehensive radiotelemetry-based study of hoary bat roosting ecology has been conducted (Willis and Brigham, 2005). That study was conducted in Canada and its applicability to ecosystems of the southeastern U.S. is unlikely.

Foliage-roosting bats of the genus *Lasiurus*, including the hoary bat, typically roost by hanging from leaves, petioles, twigs and branches within tree canopies (Constantine, 1966; Menzel *et al.*, 1998). The hoary bat typically roosts alone, in coniferous trees in Saskatchewan (Willis and Brigham, 2005) and in deciduous trees in Iowa (Constantine, 1966). However, in mixed pine-hardwood forests of the southeastern U.S., characteristics of roosts trees used by hoary bats are unknown. Furthermore, no information is available on habitat associations. Here, we characterized roosts used by nine hoary bats during late spring and early summer in the Ouachita Mountains of Arkansas. We also compared vegetative attributes surrounding a subset of roost trees with random trees to determine tree and surrounding forest characteristics that may influence roost selection.

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METHODS

We conducted our study in the 6545-ha Upper Lake Winona Basin, situated in the Ouachita Mountains of central Arkansas, USA (approx. 34°48′N, 92°58′W). The Ouachita Mountains are a series of east-west aligned ridges and valleys ranging from central Arkansas into eastern Oklahoma. The climate is humid, with hot, frequently dry summers and mild winters. The study area was completely forested; no residential areas, buildings or agricultural lands existed in the Winona Basin where our study was conducted. Predominant forest types were shortleaf pine (*Pinus echinata*)-hardwood and oak (*Quercus* spp.)-hickory (*Carya* spp.). Twelve percent (778 ha) of the area was industrial timberlands consisting primarily of closed canopy and older, thinned loblolly pine (*P. taeda*) plantations intensively managed by Weyerhaeuser Company. National forest lands, which comprised the remaining ownership in the basin, included several blocks of forest that underwent silviculture treatments in 2000. These areas included partial harvesting and midstory removal (2096 ha) and group selection harvesting (1044 ha; Guldin, 2004). A 1791-ha unit was managed using a mix of management, including single-tree selection, group selection and seed-tree cuts. Throughout the basin, unharvested stands were interspersed among these treatment units. Thus, with its silviculture treatment units, untreated areas, and industrial timberlands, the Winona Basin contained most of the predominant forest types and forest management practices that existed in the Ouachita Mountains.

From mid-May until late July 2000–2005, we captured bats between 2100 and 0130 h CST using 3–8 mist nets (2.6–12.0 m wide × 2.6 m tall). Age (juvenile or adult) was assessed based on degree of ossification of metacarpal-phalanx joints (Racey, 1974) and female reproductive condition was determined by abdominal palpation and by inspection of mammae.

We used 0.70–0.89-g radiotransmitters (Blackburn Transmitters, Nacogdoches, Texas)[1] with 21-d life spans to locate adult bats at their diurnal roosts. We attached radiotransmitters to the mid-scapular region with surgical adhesive (Skin Bond; Smith and Nephew Inc., Largo Florida) following partial hair removal with scissors. Transmitter load was 2.0–4.1% of body mass and averaged 3.2% (±0.2 SE). Bats were instrumented and released immediately after capture. We followed guidelines of the American Society of Mammalogists for the capture, handling and care of mammals (Animal Care and Use Committee, 1998). We radiotracked each bat to its roost and attempted to visually locate them from the ground using binoculars or by climbing the tree. If a bat could not be sighted in the tree, we collected data for the surrounding site but not the roost tree. For visually confirmed roosts, we recorded tree species, diameter at breast height (dbh) and aspect of roost (azimuth from tree trunk to roost). We visually estimated distance from roosts to the outer edge of the roost tree canopy. Percent canopy cover from roost to 2 m above and 2 m below roost was estimated independently by two observers and averaged. 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 and then multiplying these widths by total canopy height (total height - height to base of canopy).

