Am. Midl. Nat. 164:270–282

Temporal Patterns in Capture Rate and Sex Ratio of Forest Bats in Arkansas

ROGER W. PERRY[1] AND S. ANDREW CARTER
USDA Forest Service, Southern Research Station, P.O. Box 1270, Hot Springs, Arkansas 71902

AND

RONALD E. THILL
USDA Forest Service, Southern Research Station, 506 Hayter Street, Nacogdoches, Texas 75965

Abstract.—We quantified changes in capture rates and sex ratios from May to Sept. for eight species of bats, derived from 8 y of extensive mist netting in forests of the Ouachita Mountains, Arkansas. Our primary goal was to determine patterns of relative abundance for each species of bat captured over forest streams and to determine if these patterns were similar to patterns of abundance found in other types of studies, including studies of bat mortality at wind turbines. We also wanted to discern regional patterns in sex ratios that have implications for seasonal distributions and migration. Capture rates for eastern red bats (*Lasiurus borealis*) were up to 25 times greater in Aug. and Sept. than in spring or early summer. Although not significant ($P = 0.063$), capture rates of hoary bats (*L. cinereus*) peaked in both late spring and late summer. Silver-haired bats (*Lasionycteris noctivagans*) were abundant in late spring and late summer but were absent during mid summer, suggesting they migrated from the area. Sex ratios of red bats were predominately male in late spring and late summer but were dominated by females in mid summer, possibly because of increased activity of lactating females during mid summer. Female Seminole bats (*L. seminolus*) were only captured after Aug. 1, suggesting a seasonal geographic separation of sexes. Our results suggest that patterns of bat abundance derived from mist netting over forest streams may be similar to patterns of bat fatalities at wind turbines, communication towers, aircraft strikes, roads and patterns derived from trapping at cave entrances for many species, but it is unclear why this pattern appears ubiquitous.

Introduction

Conservation efforts for forest bats are complicated by a lack of information on migration, seasonal changes in distribution and abundance and sex-based geographic separation. For example, migratory tree bats, including hoary bats (*Lasiurus cinereus*) and eastern red bats (*L. borealis*) are the species of bats most often killed at wind turbines during late summer and early autumn (Cryan and Brown, 2007), and information on regional and temporal changes in relative abundance and migration eventually may help managers reduce these mortalities. Consequently, information on abundance and sex ratios in different regions throughout the year is important for understanding ecology, critical periods and critical areas of habitat needed for bats.

Although broad-scale geographic distributions generally are known for most species of bats in the United States and Canada, seasonal changes in bat abundance within their geographic range are poorly understood and temporal differences in abundance and sex ratios may occur throughout the range of many species due to sexual segregation and migration. Information compiled from museum records often notes temporal and spatial

---

[1] Corresponding author: Telephone: (501) 623-1180 (ext. 108); FAX: (501) 632-0186; e-mail: rperry03@fs.fed.us

differences in sex ratios (Findley and Jones, 1964; Barbour and Davis, 1969; Cryan *et al.*, 2000) and studies frequently suggest regional differences in abundance or sex ratios. However, only a few studies (*e.g.*, Cryan, 2003) have demonstrated geographic changes in abundance and sex ratios throughout a season.

Many bats are migratory and sex-biased migration may occur in some species whereby the sexes differ in their tendency to migrate, distances traveled or geographic location (Fleming and Eby, 2003). Among the bat species that occur in the Ouachita Mountains of Arkansas and Oklahoma, tri-colored bats (formally eastern pipistrelle, *Perimyotis subflavus*), evening bats (*Nycticeius humeralis*) and possibly Seminole bats (*Lasiurus seminolus*) are considered regional migrants (typical movements of 100–500 km; Barkalow, 1948; Humphrey and Cope, 1968; Barbour and Davis, 1969; Watkins, 1969), whereas red bats, hoary bats and silver-haired bats (*Lasionycteris noctivagans*) are considered long range migrants (movements frequently >1000 km; Fleming and Eby, 2003).

Although bat captures from mist netting can be affected by factors such as weather, bat activity and avoidance of nets by experienced bats, data from mist netting may be used as an index of relative abundance for comparing yearly or seasonal changes in bat abundance if appropriate measures are taken to ensure methods are standardized. Here, we quantified bi-weekly capture rates and sex ratios for eight species of bats from late spring to late summer (summer hereafter) that were derived from 8 y of extensive mist netting surveys in a forested landscape. Our overall goal was to determine the patterns of relative abundance and sex ratios of bats captured over streams throughout summer and whether these patterns reflected patterns of abundance from other studies, including studies of bat mortality at wind turbines. We also wanted to compile information on regional changes in sex ratios and abundance, which has implications for seasonal distributions, migration and demography.

METHODS

STUDY AREA

We conducted the study in a 6545-ha area of the Ouachita National Forest (ONF; U.S. Forest Service), in northwestern Saline County (34°45′N, 93°15′W), within the Ouachita Mountains of central Arkansas. The Ouachita Mountain ecological subregion extends from central Arkansas into eastern Oklahoma. The area is humid, with hot, frequently dry summers and mild winters. Mean annual precipitation in the Ouachita Mountains ranges from 112 to 137 cm and mean annual temperature ranges from 13.9 to 16.1 C (Skiles, 1981). Elevations in the study area ranged from 244 to 574 m above mean sea level. The study area was completely forested; no residential areas, houses or agricultural lands existed in the study area. Predominant forest types were shortleaf pine (*Pinus echinata*)-hardwood forests and oak (*Quercus* sp.)-hickory (*Carya* sp.). Twelve percent (778 ha) of the area was intensively managed industrial timberlands consisting primarily of closed canopy and older thinned plantations of loblolly pine (*P. taeda*). National forest lands 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). For a detailed description of the study area, *see* Perry *et al.* (2007).

