

BATS OF HOOSIER NATIONAL FOREST

Virgil Brack, Jr.: Environmental Solutions & Innovations, Inc., 781 Neeb Road, Cincinnati, Ohio 45233 USA

John O. Whitaker, Jr.: Department of Life Sciences, Indiana State University, Terre Haute, Indiana 47809 USA

Scott E. Pruitt: U.S. Fish and Wildlife Service, 620 S. Walker Street, Bloomington, Indiana 47403 USA

ABSTRACT. We summarize results of bat surveys in Hoosier National Forest 1981–2003. Mist net captures included the northern myotis, *Myotis septentrionalis* (137); red bat, *Lasiurus borealis* (132); eastern pipistrelle, *Pipistrellus subflavus* (131); big brown bat, *Eptesicus fuscus* (43); little brown myotis, *Myotis lucifugus* (40), Indiana myotis, *Myotis sodalis* (6); hoary bat, *Lasiurus cinereus* (4); silver-haired bat, *Lasionycteris noctivagans* (1); evening bat, *Nycticeius humeralis* (1); and gray myotis, *Myotis grisescens* (1). Evidence of reproduction was found for northern and little brown myotis, big brown, red, and hoary bats, and the eastern pipistrelle, but not for Indiana myotis, despite an abundance of wooded habitats. Radio-transmitters were placed on five male Indiana myotis, and 14 roost trees of five species were found in riparian and upland habitats; six trees were < 30.5 cm (12 inches) and six were > 38.1 cm (15 inches) dbh (43% each). Some species of trees are more likely to provide roosts when live (in this study, shagbark hickory, *Carya ovata*, and white oak, *Quercus alba*), while others are more likely to provide roosts when dead (pine, *Pinus* sp., American elm, *Ulmus americana*, and northern red oak, *Q. rubra*). Activity areas (\bar{x} = 95.1 ha minimum convex polygon) included wooded and open habitats, and roads ranging in size from forest trails to a divided four-lane interstate highway. Twenty-one visits to 18 caves produced eastern pipistrelles (15 caves, n = 449), little brown myotis (9 caves, n = 205), Indiana myotis (2 caves, n = 134–250), big brown bats (8 caves, n = 40), and northern myotis (3 caves, n = 4). Spring and autumn trapping at a kaolinite mine yielded 38 northern myotis, 10 eastern pipistrelles, and 4 little brown myotis.

Keywords: Bats, Hoosier National Forest, Indiana, Indiana myotis, radio-telemetry

Thirteen species of bats are known from Indiana, although the southeastern myotis (*Myotis austroriparius*) is apparently extirpated from the state, Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) is an extremely rare visitor, and the Seminole bat (*Lasiurus seminolus*) was found only when accidentally transported into the state in bundles of Spanish moss (Mumford & Whitaker 1982; Whitaker & Hamilton 1998). The remaining 10 species all use wooded lands in some capacity. Hoosier National Forest (HNF) has about 77,700 ha in public ownership, and much of this land is wooded. It is an important resource for the bat fauna of south-central Indiana. HNF also has an abundant cave resource; 7 of the 10 species of bats use caves in some capacity, often for hibernation.

Two species, the Indiana myotis (*M. sodalis*) and gray myotis (*M. grisescens*), are federally-endangered. In winter, Indiana myotis

hibernate in caves, including caves in southern portions of Indiana, and occasionally in mines, (Mumford & Whitaker 1982; Brack et al. 2003). During summer they form maternity colonies in woodlands throughout much of the state (Brack 1983; Whitaker & Brack 2002). Gray myotis typically roost in caves during both summer and winter, and often forage along wooded streams (LaVal & LaVal 1980). Only one maternity colony is known from Indiana (Brack et al. 1984), although individuals from this colony roost at two sites 8 km apart (Whitaker et al. 2001). Males have been caught in summer along the Ohio River, and occasionally individuals are found during winter hibernation (Brack et al. 2003).

The evening bat (*Nycticeius humeralis*) is listed as endangered by the State of Indiana. Initially, maternity colonies were known only from buildings (Whitaker & Gummer 1993), but now are known from more natural wooded

settings (Whitaker & Gummer 2001). It is not known where the species hibernates.

The little brown myotis (*M. lucifugus*), northern myotis (*M. septentrionalis*), big brown bat (*Eptesicus fuscus*), and eastern pipistrelle (*Pipistrellus subflavus*) all use wooded lands during summer and caves for hibernation. The red bat (*Lasiurus borealis*) and hoary bat (*L. cinereus*), are summer residents, roosting in wooded areas. Most red bats, and apparently all hoary bats, migrate south for winter. The silver-haired bat (*Lasionycteris noctivagans*) is a woodland species that is migratory through the state in spring (April–early June) and autumn (September–October), although a few individuals hibernate in Indiana (Brack et al. 2003).

Studies completed over a 23-year period were used to evaluate the seasonal distribution of bats in the Hoosier National Forest, to examine differences in the way species use the habitat, and to provide information about federally- and state-listed species on the forest.

METHODS

Studies were completed in the Hoosier National Forest in south-central Indiana (Fig. 1). About 260,700 ha lie within the forest boundary, and of this, about 77,700 ha are public lands. The northern portion of HNF is within the Brown County Hills section of the Highland Rim Natural Region. The central and southern part of the Forest is within the Crawford Upland, Mitchell Karst Plain, and Escarpment sections of the Shawnee Hills Natural Region.