To characterize habitat surrounding each roost, we collected data on site attributes in a 17.84-m radius (0.10 ha) plot centered on the roost tree. For roosts that were not visually confirmed, this plot was centered on the general area indicated by radiotelemetry. At each

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service

plot, we recorded heights of overstory trees by averaging heights for two dominant pines and two dominant hardwoods. We counted all woody stems >1 m tall and <5 cm dbh in the plot and recorded all woody stems >1 m tall and ≥5 cm dbh by diameter and species. At four locations along the outer edge of the plot, we measured canopy cover using a spherical densiometer and pine and hardwood overstory basal area (BA) using a 1-factor metric prism; data for each variable were averaged for each plot. We randomly selected the azimuth to the first location and then measured the other three points 90° apart.

To identify site characteristics that may have affected roost selection, we selected random trees and associated site plots for comparison with roost trees and sites. Identical measurements were collected for random and roost plots. To ensure that random trees and sites were available to hoary bats for roosting, we randomly chose the first tree ≥5 cm dbh and >40 m distance along a random azimuth from each roost location. We measured a random plot for each roost site located in 2001–2005 ($n = 9$) but did not collect random plots for roosts located in 2000 ($n = 3$).

We compared structural (*e.g.*, height, dbh) characteristics of randomly selected trees with roost trees using *t*-tests. We compared roost aspect with random orientation using Rayleigh's test (Zar, 1999). We compared vegetative attributes surrounding roosts with random plots using paired *t*-tests because sample sizes were too small for logistic regression (Pedhazur, 1997). Because our overall goal was to screen for potential variables that may affect roost selection, we evaluated all tests at alpha = 0.10 to reduce chances of committing Type 2 errors (Toft and Shea, 1983).

We used binomial tests to compare the proportion of roosts in each habitat type with the proportional availability of that habitat type. Vegetation classes were derived from digital maps of forest stands obtained from the Ouachita National Forest. Those maps were updated and corrected using a 10-m digital color orthoquad and ground-truthing. Global positioning system (PLGR, Rockwell Collins, Cedar Rapids, Iowa) coordinates were collected for each roost location and overlaid on vegetation maps in a geographic information system to determine the proportion of roosts in each habitat type. We determined potentially available habitat by creating a 1000-m radius circle around each roost; we combined all circles and designated the area within as the available habitat. One roost was located well outside the study area; thus, we did not include that roost in stand-level analysis because we lacked data for forest stands in that area.

RESULTS

We captured 40 hoary bats (all adults; 43% female, 57% male) over 119 nights (557 net nights) during six years (2000–2005). Hoary bats comprised 3.0% of all captures. We instrumented 19 adults (eight males and 11 females) but relocated only nine of those (four males and five females). We identified 12 roost locations (six male and six female), of which seven were visually confirmed (two male and five female). We collected data for random locations for nine of the roosts (those collected after 2000).

All visually confirmed roosts were in live foliage of tree canopies. Hoary bats roosted by clinging to leaves, pine needles, petioles, pine cones, branches and limbs in the upper canopies of trees. For visually confirmed roosts, four (57%) female roosts (two maternity) were in shortleaf pine, two (29%) male roosts were in white oaks (*Quercus alba*) and one (14%) female roost was in a post oak (*Q. stellata*). Although not visually confirmed, radiotelemetry suggested two additional roosts (one male and one female) were in shortleaf pines and one (male) roost was in a white oak.

TABLE 1.—Attributes of seven trees used by hoary bats for roosting and seven random trees in the Ouachita Mountains of Arkansas during summer, 2000–2005

Attributes	Roost		Random		
	Mean	SE	Mean	SE	P[a]
Tree characteristics					
Tree height (m)	19.3	1.8	13.2	2.4	0.065
Tree diameter (dbh, cm)	36.2	5.1	18.9	4.6	0.026
Height to base of canopy (m)	8.6	1.8	6.3	1.8	0.386
Canopy volume (m^3)	943	277	253	108	0.049

[a] Probability based on student's *t*-test (alpha = 0.10)

All roosts were in dominant or codominant overstory trees >21.0 cm dbh. Roost trees were taller, greater in diameter and had greater canopy volumes than random trees (Table 1). Mean (±SE) roost height was 16.5 ± 2.2 m, distance from roost to edge of the roost tree canopy was 48.1 ± 9.9 cm, canopy closure above roosts was 70.7 ± 7.0% and closure below roost was 28.4 ± 5.0%. Roost aspect differed from random (Rayleigh's z = 3.11, $P < 0.05$); most (86%) roosts were on the easterly sides of tree canopies (mean angle = 67°).