BAT CAPTURE

We captured bats with 2–8 mist nets (2.6–12.0 m wide × 2.6 m tall) between 1 May and 17 Sept., 2000–2005 and again in 2007–2008. Nets were opened at dusk (approx. 2115–2200 h CDT, depending on month) and monitored continuously for an average of 3.27 ± 0.05 h. Although we typically netted during nights of dry weather, we occasionally (6% of nights) netted on nights of intermittent light rain. We netted bats at 21 sites distributed throughout the study area. However, most (90%) netting was concentrated at 10 highly productive sites. Trapping sites were distributed across an area approx. 4.5 × 10.3 km. These sites were centered on pools (typically about 600 m^2) that occurred either along small intermittent streams beneath the forest canopy (n = 9), or on the Alum Fork of the Saline River (n = 1). At each capture site, multiple mist nets were placed in a variety of locations but primarily over water. Among all trap sites, net locations included roads (47 net nights; 1 net night = 1 net open for 1 evening), forests (8 net nights), streams (625 net nights), dry creek beds (30 net nights) and ponds (3 net nights). Elevations of trap sites ranged from 244 to 347 m above sea level.

For all captured bats, we determined sex and female reproductive condition by abdominal palpation and mammae inspection. We determined age class (juvenile or adult) based on the degree of ossification of metacarpal-phalanx joints (Racey, 1974), but we could not distinguish juveniles from adults for most species beyond the first week of Aug. We affixed bands to the forearms of captured bats to distinguish individuals; each band had a unique identification number. We followed the guidelines of the American Society of Mammalogists for the capture, handling and care of mammals (Gannon *et al.*, 2007).

ANALYSES

Comparing captures among areas or time periods with mist netting surveys can be complicated because of differences in trapping effort. These differences include different sizes or numbers of nets and differences in time nets are open. Therefore, to standardize capture rate estimates among weekly time periods, we calculated a catch per unit effort (CPU) that adjusted for differences in net length (sample area), number of nets open, length of time nets were open (sampling duration) and number of nights trapped among weekly periods. As our CPU, we used captures/100 net-meter-hours (NMH); NMH was derived as the total length (m) of 2.6-m-tall net multiplied by hours open. All nets, regardless of length, were 2.6-m tall. Because nets were monitored continuously, we included captured bats that were identified to species before they escaped from nets but lacked other information such as sex or reproductive status. We included recaptures in estimates of capture rates although recaptures comprised only 3.4% of total captures.

To determine if capture rates changed significantly throughout the summer, we calculated our CPU for each night, then compared mean capture rates (both sexes combined) among 10 time periods (2 wk intervals) using analysis of variance on ranks (ANOVA) (Conover and Iman, 1981). When significant effects were indicated via ANOVA, we conducted multiple comparisons on least-squared means with a Tukey-Kramer adjustment for multiplicity. We determined overall sex ratios throughout the summer for each species without including recaptures. We tested whether sex ratios differed from 50:50 using chi-square tests. Throughout, we present all means ± SE and all statistical tests were conducted at alpha = 0.05.

RESULTS

Over eight summers, we trapped 159 nights (713 net nights) or 18,701 net-meter-hours (NMH; Table 1) and had 2199 captures. On 20 nights, we trapped at multiple sites. On 24 (15%, or 99 net nights) occasions, the same site was trapped during two consecutive nights (97% of nets were in identical locations at each area). However, mean capture rate at sites trapped the first night (6.65 ± 2.02 bats/100 NMH) did not differ from mean capture rate the second night (7.10 ± 2.76 bats/100 NMH) when compared using a paired *t*-test (*t* =

TABLE 1.—Trapping effort for each 2 wk interval, including total nights trapped, net nights, net-meter-hours (NMH) and total number of years trapped, compiled during 8 y (2000–2005 and 2007–2008) of summer mist netting for bats in the Ouachita Mountains of Arkansas

Week	Nights trapped	Net nights[a]	NMH[b]	Years trapped
1–14 May	12	56	1,422	3
15–28 May	19	98	2,441	6
29 May–11 Jun.	16	73	2,075	5
12–25 Jun.	24	111	2,662	6
26 Jun.–9 Jul.	15	66	1,717	7
10–23 Jul.	22	100	2,654	6
24 Jul.–6 Aug.	17	79	2,223	6
7 Aug.–20 Aug.	14	44	883	2
21Aug.–3 Sept.	10	38	921	2
4 Sept. –17 Sept.	10	48	1,703	4
All weeks	159	713	18,701	

[a] 1 net night = 1 net (regardless of size) open for 1 night

[b] 1 NMH = 1 liner meter of 2.6-m high net multiplied by hours open

−0.34, df = 23, P = 0.736). For all weeks and years combined, we captured 1602 (76%) different red bats, 164 (8%) northern long-eared bats (*Myotis septentrionalis*), 86 (4%) evening bats, 84 (4%) tri-colored bats, 52 (2%) hoary bats, 49 (2%) Seminole bats, 45 (2%) silver-haired bats and 25 (1%) big brown bats (*Eptesicus fuscus*).

MIGRATORY BATS

Red bats were the most often captured species throughout the sampling season (Fig. 1). We found a significant difference among time periods in capture rates of red bats ($F = 21.27$, $P < 0.001$) (Fig. 2). Capture rates were similar from May through late Jul. but were substantially greater from mid Aug. to mid Sept. During this peak period, capture rates were up to 25 times greater than rates in May–Jul. and often we captured >50 red bats per night in 2–3 nets. Sex ratios varied throughout the season for red bats. Males comprised 75% of red bat captures in May and up to 90% of captures in mid Sept., whereas females made up 62% of red bat captures during Jun. Overall sex ratio for red bats was dominated by males; ratio of adult males to females (2.4:1) differed from 1:1 ($\chi^2 = 226.4$, df = 1, $P < 0.001$) and overall sex ratio among juveniles (n = 116 bats) was 1.9M:1F, which also differed from 1:1($\chi^2 = 9.97$, df. = 1, P = 0.002).