Summer maternity studies.—Bats were captured with mist nets, primarily 15 May–15 August, during several years. Netting studies were completed in 1981 in Jackson County, in 1990 in Lawrence, Martin, Orange, Crawford, and Perry counties, in 1998 in Crawford and Perry counties, and in 1996 and 1999 in Jackson and Lawrence counties. Nets were stacked 6–9 m high across flight corridors. Sites were typically netted dusk to dawn in 1990, dusk to 0200 h in 1998, and dusk to midnight in 1996 and 1999. In 1981, six net-nights of effort were completed at three riparian net sites. In 1990, 14 paired upland and riparian sites were netted. Two net-nights of effort, over two nights, were completed at most sites, for 26 net-nights in riparian and 24 net-nights in upland habitats. In 1998, 22 sites

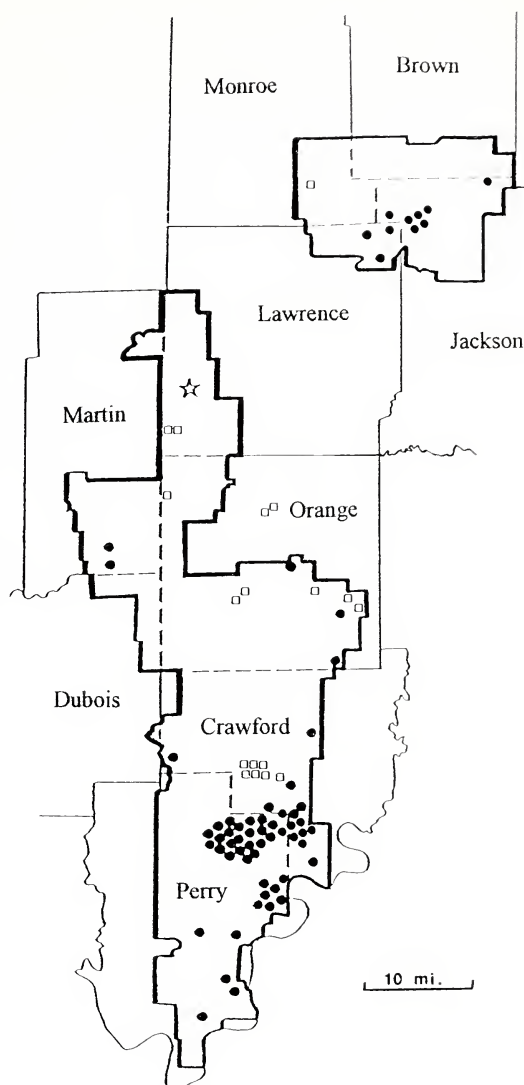


Figure 1.—Map of the Hoosier National Forest showing locations of sites netted during summer (maternity season) surveys (●), a kaolin mine where trapping was done in spring and autumn (☆), and caves entered during winter (hibernacula) surveys (□).

were netted in riparian and 12 in upland habitat, with each site typically consisting of two nets ≥ 30 m apart for two nights (four net-nights per site). One riparian site was netted only one night, resulting in a total effort of 134 net-nights. Net sites in 1996 and 1999 included five wooded riparian sites and two upland pond sites; 19 net-nights of effort were completed in 1996 and 20 net-nights in 1999.

From 1992–1999, Whitaker & Gummer

(2001) netted bats in bottomlands of south-western Indiana, including eight net-nights in HNF near the Ohio River in Crawford County (4 sites) and Perry County (3 sites). Nets were stacked 6 m high across flight corridors and were run dusk–0200 h.

Point-quarter studies were used in 1990 to collect data on five habitat variables: percent canopy closure, number of tree species, number of snags, diameter at breast height (dbh) of trees > 12 cm, and distance between trees > 12 cm dbh. Transects of 100 m were followed in the four cardinal compass directions from the mist net, and samples were taken at 20 m intervals. Microstat version 4.1 (Ecosoft, Inc.) was used for single-factor linear regression analysis between each of the five habitat variables and numbers of bats (by species) caught per site in riparian, upland, and combined riparian and upland sites.

Weight, sex, age, and reproductive condition were recorded. Reproductive females (pregnant, lactating, or post-lactating) or juveniles (determined by degree of epiphyseal-diaphyseal calcification of wing phalanges) were considered evidence of reproduction. Capture data were examined by rate of catch per site, rate of catch per net-night, and habitat of capture (riparian versus upland). Chi-square analysis was used to compare capture between riparian and upland sites (weighted by level of effort) and sex of adult bats. MacArthur's (1972) Species Diversity Index ($1/\sum P_i^2$, where P_i is the proportion of bats belonging to species "i") was used to compare samples.

In 1996, a single male Indiana myotis from the Brownstown Ranger District, Jackson County was equipped with a radio-transmitter. In 1998, four male Indiana myotis from the Tell City Ranger District, Perry and Crawford counties, were equipped with radio-transmitters (Wildlife Materials Model SOPB-201) and followed using receivers (TRX 2000) and 3-element Yagi hand-held antennas. In 1996 and 1998, bats were followed to day roosts for at least three days after transmitters were attached. Data collected on each roost tree included: species, dbh, live or dead, percent exfoliating bark, and percent canopy closure.

In 1998, for 3–6 nights (dusk–0100 h) following transmitter attachment, activity areas of each bat, including foraging, were established using triangulation, coordinated with

two-way radios at 5 minute intervals. The computer program TelemPC (January 1989 version; Method O) was used for these analyses. To minimize the error polygon at each telemetry location, paired bearings with an angular difference $\leq 10^\circ$ were excluded. Activity areas were estimated using three methods: 95% minimum convex polygon, capture radius, and non-circular.

Spring staging and autumn swarming studies.—Trapping was done at Dillon Cave, Valeene Quadrangle, Orange County on 20 August 1981. Traps were set at the entrance to a kaolinite mine on Gardener Ridge, Williams Quadrangle, Lawrence County four times in spring (8 April 1998, 6 May 1999, 26 April 2001, and 3 April 2003) and four times in autumn (15 October 1998, 22 September 1999, 24 September 2002, and 22 October 2002).