Roost sites averaged 7.7 m^2/ha BA of overstory pines, 4.4 m^2/ha BA of overstory hardwoods and 80% canopy cover (Table 2). The only variable that differed between roost and random sites was number of stems in the understory (stems <5 cm dbh); roost sites had greater numbers of stems than random sites. Hoary bats roosted in four types of forest stand (Table 3). Proportional use of each of those four stand types did not differ from available proportions; however, the "all other habitats" class was used less than available. All roosts were located in stands dominated by mature (>50 y old) overstory trees. Four roosts (two male and two maternal female) were in stands that had been thinned in 2000 to approximately 13.8 m^2/ha overstory BA, had the midstory removed and were prescribed burned in 2001. Remaining roosts were in second-growth unharvested stands >50 y old that had received little recent management.

TABLE 2.—Mean site characteristics from 0.10-ha plots surrounding nine roosts of hoary bats and nine random trees in the Ouachita Mountains of Arkansas during summer, 2000–2005

Attribute	Roost		Random		
	Mean	SE	Mean	SE	P[a]
Overstory pine height (m)	17.2	2.4	16.7	2.7	0.672
Overstory hardwood height (m)	16.5	0.8	16.2	1.7	0.826
Overstory pine BA (m^2/ha)	7.7	1.6	8.7	1.4	0.409
Overstory hardwood BA (m^2/ha)	4.4	0.9	5.3	0.6	0.309
Canopy cover (%)	80.0	4.7	81.2	4.9	0.841
No. stems <5 cm dbh	318	118	236	94	0.037
No. pine stems 5.0–9.9 cm dbh	4.4	2.3	2.3	1.3	0.456
No. pine stems 10–24.9 cm dbh	16.8	7.0	12.8	4.5	0.542
No. pine stems ≥25.0 cm dbh	7.8	1.8	9.9	2.8	0.263
No. hardwood stems 5.0–9.9 cm dbh	32.6	7.8	33.8	8.7	0.815
No. hardwood stems 10–24.9 cm dbh	25.1	6.9	25.1	5.7	1.000
No. hardwood stems ≥25.0 cm dbh	3.1	0.9	3.2	0.9	0.855

[a] Probability based on paired t-test (alpha = 0.10)

TABLE 3.—Proportions of available habitat, number[a] of hoary bat roosts in each habitat, and binomial comparisons of roost proportions with random proportions in the Ouachita Mountains of Arkansas, 2000–2005

Habitat description	Avail. %	Number of roosts (%)	Z	P[b]
Unharvested mixed pine-hardwood, 50–99 years old	25.7	3 (27)	0.12	0.905
Unharvested hardwood, 50–99 years old	17.2	3 (27)	0.89	0.376
Unharvested mixed pine-hardwood, ≥100 years old	4.3	1 (9)	0.78	0.434
Mixed pine-hardwood, 50–99 years old, thinned and burned	24.3	4 (36)	0.93	0.351
Other habitats	28.5	0 (0)	−2.09	0.036

[a] Included 11 roosts; one additional roost (located in a thinned pine stand) was outside the study area
[b] Probability based on binomial test (alpha = 0.10)

Behavior of bats instrumented before June 1 and after July 27 suggested they were migrating and individuals frequently moved great distances. Distances between capture and roost locations for hoary bats (average of 4.2 ± 0.87 km) were generally much greater than other bat species, such as eastern red bats (*Lasiurus borealis*) and Seminole bats (*L. seminolus*), that we radiotracked in the Winona Basin. For bats that were instrumented before June 1 and after July 27, we typically located a single roost where the bat remained for only one day. During these times, we rarely located bats the second day after instrumentation, suggesting that they had moved outside the study area. For example, one individual instrumented in late May was triangulated the following morning to a position approximately 33 km northeast of the capture sight. Nonetheless, two maternal females (captured 8 June and 26 June, respectively) remained in their roosts for extended periods. For these two maternal roosts (each containing two pups), one female remained in her roost with two pups >26 d and the other remained in her roost with two pups for >23 d.