The greatest numbers of hoary bats were captured 15–28 May (Fig. 1). Based on capture rates, mid May and mid Aug. were two periods when hoary bat capture rates peaked (Fig. 2). However, because of relatively low sample sizes, differences in capture rate among time periods was just above significant (P = 0.063). From late Jun. to late Jul., capture rates were low and we captured no hoary bats during many of these mid-summer weeks. Most adult captures were males, but overall ratio of adult males to females (1.6:1) did not differ significantly from 1:1 ($\chi^2 = 2.69$, df = 1, P = 0.101). We captured only one juvenile hoary bat (male; Fig. 1), which was captured on 2 Aug.

Silver-haired bats were captured only before early Jun. and in Sept. (Fig. 1). We captured no silver-haired bats between 3 Jun. and 9 Sept. Two female silver-haired bats were captured in Sept., but all other captures were male. Capture rates peaked in early May (Fig. 2), but we did not conduct analyses on these data because we captured no silver-haired bats during

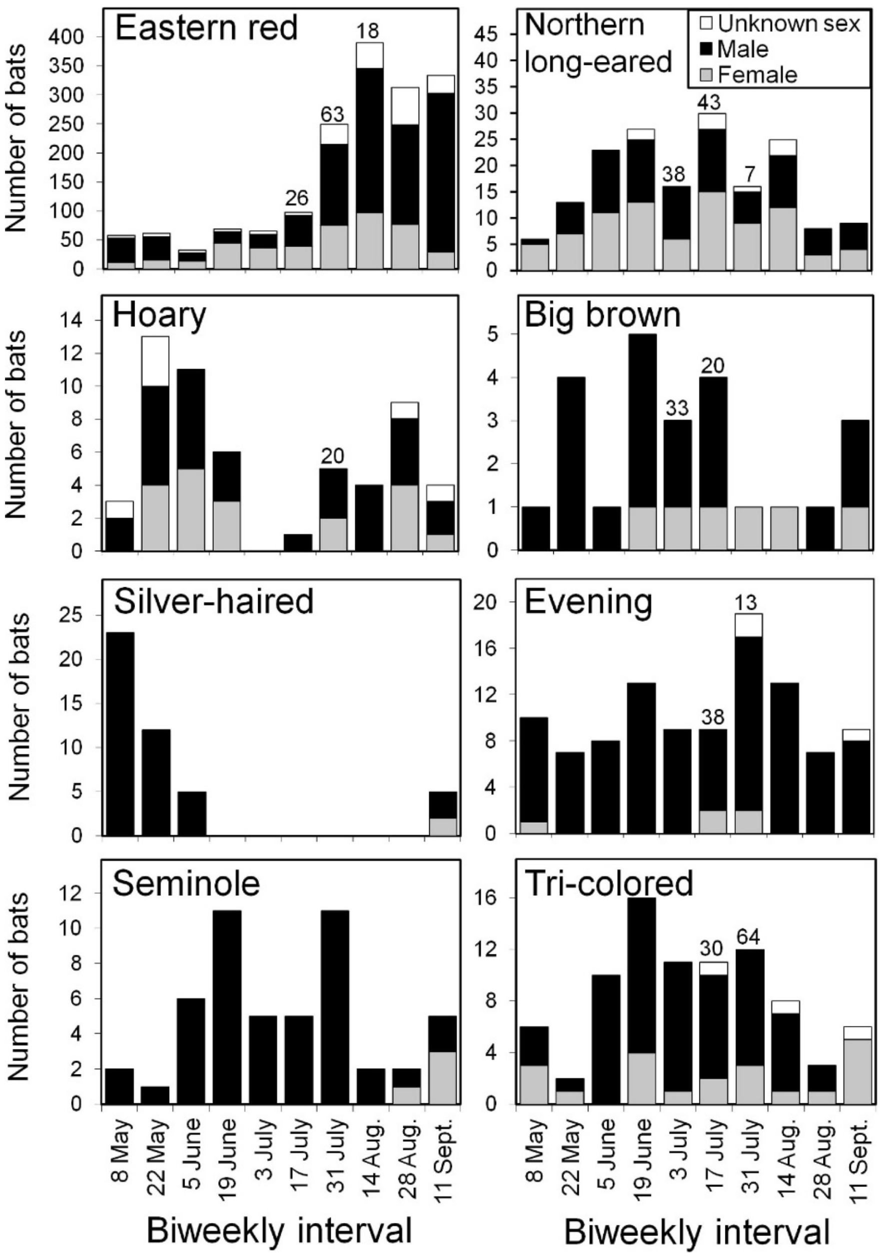

FIG. 1.—Total number of 8 species of bats (by sex) captured during each 2 wk interval, combined from 8 y (2000–2005 and 2007–2008) of mist netting in forests of the Ouachita Mountains, Arkansas. Numbers above columns indicate the percent of total captures that were juveniles during that period. Dates on x axis indicate mid-point for each 2 wk period. Note the different scales on y-axis