Winter hibernation studies.—Twenty-one visits were made to 18 caves to look for hibernating bats. Two caves were entered in winter 2001, 17 caves were entered in winter 2002, including one visited in 2001, and two caves were visited in 2003, including one visited in 2001 and one visited in 2002. Caves were in four counties: seven in Crawford, two in Martin, one in Monroe, and eight in Orange. Bats were tallied by species and by location in the cave. Temperatures were taken outside cave entrances, in the twilight area, and near concentrations of bats. Surveys were often terminated when the frequency of bats encountered decreased markedly or warm ambient temperatures reduced the probability of finding concentrations of bats.

RESULTS

Ten of the 12 species of bats naturally occurring in Indiana were caught in HNF.

Summer netting.—Summer netting (237 net-nights) 1981–1999 resulted in capture of 496 bats of 10 species (Table 1). Collectively, the northern myotis, red bat, and eastern pipistrelle accounted for about 80% of the catch. The species diversity index was 4.3 and the catch per net-night was 2.1 bats. Evidence of reproduction was obtained for six species: northern and little brown myotis, big brown, red, and hoary bats, and eastern pipistrelle.

In 1990, bats were caught at 13 of 14 paired riparian-upland locations; the catch per net-night was 5.8 in riparian habitat, and 0.6 in

Table 1.—Species of bats, numbers of net-nights, and numbers of bats captured during summer surveys in Hoosier National Forest, 1981–1999.

| | 1981 | 1990 | 1996 | 1998 | 1999 | 1992–99 | Total |
|---------------------------|------|------|------|------|------|---------|-------|
| <i>M. sodalis</i> | | 1 | 1 | 4 | | | 6 |
| <i>M. grisescens</i> | | | | 1 | | | 1 |
| <i>M. septentrionalis</i> | | 8 | 22 | 81 | 6 | 20 | 137 |
| <i>M. lucifugus</i> | | 13 | 4 | 4 | 19 | | 40 |
| <i>E. fuscus</i> | | 22 | 5 | 15 | | 1 | 43 |
| <i>L. borealis</i> | 3 | 53 | 14 | 49 | 5 | 8 | 132 |
| <i>L. cinereus</i> | 1 | 1 | | | 2 | | 4 |
| <i>P. subflavus</i> | 2 | 67 | 16 | 35 | 9 | 2 | 131 |
| <i>L. noctivagans</i> | | | | 1 | | | 1 |
| <i>N. humeralis</i> | | | | 1 | | | 1 |
| Total | 6 | 165 | 62 | 191 | 41 | 31 | 496 |
| Net-nights | 6 | 50 | 19 | 134 | 20 | 8 | 237 |

upland habitat (Table 2). Only 14 bats were caught in uplands. The greatest rate of catch was for the eastern pipistrelle in riparian habitat, at 2.5 bats per net-night (Table 2). Eastern pipistrelles were caught at the greatest number of locations ($n = 12$; 85.7%), followed by red bats ($n = 11$; 78.6%), big brown bats ($n = 7$; 50.0%), northern myotis ($n = 6$; 42.9%), Indiana myotis ($n = 1$; 7.1%), little brown my-

otis ($n = 1$; 7.1%), and hoary bats ($n = 1$; 7.1%). Six species of bats were caught at one site, and no bats were caught at one site; the mean was 2.9 species ($SD = 1.5$). The species diversity index for these 14 sites was 3.4.

Adult male big brown bats were caught more frequently than reproductive females ($\chi^2 = 4.7647$; $P = 0.0290$), as were adult male eastern pipistrelles ($\chi^2 = 27.0000$; $P <$

Table 2.—Numbers of bats caught, catch per net-night, and chi-square analysis of catch in riparian and upland net sites in Hoosier National Forest. The 1990 survey included 26 riparian and 24 upland sites, while the 1998 survey included 22 riparian and 12 upland sites.

| Species | Riparian | | Upland | | χ^2 | P | Catch/net-night | | |
|---------------------------|----------|------|--------|------|----------|---------|-----------------|--------|-------|
| | Bats | % | Bats | % | | | Riparian | Upland | Total |
| 1990 | | | | | | | | | |
| <i>M. sodalis</i> | 1 | 0.7 | 0 | 0.0 | | | 0.04 | 0.00 | 0.02 |
| <i>M. septentrionalis</i> | 6 | 4.0 | 2 | 14.3 | | | 0.23 | 0.08 | 0.16 |
| <i>M. lucifugus</i> | 13 | 8.6 | 0 | 0.0 | 12.0000 | 0.0005 | 0.50 | 0.00 | 0.26 |
| <i>E. fuscus</i> | 17 | 11.3 | 5 | 35.7 | 5.6297 | 0.0177 | 0.65 | 0.21 | 0.44 |
| <i>L. borealis</i> | 47 | 31.1 | 6 | 42.9 | 28.5675 | <0.0000 | 1.81 | 0.25 | 1.06 |
| <i>L. cinereus</i> | 1 | 0.7 | 0 | 0.0 | | | 0.04 | 0.00 | 0.02 |
| <i>P. subflavus</i> | 66 | 43.7 | 1 | 7.1 | 58.0589 | <0.0000 | 2.54 | 0.04 | 1.34 |
| Total | 151 | | 14 | | | | 5.81 | 0.58 | 3.30 |
| 1998 | | | | | | | | | |
| <i>M. sodalis</i> | 3 | 2.2 | 1 | 1.9 | | | 0.03 | 0.02 | 0.03 |
| <i>M. grisescens</i> | 1 | 0.7 | 0 | 0.0 | | | 0.01 | 0.00 | 0.01 |
| <i>M. septentrionalis</i> | 43 | 30.9 | 38 | 73.1 | 5.6908 | 0.0171 | 0.49 | 0.83 | 0.60 |
| <i>M. lucifugus</i> | 4 | 2.9 | 0 | 0.0 | | | 0.05 | 0.00 | 0.03 |
| <i>E. fuscus</i> | 14 | 10.1 | 1 | 1.9 | 5.0912 | 0.0240 | 0.16 | 0.02 | 0.11 |
| <i>L. borealis</i> | 38 | 27.3 | 11 | 21.2 | 3.0673 | 0.0799 | 0.43 | 0.24 | 0.37 |
| <i>P. subflavus</i> | 33 | 23.7 | 2 | 3.8 | 12.7115 | 0.0004 | 0.38 | 0.04 | 0.26 |
| <i>L. noctivagans</i> | 1 | 0.7 | 0 | 0.0 | | | 0.01 | 0.00 | 0.01 |
| <i>N. humeralis</i> | 1 | 0.7 | 0 | 0.0 | | | 0.01 | 0.00 | 0.01 |
| Total | 138 | | 53 | | | | 1.57 | 1.55 | 1.43 |