DISCUSSION

Hoary bats roosted in the canopies of mature overstory pines and oaks within unmanaged and recently thinned forest stands in the Ouachita Mountains during summer. Among foliage-roosting species in the southeastern U.S., eastern red bats typically roost in deciduous foliage of hardwoods, whereas Seminole bats typically roost in the needles of pines (Menzel *et al.*, 1998). Based on previous studies (Constantine, 1966; Willis and Brigham, 2005) and our results, hoary bats appear to roost readily in both hardwoods and conifers. This flexibility in roosting behavior may account for its broad distribution across two continents.

Based on mist-net captures, hoary bats are relatively abundant in Arkansas and southwestern Oklahoma during late spring and late summer (Baker and Ward, 1967; Gardner and McDaniel, 1978; Claire *et al.*, 1986; Saugey *et al.*, 1989), but are generally uncommon in early to mid-summer. Because hoary bats are believed to be long-distance migrants (Barbour and Davis, 1969; Shump and Shump, 1982; Fleming and Eby, 2003), these changes in relative abundance likely reflect migration. Behavior of bats that we instrumented with transmitters during late spring and late summer suggested they were migrating. However, females with young that we tracked in mid June showed a high level of roost fidelity (23–26 d in the same roost). Our experience in Arkansas suggests that hoary bats (at least females with pups) captured between mid-June and mid-July have greater site fidelity and are more likely to roost close enough to trapping locations to allow land-based radiotelemetry.

In Canada, Willis and Brigham (2005) found roosts of hoary bats were not located randomly in tree canopies; roosts were generally on south sides of tree canopies. We found hoary bats most often roosted on the easterly sides of trees. This finding is in contrast with studies of foliage-roosting bats that found no difference between aspect of roost and random placement (*e.g.*, Menzel *et al.*, 1998; Veilleux *et al.*, 2003). Because most bats were tracked during late spring, when evenings and mornings were still relatively cool, bats may have positioned themselves on the east side of tree canopies to facilitate warming during cool mornings.

Roost heights were similar to those of red bats (16 m) and Seminole bats (17 m; Menzel *et al.*, 1998) and much higher than those reported by Constantine (1966). Roost trees were slightly taller than those used by red bats (average height = 17.0 m) and shorter than trees used by male Seminole bats (average height = 21.5 m) in the same study area. Nonetheless, all three of these *Lasiurus* species appear to prefer large overstory trees for roosting. Studies indicate many forest bats, including lasiurines, prefer to roost in the larger trees of their environment (Hutchinson and Lacki, 2000; Menzel *et al.*, 2000; Mager and Nelson, 2001).

Our relatively small sample sizes reduced our ability to clearly distinguish site variables that affected roost selection. The only variable that differed between roost and random sites was understory stem density, suggesting that hoary bats roosted at sites with a denser understory. A dense understory may provide concealment from terrestrial predators (Constantine, 1966; Barbour and Davis, 1969). Alternatively, reducing overstory tree densities typically results in increased understory vegetation as more light is allowed to reach the forest floor, and many bat species prefer to roost in forests with reduced overstory density (Perry *et al.*, 2007). Thus, the greater abundance of understory vegetation at roost sites may have been a result of different overstory conditions. Nevertheless, this result may have been spurious due to small sample size, and additional study with increased sample sizes is warranted.

Hoary bats roosted in stands dominated by large mature (>50 y old) trees. We located no roosts in stands with an overstory <50 y old. Nonetheless, they readily roosted in thinned and untreated mature stands of mixed pine-hardwood and untreated hardwood stands. Because they roost in both conifers and hardwoods, they likely are adaptable to many forest types that contain large overstory trees.

Although our sample size was small, this is the first quantitative assessment of hoary bat roosting in the southeastern U.S. The hoary bat is considered uncommon in the southeastern U.S. during summer (Cryan, 2003). Our results indicate that, although not abundant in summer (June–July), this species does reproduce in the region. A single record of a female with two mature pups, which was received by the Arkansas Department of Health (D. A. Saugey, pers. comm.), suggested that this species reproduced in Arkansas. However, our results are the first to confirm this record of hoary bats reproducing in Arkansas.

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