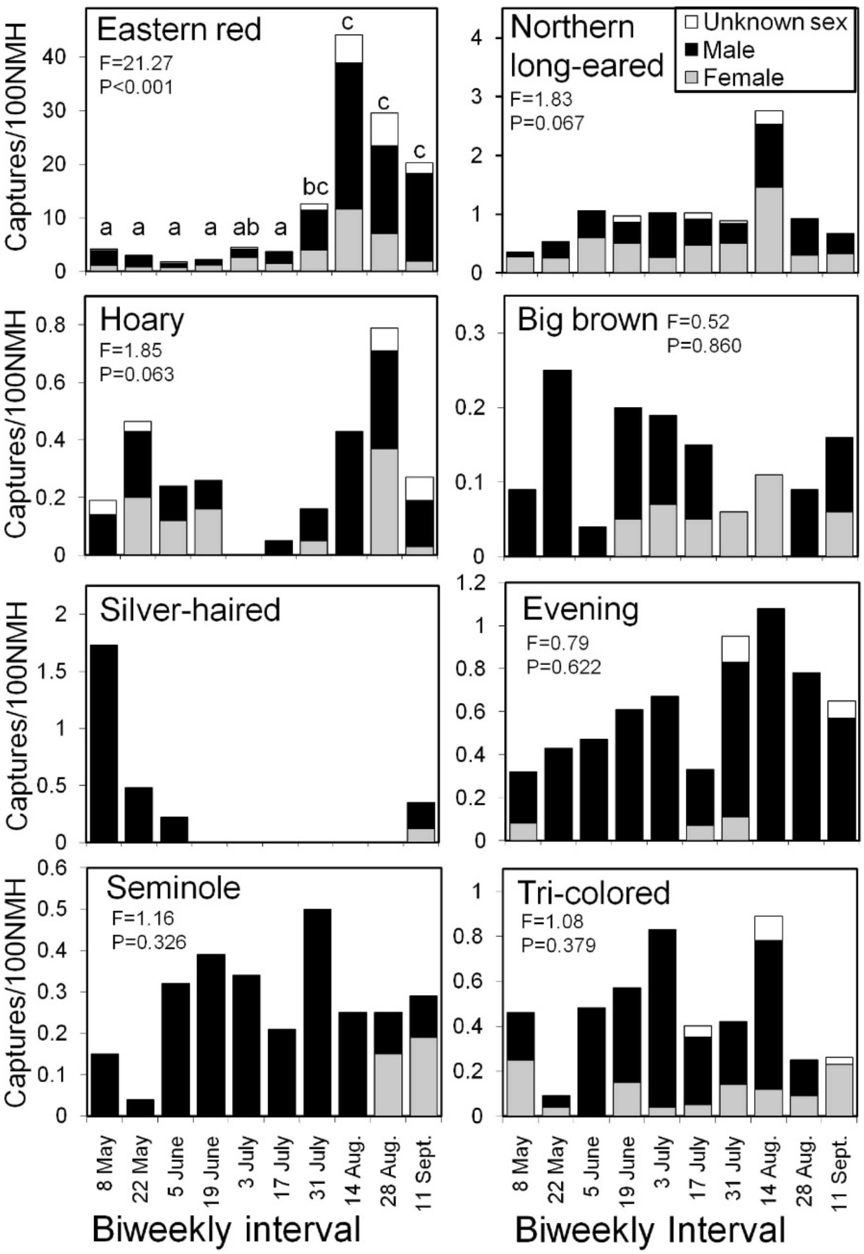

FIG. 2.—Capture rates (captures/100 net-meter-hours; NMH) for 8 species of bats (by sex) derived during ten 2 wk intervals over 8 y (2000–2005 and 2007–2008) of mist netting in forests of the Ouachita Mountains, Arkansas, including analysis of variance results comparing capture rate (both sexes combined) among time periods. Degrees of freedom for each test was 9, 149. Like letters above columns indicate no significant differences using a Tukey-Kramer adjustment for multiplicity. Dates on x axis indicate mid-point for each week. One NMH = 1 linear meter of 2.6-m-high net open for 1 h. Note the different scales on y-axis

most periods. Overall sex ratio of adults (24M:1F) differed from 1:1 ($\chi^2 = 37.36$, df = 1, $P < 0.001$), and no juveniles were captured.

REGIONAL MIGRANTS OR NONMIGRATORY BATS

Captures of Seminole bats were almost exclusively male and overall sex ratio of adults (10.1M:1F) differed from 1:1 ($\chi^2 = 32.36$, df = 1, $P < 0.001$; Fig. 1). Only four female Seminole bats were captured during the study and all were captured after Aug. 29. Furthermore, we captured no juvenile Seminole bats. Capture rates of Seminole bats fluctuated throughout the season, but we found no significant difference among time periods (Fig. 2).

Northern long-eared bats were the second most captured species (Fig. 1). In early May, capture rates were relatively low and were primarily females (Fig. 2). An overall peak in capture rates was apparent in mid-Aug., but differences among time periods was just above significant ($P = 0.067$). Overall proportion of adult males to females was 1:1.1, which did not differ from 1:1 ($\chi^2 = 0.26$, df = 1, $P = 0.610$). Sex ratio among juveniles (n = 18 bats; 1.6M:1F) did not differ from 50:50 ($\chi^2 = 0.89$, df = 1, $P = 0.346$).

Big brown bats were the least captured species (Fig. 1). We captured 19 male big brown bats (2 juveniles) but only 6 adult females. Capture rates among time periods did not differ ($P = 0.860$) (Fig. 2). Overall proportion of adult males to females (2.8M:1F) differed from 1:1 ($\chi^2 = 5.26$, df = 1, $P = 0.022$.

Evening bat captures were almost entirely male (Fig. 1). Females were captured only between 12 Jul. and 31 Jul. and a pregnant female was captured on 12 May. In late Jul., we captured five females (three juvenile). Capture rates of evening bats peaked during late Jul. and early Aug. (Fig. 2), but overall capture rates did not differ among time periods ($P = 0.622$). Overall sex ratio of adults (32M:1F) differed from 1:1 ($\chi^2 = 70.21$, df = 1, $P < 0.001$). Sex ratio for juvenile evening bats was 1M:1.5F, but sample size (n = 5 bats) was too low to determine significance.

Captures of tri-colored generally bats were low and sporadic (Fig. 1). We found no clear pattern in abundance and no significant difference in capture rates among time periods ($P = 0.379$) (Fig. 2). Overall sex ratio among adults was predominantly male (3M:1F), which differed from 1:1 ($\chi^2 = 17.25$, df = 1, $P < 0.001$). We captured 10 juvenile tri-colored bats and their sex ratio (2.3M:1F) did not differ from 1:1 ($\chi^2 = 1.60$, df = 1, $P = 0.206$; Fig. 1).