0.0000). The catch of little brown myotis, red bats, and eastern pipistrelles was significantly greater in riparian than in upland habitat; and there was some indication this was also true for the big brown bat (Table 2). Linear regression provided no significant ($\alpha < 0.05$) single-factor correlation between five habitat variables and numbers of bats of any species caught per site in riparian, upland, or combined riparian and upland sites.

Bats were caught at all 22 riparian net sites and 10 of 12 upland sites in 1998; the catch per net-night was 1.6 in both types of habitat (Table 2). Northern myotis were caught at the greatest number of locations ($n = 27$; 79.4%), followed by red bats ($n = 22$; 64.7%), eastern pipistrelles ($n = 15$; 44.1%), big brown bats ($n = 10$; 29.4%), Indiana myotis ($n = 4$; 11.8%), little brown myotis ($n = 3$; 8.8%), gray myotis ($n = 1$; 2.9%), silver-haired bats ($n = 1$; 2.9%), and evening bats ($n = 1$; 2.9%). Five species were caught at three sites, and no bats were caught at two sites; the mean was 2.5 species (SD = 1.4). The species diversity index for these 34 sites was 3.5.

The four Indiana myotis captured were adult males, two each in Perry and Crawford counties. An adult male gray myotis captured over Stinking Fork Creek, Crawford County on 19 July 1998 was the first record of a gray myotis from HNF. An adult male evening bat was captured over a tributary to the Little Blue River on 5 July 1998.

In 1998, male big brown bats ($n = 10$) were caught more frequently ($\chi^2 = 5.3333$; $P = 0.0209$) than reproductive females ($n = 2$), as were male eastern pipistrelles ($\chi^2 = 10.1250$; $P = 0.0015$; male = 25 and reproductive female = 7). Reproductive female red bats ($n = 18$) were caught more frequently ($\chi^2 = 4.8400$; $P = 0.0278$) than adult males ($n = 7$). Reproductive female and juvenile northern myotis, big brown bats, and red bats were caught in both riparian and upland habitats; reproductive female and juvenile eastern pipistrelles were found only in riparian habitat. Three of four male Indiana myotis were caught in riparian habitat. The highest rate of capture for any species was for the northern myotis in upland habitat and the catch of northern myotis was greater in upland than in riparian habitat (Table 2). The catch of eastern pipistrelles was greater in riparian than in upland habitat, and there was some indication

this was also true for big brown and red bats (Table 2).

Collectively, 103 bats of 7 species were captured in 1996 and 1999 (Table 1); the catch per net-night was 2.6 bats and the species diversity index was 4.6 (3.9 in 1996 and 3.3 in 1999). Female little brown myotis ($n = 10$) were caught more frequently ($\chi^2 = 5.3333$; $P = 0.0209$) than adult males ($n = 2$), while adult male northern myotis ($n = 14$; $\chi^2 = 4.2632$; $P = 0.0389$) and red bats ($n = 9$; $\chi^2 = 6.4000$; $P = 0.0114$) were caught more frequently than reproductive females ($n = 5$ and 1, respectively). Seven sites were netted 1992–1999 in HNF during studies of southwest bottomlands of Indiana (Whitaker & Gummer 2001). A total of 31 bats of four species was caught (Table 1). The species diversity index was 2.0.

Telemetry of male Indiana myotis.—Between 9–16 July 1996, one male Indiana myotis was tracked to two roost trees (Table 3). Both roosts were live shagbark hickories (*Carya ovata*); one roost was used twice. They were about 30 m from one another and were in an even-aged oak-hickory stand where most trees were 20–30 cm dbh. Four male Indiana myotis were tracked to 12 day-roosts 16 June–14 July 1998; each used 2–5 roosts in five species of trees (Table 3). Two roost trees were used twice. American elm (*Ulmus americana*) was used most frequently as a roost, and one of these roost trees had been girdled by HNF. All shagbark hickory and white oak (*Quercus alba*) roost trees were live; all pine (*Pinus* sp.), American elm, and northern red oak (*Q. rubra*) roost trees were dead. Six roost trees (43%) were < 30.5 cm (12 inches) dbh, and six roost trees (43%) were > 38.1 cm (15 inches) dbh. Mean solar exposure was 51% and mean bark retention was 25% (Table 3). Two bats roosted only in riparian habitats, and three bats roosted only in upland habitat. One roost tree was adjacent to the cleared right-of-way of eastbound lanes of the Interstate 64 highway.

The four male Indiana bats caught in 1998 were tracked for 21 nights, 3–7 nights each. The mean activity area (including foraging) of all bats was 95.1–151.9 ha based on the method of estimation, and the mean activity areas of individual bats were 43.1–314.2 ha across all three methods of estimation (Table 4). Activity areas determined with a 95% minimum

Table 3.—Characteristics of 14 roost trees used by five adult male Indiana myotis in Hoosier National Forest. One bat was monitored 9–16 July 1996, and four bats were monitored 16 June–14 July 1988.

| Bat No. | Tree species | Status | dbh (cm) | % of bark exfoliating | % Canopy closure | Roost habitat |
|---------|------------------------|--------|----------|-----------------------|------------------|---------------|
| 1996 | | | | | | |
| 1 | <i>Carya ovata</i> | live | 20.3 | | 80 | upland |
| | <i>Carya ovata</i> | live | 28.0 | | 80 | upland |
| 1998 | | | | | | |
| 1 | <i>Ulmus americana</i> | dead | 33.3 | 40 | 10 | riparian |
| | <i>Ulmus americana</i> | dead | 48.5 | 40 | 60 | riparian |
| 2 | <i>Pinus</i> sp. | dead | 35.1 | 10 | 50 | upland |
| | <i>Pinus</i> sp. | dead | 23.6 | 10 | 60 | upland |
| | <i>Quercus rubra</i> | dead | 71.9 | 25 | 35 | upland |
| | <i>Carya ovata</i> | live | 29.2 | 70 | 80 | upland |
| | <i>Quercus alba</i> | live | 38.1 | 15 | 80 | upland |
| 3 | <i>Ulmus americana</i> | dead | 26.2 | 20 | 70 | riparian |
| | <i>Ulmus americana</i> | dead | 48.5 | 35 | 50 | riparian |
| 4 | <i>Quercus alba</i> | live | 41.9 | 10 | 30 | upland |
| | <i>Quercus rubra</i> | dead | 41.4 | 20 | 20 | upland |
| | <i>Pinus</i> sp. | dead | 19.8 | 10 | 40 | upland |
| | Mean | | 38.1 | 25 | 49 | |
| | S.D. | | 14.1 | 18 | 23 | |

convex polygon were consistently the smallest, and areas determined using the capture radius method were consistently the largest.

Based on USGS topographic maps, activity areas included wooded riparian and upland areas and open lands. Three of four activity areas included perennial streams. One bat’s activity area included a gravel road, another a two-lane state highway, and a third a state highway and a divided, four-lane interstate highway. The bat with the largest activity area used the largest number of roosts.

Spring staging and autumn swarming.—On 20 August 1981, seven bats of three species were caught at the entrance to Dillon Cave: an adult male, adult female, and a juvenile little brown bat; an adult male and two juvenile northern myotis; and an adult male eastern pipistrelle.

Spring trapping at the kaolinite mine produced 17 northern myotis, 6 eastern pipistrelles, and 1 little brown myotis. Autumn trapping yielded 21 northern myotis, 4 eastern pipistrelles, and 3 little brown myotis. The mean spring capture was 6 bats and 1.75 species; the mean autumn catch was 7 bats and 2 species. More bats ($n = 8$) of more species ($n = 3$) were caught in May than April (\bar{x} number of bats = 5.3; \bar{x} number of species = 1.3). More bats (\bar{x} number of bats = 11.5) of more species (\bar{x} number of species = 3.0) were caught in September than October (\bar{x}

Table 4.—Estimates of activity areas (ha) of four male Indiana myotis in Hoosier National Forest in 1998 based on three methods of calculation: 95% minimum convex polygon (MCP), non-circular, and capture radius.

| | No. of nights | 95% MCP | Non-circular | Capture radius | Mean | S.D. |
|-------|---------------|---------|--------------|----------------|-------|------|
| Bat 1 | 6 | 53.6 | 82.7 | 84.4 | 73.6 | 17.3 |
| Bat 2 | 5 | 226.1 | 317.0 | 399.4 | 314.2 | 86.6 |
| Bat 3 | 7 | 67.3 | 68.3 | 73.3 | 69.6 | 3.2 |
| Bat 4 | 3 | 33.3 | 45.5 | 50.5 | 43.1 | 8.9 |
| Mean | | 95.1 | 128.4 | 151.9 | | |
| S.D. | | 88.5 | 126.7 | 165.6 | | |

number of bats = 2.5; \bar{x} number of species = 1.0).

Winter hibernation.—A total of 1083 bats was found in 17 of 18 cave visits (94.4%) during 20 of 21 visits (Table 5). Collectively, five species of bats were found and 0–5 species were found per cave visit (\bar{x} = 2.1; SD = 1.4). The species diversity was 3.0. The most bats in any cave on any single visit was 307 (\bar{x} = 51.6; SD = 88.0), in Gypsy Bill Allen Cave.

The species found in the most caves was the eastern pipistrelle (n = 15; 83.3%), and despite typically low numbers per cave (0–98; \bar{x} = 21.4; SD = 32.8) was most abundant overall (n = 449; 41.5% of the total). Three caves (Elrod, Mesmore Springs, and Dillon) had > 50 individuals. This species is often the only species in small caves, and most caves visited were small. Eastern pipistrelles were often found over the range of temperatures available in each cave, typically 5–12° C.

Indiana myotis were found in the fewest caves (n = 2; 11.1%). However, because of the concentration in Gypsy Bill Allen Cave (visited on two occasions), this species was the second most common species found (n = 385; 35.6% of the total). On 3 February 2001, which is slightly past the coldest time of year, 134 Indiana myotis were found in Gypsy Bill Allen Cave at 9.0° C. During the 27 January 2003 visit, Indiana myotis were encountered in three areas, with temperatures of 2.1° C (n = 67), 5.0° C (n = 94), and 5.2° C (n = 89), for a weighted average temperature of 4.3° C. One Indiana myotis was found in Bluff House Cave in 2002 hibernating at a temperature of 5.0° C, but none were found in 2003.

The little brown myotis was found in the second greatest number of caves (n = 9; 50%) and was third most abundant overall (n = 205; 18.9% of the total). Numbers of little brown myotis varied widely among caves (0–112; \bar{x} = 9.8; SD = 25.8). This species was found hibernating across a wide range of temperatures. The largest concentration, 106 individuals in Mesmore Springs Cave, hibernated in an area that was 11.7° C. However, most individuals in Gypsy Bill Allen Cave, in both 2001 and 2003, were in areas \leq 5.2° C. The third largest concentration of little brown myotis (n = 16), in Red Berry Cave, hibernated at 4.5° C.