DISCUSSION

Indices of abundance are affected by true abundance, observer effect, environmental effects and aspects of animal behavior such as catchability (O'Shea and Bogan, 2003). Using mist nets to estimate relative abundance is affected by extraneous variables such as bat activity, weather, net location and net placement. Because perceived bat activity can be highly variable among sampling nights (Hayes, 1997; Seidman and Zabel, 2001), relative abundance indices derived via mist netting are likely to discern only coarse-scale changes of relatively large magnitude (O'Shea and Bogan, 2003). Herein, we employed the same trapping methods using the same personnel throughout the study to reduce observer bias and we trapped primarily (90% of trapping) in the same 10 locations to reduce trap site effects. Furthermore, we used multiple trap nights and years for each 2 wk sample period to reduce the effects of variable weather. Also, we standardized trapping effort among nights by using a standardized capture rate (captures/100 NMH) that compensated for differences in number of nets, size of nets and length of times nets were open. Consequently, we believe effects of trapping location, trapping effort, observer bias and weather on temporal changes in relative abundance were reduced with our design.

Studies suggest that trapping success decreases when trapping is conducted on consecutive nights at the same location (Kunz and Brock, 1975; Larsen *et al.*, 2007; Robbins *et al.*, 2008; Winhold and Kurta, 2008). Although 15% of our trapping effort was consecutive nights of trapping at the same location, we found no difference in trapping success between the first night and the second night at sites trapped for two consecutive nights. In addition, our sample size (number of net nights) was substantially larger than most previous studies comparing trap success between consecutive nights.

We found adult sex ratios were predominately male for all species except hoary bats and northern long-eared bats. Bat populations frequently are skewed toward males (*e.g.*, Kurta and Matson, 1980; Agosta *et al.*, 2005) and males may have greater survival than females (Keen and Hitchcock, 1980; Kurta and Matson, 1980), possibly because of additional energetic pressures associated with pregnancy and lactation. However, differences in spatial or temporal patterns of abundance between the sexes may account for some observed differences in sex ratios (*see* below). Although captures of adult red bats were mostly male (71%), we found females dominated in mid-Jun. to early Jul., similar to observations of Caire *et al.* (1988) in southeastern Oklahoma. Females of some bat species may increase their activity (*e.g.*, foraging and/or drinking) during lactation when energy and water requirements increase (Barclay, 1989; Adams and Hayes, 2008) and the weeks when females dominated red bat capture rates coincided precisely with red bat lactation in our study area. Alternatively, some males may have migrated to other areas during this period.

For red bats, capture rates in Aug. and Sept. were up to 25 times greater than in May to Jul. and large concentrations of red bats typically were observed over roads in the study area in Aug. and Sept. of most years. Similar mass concentrations, consisting primarily of male red bats, have been reported by others in the mid-southern United States during Aug. and Sept. (Baker and Ward, 1967; LaVal and LaVal, 1979; Saugey *et al.*, 1989). Explanations for the apparent increase in red bats during late summer include increases in abundance, increases in activity or movements, or a combination of these factors. Potential hypotheses to explain this peak include: (1) an overall increase in bats resulting from additional migrating individuals; (2) an increase in the population resulting from the addition of first-year cohorts in a species that typically produces larger litters than other bat species; (3) increased trapability of less experienced first-year juveniles (*e.g.*, LaVal and LaVal, 1979) that could not be distinguished from adults; (4) bats concentrating their activity at gather sites such as riparian areas for mating; or (5) increased capture rate of bats concentrating more on mating and fighting than avoiding minor obstacles such as nets (Tumlison *et al.*, 2002).

Although low capture rates of hoary bats reduced our ability to discern significant differences among time periods ($P = 0.063$) capture rates peaked in May and Aug., which likely coincided with individuals migrating. These two peaks in capture rate are similar to observations made in Arkansas and southwestern Oklahoma by others (Baker and Ward, 1967; Gardner and McDaniel, 1978; Caire *et al.*, 1986; Saugey *et al.*, 1989). Furthermore, movements of hoary bats we instrumented with radiotransmitters in late May suggested most were migrating (Perry and Thill, 2007). Cryan and Brown (2007) found relative abundance of migrating hoary bats peaked during mid Sept. on an island off the coast of California. Furthermore, this peak in abundance coincided temporally with hoary bat mortalities at wind turbines and published observations of hoary bats (Cryan and Brown, 2007; Arnett *et al.*, 2008).

Using museum records, Cryan (2003) suggested silver-haired bats were absent in the southeastern United States between May and Sept. However, they are present during winter in the Ouachita Mountains (Perry *et al.*, *in press*). Although there is no evidence that they breed in the Ouachita Mountains and likely are not present during the summer, we captured silver-haired bats as late as 3 Jun. and as early as 9 Sept. They were absent in samples from mid-Jun. to mid-Sept. Only two female silver-haired bats were captured, both in mid-Sept. Similarly, Saugey *et al.* (1989) indicated that captures in the Ouachita Mountains typically were males in Apr. and May, whereas both sexes were captured in autumn and winter. Our results suggest female silver-haired bats may migrate from the area earlier than males and subsequently return before males, similar to findings of Cryan (2003). Similarly, females of many bat species depart hibernacula and migrate to summer areas before males (*e.g.*, Fenton, 1970; Humphrey *et al.*, 1977; Rodrigues and Palmeirim, 2008).