Relatively few big brown bats (n = 40;

3.7% of the total) were found in 8 caves (44.4% of caves visited), and numbers were variable (0–15; \bar{x} = 1.9; SD = 3.9). Big brown bats were typically found singly or in small clusters close to the entrance in areas with colder temperatures (3.8–6.3° C). The northern myotis was found infrequently (n = 4; 0.4% of the total). Two individuals were found in Gypsy Bill Allen Cave, one each in 2001 and 2003, and one each in Mesmore Springs and Treasure caves (at temperatures of 4.9° C and 7.7° C, respectively).

DISCUSSION

Hoosier National Forest is an important resource for bats in southern Indiana; 10 of 12 species native to Indiana were found there, with evidence of reproduction for six species. Of the two species not found, one is extirpated and one is of accidental occurrence in Indiana. HNF provides habitat for two federally-endangered and one state-endangered species. Although only one silver-haired bat, one evening bat, and one gray myotis were caught, they added to species richness.

Northern myotis.—This species is common in summer in HNF, and evidence of reproduction was found each summer of sampling, indicating maternity colonies are present. It was the most commonly caught species during spring, summer, and autumn studies; and although it hibernates in caves, it was rarely found there. This species often hibernates individually in small cracks and crevices in warmer areas (Whitaker & Rissler 1992a, 1992b; Brack et al. 2003). Although difficult to find in hibernacula, it is frequently found entering and exiting caves and mines in spring and autumn, providing indirect evidence of winter use. Northern myotis were 73% of spring and autumn captures at the kaolin mine. Whitaker et al. (2002) found numbers of this species in Indiana stable over time. In summer habitats, the northern myotis is sometimes considered more common in uplands than along streams and water bodies; and in the 1998 sample that appeared true. It was the only species caught significantly more often in upland habitat. The rate of catch in 1990 was higher, and that of 1998 was lower than the rate of catch by Brack (1983) in northern Indiana (0.03 riparian, 0.25 upland, and 0.17 total).

Red bat.—The red bat was the second most

Table 5.—Bats found in caves in the Hoosier National Forest.

| Cave | Year | <i>Myotis sodalis</i> | <i>Myotis septentrionalis</i> | <i>Myotis lucifugus</i> | <i>Eptesicus fuscus</i> | <i>Pipistrellus subflavus</i> | Total bats |
|--------------------------|------|-----------------------|-------------------------------|-------------------------|-------------------------|-------------------------------|------------|
| Gypsy Bill Allen | 2001 | 134 | 1 | 44 | 15 | 34 | 228 |
| | 2003 | 250 | 1 | 24 | 11 | 21 | 307 |
| Wesley Chapel Gulf Elrod | 2002 | | | 1 | | 7 | 8 |
| | 2001 | | | | 2 | 93 | 98 |
| | 2002 | | | | | 98 | 95 |
| Patton | 2002 | | | 1 | 4 | 3 | 8 |
| Red Berry | 2002 | | | 16 | | 6 | 22 |
| Dillon | 2002 | | | 2 | 1 | 51 | 54 |
| Duggins Springs | 2002 | | | | | 6 | 6 |
| Bluff House | 2002 | 1 | | | | 7 | 8 |
| | 2003 | | | 2 | 2 | 4 | 8 |
| Spring Springs | 2002 | | | | | 7 | 7 |
| Diggers Delight | 2002 | | | | | 3 | 3 |
| Big Circle | 2002 | | | | | 5 | 5 |
| Sentinel Rock | 2002 | | | | | 0 | 0 |
| Pavey | 2002 | | | 1 | 1 | 3 | 5 |
| Across The Valley | 2002 | | | | | 2 | 2 |
| Hermit | 2002 | | | 2 | | | 2 |
| Mesmore Springs | 2002 | | 1 | 112 | 1 | 91 | 205 |
| Tucker Lake Spring | 2002 | | | | 3 | 8 | 11 |
| Treasure | 2002 | | 1 | | | | 1 |
| No. caves | | 2 | 3 | 9 | 8 | 15 | 18 |
| No. bats | | 385 | 4 | 205 | 40 | 449 | 1,083 |

commonly-caught species in summer mist net surveys. The red bat is migratory, although some individuals likely remain in Indiana and HNF throughout the year. Accordingly, it was not represented in spring and autumn surveys of the kaolinite mine or in winter surveys of caves. Whitaker et al. (2002) considered the species to be declining in Indiana; the rate of catch was lower in 1998 than in 1990. The rates of catch in 1990 in upland and all habitats were greater than in northern Indiana (0.92 riparian, 0.40 upland, and 0.61 total; see Brack 1983), but the catch in both 1998 and combined 1996/1999 was less than in northern Indiana. Like in northern Indiana, red bats were more common in riparian habitat. Evidence of reproduction was found during each summer of sampling. In 1998, reproductive female red bats were more common than adult males. In the Appalachian Mountains, abundance of reproductive females is inversely related to elevation; the weather is harsher (colder, wetter, and more variable) at higher elevations (Brack et al. 2002).

Eastern pipistrelle.—This species is common in the southern portion of the state but less common in northern areas, where it is most often found along major drainages (Brack & Mumford 1984). It was among the most commonly-caught species in mist nets in HNF, where the rate of catch was much greater than found by Brack (1983) in northern Indiana (0.18 riparian and 0.07 total); and it was more common in riparian than upland habitats. In each summer of sampling, we found evidence of reproduction. In both 1990 and 1998, male pipistrelles were more common in mist nets than reproductive females; but we have no explanation why this occurred. Abundance of this species in Indiana is apparently increasing (Whitaker et al. 2002). It forms maternity colonies in clusters of leaves (Veilleux et al. 2003) and in winter it hibernates in small numbers in many caves. In HNF, the eastern pipistrelle was common in winter hibernacula, and it was commonly taken at cave and mine entrances.