Besides a few roosting studies, little is known of the ecology of Seminole bats or the extent to which they migrate. Barkalow (1948) suggested Seminole bats in northern portions of their range move southward during autumn and winter, which suggests they are short-range migrants. Of 48 Seminole bats captured, only four were female and all females were captured after 28 Aug. We found no evidence that Seminole bats reproduce in the Ouachita area; no juveniles were captured and no females were captured during the reproductive period (late May–Jul.). In contrast, female Seminole bats tend to dominate summer captures in more easterly areas of their range (*e.g.*, Jennings, 1958; Miller, 2003; Miles *et al.*, 2006). Although others have reported female Seminole bats collected in Arkansas, those bats were collected after 30 Jul. (Wilhide *et al.*, 1998a; Fokidis *et al.*, 2005). This absence of females during the maternity period suggests a partial geographic segregation of sexes throughout the summer range; males may reside further north and west than females in early to mid summer. Nevertheless, we recaptured one male at the same location where it was banded the previous year, which suggests this individual was a permanent resident or returned to the same area in consecutive summers. Geographic differences in sex ratios have been reported for many bat species (*e.g.*, Findley and Jones, 1964; Kurta and Matson, 1980; Bain and Humphrey, 1986) and possible explanations include differences in migratory routes and summer ranges (Barbour and Davis, 1969; LaVal and LaVal, 1979; Whitaker and Hamilton, 1998). Geographic differences in temperature coupled with the different physiological needs of each sex may lead to geographic sexual segregation (Cryan *et al.*, 2000; Ford *et al.*, 2002).

Captures of evening bats mostly were males and only five females were captured (three juveniles and two adults) and females were not captured during the juvenile growth period (generally mid-Jun. to mid-Jul.). Female evening bats are captured as often as males during summer in other areas of Arkansas (Baker and Ward, 1967; Wilhide *et al.*, 1998b; Fokidis *et al.*, 2005). Maternity colonies of female evening bats are common in buildings approx. 20 km from our study area (Saugey *et al.*, 1989). Towns, with their abundance of permanent structures and heat island effect, may provide better roosting areas for maternal females of some species. Lausen and Barclay (2006) suggested manmade structures may provide thermoregulatory benefits over natural roosts during the juvenile growth period for some bats. Thus, female evening bats in the vicinity of our study area may have roosted primarily in buildings or manmade structures, which were absent in our study area and the juveniles we captured may have been dispersing from these locations.

Similar to evening bats and Brazilian free-tailed bats (*Tadarida brasiliensis*), maternity colonies of big brown bats often are found in manmade structures such as buildings and bridges; they are common in towns of the Ouachita Mountain region, but their abundance in forested areas lacking these structures is relatively low (Saugey *et al.*, 1988, 1989). Most (74%) captures of big brown bats were male. Males of both evening bats and big brown bats (which roost solitarily) may be distributed more evenly across the landscape whereas distributions of females (which roost in colonies) may be concentrated in more urban areas or locations with manmade structures.

Significant peaks in capture rate in late summer for red bats, and likely peaks for hoary bats and northern long-eared bats ($P = 0.067$) were similar to peaks in bat fatalities at wind turbines (Arnett *et al.*, 2008), static communication towers (Crawford and Baker, 1981), collisions with aircraft (Peurach *et al.*, 2009) and observations of bats on remote islands (Cryan and Brown, 2007). Activity and mortality on roads also has been found to peak in Sept. in European bats (Gaisler *et al.*, 2009). Furthermore, the late-summer peak in capture rates mirror peaks found in other species captured at cave entrances during swarming (Hall and Brenner, 1968; Whitaker and Rissler, 1992; Agosta *et al.*, 2005), suggesting that forested streams may also be used as swarming sites by some species. Reasons why this pattern appears ubiquitous is unclear and it is unknown if this pattern reflects sites where bats congregate during late summer (*e.g.*, wind turbines, roads, streams, islands, caves or roads), or whether this pattern reflects changes in movements, bat activity, vigilance or actual increases in abundance.

Determining species presence, relative abundance or population trends is important for developing conservation strategies. We found capture rates and sex ratios of forest bats during summer derived from mist netting were contingent on the period of summer in which surveys were conducted. Mist netting is a common method used to determine species presence, relative abundance and diversity of bats (*e.g.*, Gardner *et al.*, 1996; Jung *et al.*, 1999; Lacki and Hutchinson, 1999). Because abundance, sex ratios and presences of some species changed throughout the sampling period, multiple surveys, distributed throughout the summer, likely are needed to accurately reflect species presence, relative abundance and sex ratios.

Acknowledgments.—We thank D. Saugey, J. Williamson, R. Buford and students from Stephen F. Austin University, University of Arkansas at Monticello and Arkansas Tech University for their field assistance. We thank D. Saugey, S. Loeb, M. Ford, N. Koerth, C. Voigt, B. Fenton and P. Cryan for comments on earlier versions of this manuscript. Funding was provided by the Ouachita National Forest and the Southern Research Station through efforts of L. Hedrick and J. Guldin, respectively. Additional funding was provided by the Arkansas Game and Fish Commission through efforts of D. Sasse. The use of trade or firm names in this publication is for reader information and does not imply endorsement of any product or service by the U.S. Department of Agriculture.

LITERATURE CITED

ADAMS, R. A. AND M. A. HAYES. 2008. Water availability and successful lactation by bats as related to climate change in arid regions of western North America. *J. Anim. Ecol.*, **77**:1115–1121.

AGOSTA, S. J., D. MORTON, B. D. MARSH AND K. M. KUHN. 2005. Nightly, seasonal, and yearly patterns of bat activity at night roosts in the central Appalachians. *J. Mammal.*, **86**:1210–1219.

ARNETT, E. B., W. K. BROWN, W. P. ERICKSON, J. K. FIEDLER, B. L. HAMILTON, T. H. HENRY, A. JAIN, G. D. JOHNSON, J. KERNS, R. R. KOFORD, C. P. NICHOLSON, T. J. O'CONNELL, M. D. PIORKOWSKI AND R. D. TANKERSLEY, JR. 2008. Patterns of bat fatalities at wind energy facilities in North America. *J. Wildl. Manage.*, **72**:61–78.

BAIN, J. R. AND S. R. HUMPHREY. 1986. Social organization and biased sex ratio of the evening bat, *Nycticeius humeralis*. *Fla. Scientist*, **49**:22–31.

BAKER, R. J. AND C. M. WARD. 1967. Distribution of bats in southeastern Arkansas. *J. Mammal.*, **48**:130–132.

BARBOUR, R. W. AND W. H. DAVIS. 1969. Bats of America. University of Kentucky Press, Lexington. 286 p.

BARCLAY, R. M. R. 1989. The effects of reproductive condition on the foraging behavior of female hoary bats, *Lasiurus cinereus*. *Behav. Ecol. Sociobiol.*, **24**:31–37.

BARKALOW, F. S., JR. 1948. The status of the Seminole bat, *Lasiurus seminolus* (Rhoads). *J. Mammal.*, **29**:415–416.

CAIRE, W., R. M. HARDISTY AND K. E. LACEY. 1986. Ecological notes on *Lasiurus cinereus* (Chiroptera: Vespertilionidae) in Oklahoma. *Proc. Okla. Acad. Sci.*, **66**:41–42.

———, ——— AND ———. 1988. Capture heights and times of *Lasiurus borealis* (Chiroptera: Vespertilionidae) in southeastern Oklahoma. *Proc. Okla. Acad. Sci.*, **68**:51–53.

CONOVER, W. J. AND R. L. IMAN. 1981. Rank transformations as a bridge between parametric and nonparametric statistics. *Am. Statistician*, **35**:124–129.

CRAWFORD, R. L. AND W. W. BAKER. 1981. Bats killed at a north Florida television tower: a 25-year record. *J. Mammal.*, **62**:651–652.

CRYAN, P. M. 2003. Seasonal distribution of migratory tree bats (*Lasiurus* and *Lasionycteris*) in North America. *J. Mammal.*, **84**:579–593.

———, M. A. BOGAN AND J. S. ALTENBACH. 2000. Effects of elevation on distribution of female bats in the Black Hills, South Dakota. *J. Mammal.*, **81**:719–725.

——— AND A. C. BROWN. 2007. Migration of bats past remote islands offers clues toward the problem of bat fatalities at wind turbines. *Biol. Conserv.*, **139**:1–11.

FENTON, M. B. 1970. Population studies of *Myotis lucifugus* (Chiropters: Vespertilionidae) in Ontario. *Life Sci. Contrib., Royal Ontario Mus.*, **77**:1–34.

FINDLEY, J. S. AND C. JONES. 1964. Seasonal distribution of the hoary bat. *J. Mammal.*, **45**:461–470.

FLEMING, T. H. AND P. EBY. 2003. Ecology of bat migration, p. 157–208. *In:* T. H. Kunz and M. B. Fenton (eds.). Bat ecology. University of Chicago Press, Chicago, Illinois. 779 p.

FOKIDIS, H. B., S. C. BRANDEBURA AND T. S. RISCH. 2005. Distribution of bats in bottomland hardwood forests of the Arkansas Delta Region. *J. Ark. Acad. Sci.*, **59**:74–79.

FORD, W. M., M. A. MENZEL, J. A. MENZEL AND D. J. WELCH. 2002. Influence of summer temperatures on sex ratios in eastern red bats (*Lasiurus borealis*). *Am. Midl. Nat.*, **147**:179–184.

GAISLER, J., Z. ŘEHÁK AND T. BARTONIČKA. 2009. Bat casualties by road traffic (Brno-Vienna). *Acta Theriologica*, **54**:147–155.

GANNON, W. L., R. S. SIKES, AND THE ANIMAL CARE AND USE COMMITTEE OF THE AMERICAN SOCIETY OF MAMMALOGISTS. 2007. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. *J. Mammal.*, **88**:809–823.

GARDNER, J. E., J. E. HOFMANN AND J. D. GARNER. 1996. Summer distribution of the federally endangered Indiana bat (*Myotis sodalis*) in Illinois. *Trans. Illinois State Acad. Sci.*, **89**:187–196.

——— AND V. R. MCDANIEL. 1978. Distribution of bats in the Delta region of northeastern Arkansas. *Proc. Ark. Acad. Sci.*, **32**:46–48.

HALL, J. S. AND F. J. BRENNER. 1968. Summer netting of bats at a cave in Pennsylvania. *J. Mammal.*, **46**:779–781.

HAYES, J. P. 1997. Temporal variation in activity of bats and the design of echolocation-monitoring studies. *J. Mammal.*, **78**:514–524.

HUMPHREY, S. R. AND J. B. COPE. 1968. Records of migration of the evening bat, *Nycticeius humeralis*. *J. Mammal.*, **49**:329.

———, A. R. RICHTER AND J. B. COPE. 1977. Summer habitat ecology of the endangered Indiana Bat, *Myotis sodalis*. *J. Mammal.*, **58**:334–346.

JENNINGS, W. L. 1958. The ecological distribution of bats in Florida. Ph.D. dissertation. University of Florida, Gainesville, Florida. 125 p.

JUNG, T. S., I. D. THOMPSON, R. D. TITMAN AND A. P. APPLEJOHN. 1999. Habitat selection by forest bats in relation to mixed-wood stand types and structure in central Ontario. *J. Wildl. Manage.*, **63**:1306–1319.

KEEN, R. AND H. B. HITCHCOCK. 1980. Survival and longevity of the little brown bat (*Myotis lucifugus*) in southeastern Ontario. *J. Mammal.*, **61**:1–7.

KUNZ, T. H. AND C. E. BROCK. 1975. A comparison of mist nets and ultrasonic detectors for monitoring flight activity of bats. *J. Mammal.*, **56**:907–911.