Big brown bat.—The big brown bat is common in many portions of its range, including Indiana, where it co-exists with man and readily uses a landscape heavily modified by man. Statewide, it appears to be increasing in abundance (Whitaker et al. 2002). Although often found in caves and mines in autumn,

winter, and spring, numbers of individuals are low because most individuals hibernate in buildings where temperatures remain above freezing (Whitaker & Gummer 1992, 2000). Evidence of reproduction was found in most summer samples. In both 1990 and 1998, male big brown bats were more common than reproductive females. This may be because maternity colonies are often in buildings, which were uncommon in wooded areas netted, and this may also account for the overall low rate of catch. In northern Indiana, Brack (1983) had a rate of catch per net-night substantially greater (1.80 riparian, 1.65 upland, and 1.71 total) than in HNF. There was evidence big brown bats were more common in riparian than upland sites in both 1990 and 1998.

Little brown myotis.—The little brown myotis is often considered one of the more common bats throughout its range. It was not common in either the 1990 or 1998 mist net surveys, perhaps because maternity colonies are often formed in buildings, which were uncommon in areas netted. However, it was common in the 1996/1999 mist net surveys. Most summer surveys provided evidence of reproduction. Based largely on summer occurrences, Whitaker et al. (2002) thought the species to be decreasing in Indiana, although Brack et al. (2003) found the species may be increasing in winter hibernacula. Foraging and other activities are sometimes considered more common along streams and near bodies of water, as it apparently was in 1990. The rate of capture in mist nets in northern Indiana (0.82 riparian, 0.09 upland, and 0.39 total) reported by Brack (1983) was comparable to the 1990 rate of catch but much greater than the rate in 1998. This is one of three species that commonly hibernates in caves and mines in Indiana. It was the second most common species in caves examined in HNF, and the second most abundant species taken in spring and autumn trapping at the kaolinite mine. Differences between summer and winter abundance may be related to the relatively long distances this species sometimes migrates.

Indiana myotis.—The Indiana myotis is a federally-endangered species. In summer, females form maternity colonies in trees with sloughing bark in wooded or more open habitats. Indiana myotis sometimes migrate long distances between hibernacula and maternity roosts. Although wooded habitats are plentiful

in HNF, no evidence of reproduction was found. While this does not preclude the presence of maternity colonies, they are apparently less abundant here than in many portions of the range. Brack et al. (2002) noted a lack of correlation between an abundance of trees and an abundance of Indiana myotis at the landscape level. During summer, adult males frequently remain geographically close to winter caves (Whitaker & Brack 2002), and six adult males were caught during summer netting. Rates of catch per net-night of effort in 1990 and 1998, and collectively in HNF, were much less than rates of catch (0.36 riparian, 0.12 upland, 0.22 total) in northern Indiana (Brack 1983).

Males wearing radio-transmitters roosted and were active in both riparian and upland habitats in HNF. Activity areas, including foraging habitat, encompassed wooded and open habitats and roads varying in size from forest trails to a divided four-lane interstate highway. Humphrey et al. (1977) reported members of a nursery colony foraged only in riparian habitat. However, Brack (1983) found no demonstrable difference in activities between riparian and upland habitats either in terms of foraging activities or in terms of the rate of catch. Some species of trees are more likely to provide roosts when live (in this study, shagbark hickory and white oak), while others are more likely to provide roosts when dead (pine, American elm, and northern red oak). The species of roost tree was indicative of the habitat, with oaks, hickories, and pines in uplands and American elm in riparian areas. Roost use in HNF was similar to use in Daniel Boone National Forest (DBNF), Kentucky (Gumbert 2001). Like HNF, only adult males were found in DBNF during summer. In DBNF, adult males roosted more frequently in pine in summer (24 of 41 roosts) and autumn than in spring, when more shagbark and mockernut (*C. tomentosa*) hickories and white oaks were used. Only 1 of 41 summer roosts in DBNF was in an American elm. In DBNF, no live trees were used as summer roosts; 40 of 41 summer roosts had < 10% usable bark; and 37 of 41 roosts had open (received direct sunlight from top and sides) to intermediate (limited overhead but direct sunlight on at least one side) canopy cover. Summer roosts in DBNF were 6.4–51.5 cm (\bar{x} = 28.3 cm), or about 10 cm smaller than in HNF. Of 23

adult males radio-tagged in DBNF in summer, 19 were found in 41 roost trees.

Although Indiana myotis were not common in summer surveys, they were a large percentage of bats in winter surveys because of clusters in one hibernaculum, Gypsy Bill Allen Cave. This cave was first surveyed in 2001 and contained 134 Indiana myotis, predominately in a single cluster. In 2003, 250 bats were found in three areas of the cave. This population of bats may have been hibernating in this cave undetected for many years, or use may have begun in recent years, as it has at several other Indiana caves (Brack et al. 2003). The area used in 2001 was warmer, and areas used in 2003 were colder than hibernacula containing the largest and increasing populations of Indiana myotis. Variability in use of locations and temperatures may be associated with new or re-colonized hibernacula. A single Indiana myotis was found in a low, perhaps flood-prone, passage of Bluff House Cave in 2002, but none were present in 2003. The presence of one bat one time probably represents a natural affinity of the species to sample new areas.

Hoary bat.—The hoary bat is a woodland species that makes up a small part of the summer bat fauna in HNF. Four hoary bats, including three reproductive females, were caught. In northern Indiana, Brack (1983) had a greater catch rate of hoary bats (0.08 riparian, 0.15 riparian, and 0.12 total). Whitaker et al. (2002) considered numbers of hoary bats in the state to be decreasing.

Gray myotis.—In Indiana the gray myotis, a federally-endangered species, is on the periphery of its range. While there is no evidence of a maternity colony in HNF, a single adult male was caught in the Forest. This individual, captured in Crawford County, and another adult male captured about 0.5 km from HNF in Perry County along Knob Creek (Whitaker & Gummer 2001), were likely vagrants from Kentucky or from the only known colony in Indiana, in Clark County (Brack et al. 1984; Whitaker et al. 2001). Males have also been seen in Wyandotte Cave in summer.

Evening bat.—The evening bat is listed as endangered by the State of Indiana. It currently occurs mostly in bottomlands of the Wabash River in southwestern Indiana, although there are also colonies in Hendricks, Bartholomew and Jennings counties. The sin-

gle adult male evening bat captured was not near any known colony, which are typically made up of females and young. It is likely males of this species, like many other species of bats, wander widely during summer.

Silver-haired bat.—The single silver-haired bat taken in HNF, a male caught in late May, was undoubtedly a spring migrant. The species is also present during autumn migration and is a woodland species. In northern Indiana, Brack (1983) had a similar rate of catch of silver-haired bats (0.02 upland and 0.01 total). Although this species typically is present in Indiana only as a migrant, Whitaker et al. (2002) considered their numbers to be increasing slightly during migration.

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LITERATURE CITED

- Brack, V., Jr. 1983. The nonhibernating ecology of bats in Indiana with emphasis on the endangered Indiana bat, *Myotis sodalis*. Ph.D. dissertation, Purdue University, West Lafayette, Indiana. 280 pp.
- Brack, V. Jr., S.A. Johnson & R.K. Dunlap. 2003. Wintering populations of bats in Indiana, with emphasis on the endangered Indiana bat (*Myotis sodalis*). Proceedings of the Indiana Academy of Science 112:61–74.
- Brack, V. Jr. & R.E. Mumford. 1984. The distribution of *Pipistrellus subflavus* and the limit of the Wisconsinan glaciation: An interface. American Midland Naturalist 112:397–401.
- Brack, V., Jr., R.E. Mumford & V.R. Holmes. 1984. The gray bat (*Myotis grisescens*) in Indiana. American Midland Naturalist 111:205.
- Brack, V., Jr., C.W. Stihler, R.J. Reynolds, C. Butchkoski & C.S. Hobson. 2002. Effect of climate and elevation on distribution and abundance in the midwestern United States. Pp. 21–B28, In The Indiana Bat: Biology and Management of an Endangered Species (A. Kurta & J. Kennedy, eds.). Bat Conservation International, Austin, Texas.
- Gumbert, M.W. 2001. Seasonal roost tree use by Indiana bats in the Somerset Ranger District of the Daniel Boone National Forest, Kentucky. M.S. thesis, Eastern Kentucky University, Kentucky. 136 pp.
- Humphrey, S.R., A.R. Richter & J.B. Cope. 1977. Summer habitat and ecology of the endangered Indiana bat, *Myotis sodalis*. Journal of Mammalogy 58:334–346.
- LaVal, R.K. & M.L. LaVal. 1980. Ecological studies and management of Missouri bats, with emphasis on cave-dwelling species. Missouri Department of Conservation Terrestrial Series 8:1–53.
- MacArthur, R.H. 1972. Geographical Ecology. Harper and Row, New York. 269 pp.
- Mumford, R.E. & J.O. Whitaker, Jr. 1982. Mammals of Indiana. Bloomington University Press, Indiana. 537 pp.
- Veilleux, J., J.O. Whitaker, Jr. & S. Veilleux. 2003. Tree roosting ecology of reproductive female eastern pipistrelles, *Pipistrellus subflavus*, in Indiana. Journal of Mammalogy 84:1068–1075.
- Whitaker, J.O., Jr. & V. Brack, Jr. 2002. *Myotis sodalis* in Indiana. Pp. 53–B59, In The Indiana Bat: Biology and Management of an Endangered Species (A. Kurta & J. Kennedy, eds.). Bat Conservation International, Austin, Texas.
- Whitaker, J.O., Jr., V. Brack, Jr. & J.B. Cope. 2002. Are bats in Indiana declining? Proceedings of the Indiana Academy of Science 111:95–106.
- Whitaker, J.O., Jr. & S.L. Gummer. 1992. Hibernation of the big brown bat, *Eptesicus fuscus*, in buildings. Journal of Mammalogy 73:312–316.
- Whitaker, J.O., Jr. & S.L. Gummer. 1993. The status of the evening bat, *Nycticeius humeralis*, in Indiana. Proceedings of the Indiana Academy of Science 102:283–291.
- Whitaker, J.O., Jr. & S.L. Gummer. 2000. Population structure and dynamics of big brown bats, *Eptesicus fuscus*, hibernating in buildings in Indiana. American Midland Naturalist 143:389–396.
- Whitaker, J.O., Jr. & S.L. Gummer. 2001. Bats of the Wabash and Ohio River basins of southwestern Indiana. Proceedings of the Indiana Academy of Science 110:126–140.
- Whitaker, J.O., Jr. & W.J. Hamilton, Jr. 1998. Mammals of the Eastern United States. Cornell University Press. Ithaca, New York. 583 pp.
- Whitaker, J.O., Jr., L. Pruitt & S. Pruitt. 2001. The gray bat, *Myotis grisescens*, in Indiana. Proceedings of the Indiana Academy of Science 110:114–122.
- Whitaker, J.O., Jr. & L.J. Rissler. 1992a. Winter activity of bats at a mine entrance in Vermillion County, Indiana. American Midland Naturalist 127:52–59.
- Whitaker, J.O., Jr. & L.J. Rissler. 1992b. Seasonal activity of bats at Copperhead Cave. Proceedings of the Indiana Academy of Science 101:127–134.

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