KURTA, T. H. AND J. O. MATSON. 1980. Disproportionate sex ratios in the big brown bat (*Eptesicus fuscus*). *Am. Midl. Nat.*, **104**:367–369.

LACKI, M. J. AND J. T. HUTCHINSON. 1999. Communities of bats (Chiroptera) in the Greyson Lake Region, northeastern Kentucky. *J. Ky. Acad. Sci.*, **60**:9–15.

LARSEN, R. J., K. A. BOEGLER, H. H. GENOWAYS, W. P. MASEFIELD, R. K. KIRSCH AND S. C. PEDERSEN. 2007. Mist netting bias, species accumulation curves, and the rediscovery of two bats on Montserrat (Lesser Antilles). *Acta Chirop.*, **9**:423–435.

LAUSEN, C. L. AND R. M. R. BARCLAY. 2006. Benefits of living in a building: big brown bats (*Eptesicus fuscus*) in rocks versus buildings. *J. Mammal.*, **87**:362–370.

LAVAL, R. K. AND M. L. LAVAL. 1979. Notes on reproduction, behavior, and abundance of the red bat, *Lasiurus borealis*. *J. Mammal.*, **60**:209–212.

MILES, A. C., D. A. MILLER, S. B. CASTLEBERRY AND L. M. CONNER. 2006. Bat community structure and activity in longleaf pine forests of southwest Georgia. *Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies*, **60**:1–7.

MILLER, D. A. 2003. Species diversity, reproduction, and sex ratios of bats in managed pine forest landscapes of Mississippi. *Southeast. Nat.*, **2**:59–72.

O'SHEA, T. J. and M. A. BOGAN (eds.). 2003. Report of the workshop, p. 240–271. *In:* Monitoring trends in bat populations of the United States and territories: problems and prospects. Information and Technology Report USGS/BRD/ITR-2003-0003. U.S. Department of Interior, Geological Survey. 274 p.

PERRY, R. W., D. A. SAUGEY AND B. G. CRUMP. 2010. Winter roosting ecology of silver-haired bats in an Arkansas forest. *Southeast. Nat*, in press.

——— AND R. E. THILL. 2007. Roost characteristics of hoary bats in Arkansas. *Am. Midl. Nat.*, **158**:132–138.

———, ——— AND D. M. LESLIE, JR. 2007. Selection of roosting habitat by forest bats in a diverse forest landscape. *For. Ecol. Manage.*, **238**:156–166.

PEURACH, S. C., C. J. DOVE AND L. STEPKO. 2009. A decade of U.S. Air Force bat strikes. *Human-Wildl. Conflicts*, **3**:199–207.

RACEY, P. A. 1974. Ageing and the assessment of reproduction status of pipistrelle bats, *Pipistrellus pipistrellus*. *J. Zool.*, **173**:264–271.

ROBBINS, L. W., K. L. MURRAY AND P. M. MCKENZIE. 2008. Evaluating the effectiveness of the standard mist-netting protocol for the endangered Indiana Bat (*Myotis sodalis*). *Northeast. Nat.*, **15**:275–282.

RODRIGUES, L. AND J. M. PALMEIRIM. 2008. Migratory behavior of the Schreiber's Bat: when, where and why do cave bats migrate in a Mediterranean region. *J. Zool.*, **274**:116–125.

SAUGEY, D. A., D. R. HEATH AND G. A. HEIDT. 1989. The bats of the Ouachita Mountains. *Proc. Ark. Acad. Sci.*, **43**:71–77.

———, D. G. SAUGEY, G. A. HEIDT AND D. R. HEATH. 1988. The bats of Hot Springs National Park, Arkansas. *Proc. Ark. Acad. Sci.*, **42**:81–83.

———, R. L. VAUGHN, B. G. CRUMP AND G. A. HEIDT. 1998. Notes on the natural history of *Lasiurus borealis* in Arkansas. *J. Ark. Acad. Sci.*, **52**:92–98.

SEIDMAN, V. M. AND C. J. ZABEL. 2001. Bat activity along intermittent streams in northwestern California. *J. Mammal.*, **82**:738–747.

SKILES, A. 1981. Arkansas climate atlas. Arkansas Energy Office, Arkansas Industrial Development Commission, Little Rock, Arkansas.

TUMLISON, R., T. FULMER, T. FINLEY AND D. A. SAUGEY. 2002. Bats of the Jessieville Ranger District, Ouachita National Forest, Arkansas. *J. Ark. Acad. Sci.*, **56**:206–211.

WATKINS, W. C. 1969. Observations on the distribution and natural history of the evening bat (*Nycticeius humeralis*) in northwestern Missouri and adjacent Iowa. *Trans. Kans. Acad. Sci.*, **72**:330–336.

WHITAKER, J. O., JR. AND W. J. HAMILTON. 1998. Mammals of the eastern United States. Cornell University Press, Ithaca, New York. 583 p.

——— AND L. J. RISSLER. 1992. Seasonal activity of bats at Copperhead Cave. *Proc. Indiana Acad. Sci.*, **101**:127–133.

WILHIDE, J. D., B. BAKER AND D. A. SAUGEY. 1998a. Arkansas range extension of the Seminole bat (*Lasiurus seminolus*). *J. Ark. Acad. Sci.*, **52**:140–141.

———, M. J. HARVEY, V. R. MCDANIEL AND V. E. HOFFMAN. 1998b. Highland pond utilization by bats in the Ozark National Forest, Arkansas. *J. Ark. Acad. Sci.*, **52**:110–112.

WINHOLD, L. AND A. KURTA. 2008. Netting surveys for bats in the Northeast: Differences associated with habitat, duration of netting, and use of consecutive nights. *Northeast. Nat.*, **15**:263–274.

SUBMITTED 3 DECEMBER 2009 ACCEPTED 22 MARCH 2010