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ROOSTS OF INDIANA BATS (*MYOTIS SODALIS*) NEAR THE INDIANAPOLIS INTERNATIONAL AIRPORT (1997–2001)

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ABSTRACT. Long-term roosting ecology of the federally-endangered Indiana myotis (*Myotis sodalis*), in a rapidly-developing area immediately southwest of the Indianapolis International Airport was examined. A dead shagbark hickory, *Carya ovata*, in a woodlot 1 km S of Interstate Highway 70 was the most utilized roost tree throughout the study, from 1996 to the winter of 2001–02 when it fell. Bats arrived at this roost in April and regularly used it until October of most years, with young fledging in July. Based on consistent increases in the maximum number of bats seen exiting this roost during 1997–1999, this colony was growing. At least four other primary roosts, all cottonwoods (*Populus deltoides*), and 24 alternate roosts were used at this site. Movement patterns among and between these roosts indicate that all bats belong to one colony spread across a fairly large area.

The Indiana myotis (*Myotis sodalis*) is the most intensively studied of all tree-roosting bats, in terms of both the number of roosts that have been identified and the amount of published literature (Kurta 2005; Barclay & Kurta 2007). Despite protection of multiple high priority hibernacula and intense study of the summer needs of this bat, the species continues to decline; and the reason(s) for this decline remains poorly understood (Clawson 2005)

A typical primary maternity roost tree of this species consists of a fairly large tree (usually over 20 inches dbh) with sloughing bark that is open to the sun. Some of the initial observations of summer roosts by Indiana myotis suggest these bats make use of both primary and alternate roosts (Humphrey et al. 1977) with primary roosts receiving extensive use throughout summer. Later observations (Callahan et al. 1997) supported and further refined these observations. A maternity colony of Indiana myotis may include up to three primary roosts and many alternate roosts. Most of these previous studies often were concluded within two years, and particular colonies were studied (particularly by consultants) for only a few days or weeks. The presence of long-term data has led us to further refine the traditional definitions of primary and alternate roost as follows. A primary Class I roost was used regularly by a large number of bats over extended periods of time and usually over more than one year. A primary Class II roost was used sometimes by large numbers of bats, but over shorter periods. Traditionally, a secondary or alternate roost has been considered to be a tree used by small numbers of bats over short periods of time (Callahan et al. 1997). However, we also recognized two classes of alternate roosts. An alternate Class I roost contained a large proportion of the colony for a short period of time, whereas an alternate Class II roost was used by only a few (often one) individuals. Some trees that we recognized as alternate Class I roosts would have been considered primary roosts by some authors (Callahan et al. 1997; Gardner et al. 1996) examining them only over short periods of time. Because these trees are used for relatively short periods of time, we suspect that they are actually roosts that bats roosted in, but found unsatisfactory.

Most studies of the summer ecology of Indiana myotis have been conducted in forests or agricultural lands (Kurta 2005); and only one, a four-year study (Kurta et al. 2002), could be considered long-term. Given that the midwestern United States is undergoing extensive suburban development (Radeloff et al. 2005) one potential cause of decline is habitat loss due to urbanization. Unfortunately, no long term studies of this bat in rapidly-developing landscapes are available (Belwood 2002; Whitaker et al. 2004), and population demographics during summer are virtually unknown. Our purpose was to provide a case study of this bat in a rapidly-developing landscape at the southwest edge of Indianapolis, Indiana from 1997–1999, when we were supported by funding from the Indianapolis International Airport, and in 2000–2001 with limited monitoring.

Specifically, we sought to answer the following questions: 1) Where the bats were roosting, and how often they returned to the same roosts or roosting areas in subsequent years; 2) How much fluctuation there was in terms of numbers of bats present in known roosts, and how well fluctuations in numbers of bats within the roosts conformed to definitions of primary and secondary roosts proposed by Callahan et al. (1997) in Missouri; 3) How many colonies were present on the site, and how well this conformed to the fission/fusion model (Kurta et al. 2002) proposed for bat social colonies; 4) What was the annual pattern of variation in terms of numbers of bats using a primary roost, and how many young were produced; 5) How these data compared to those collected in more rural areas; and 6) If this colony was growing, decreasing, or stable during the study.

STUDY SITE AND HISTORICAL BACKGROUND

Indianapolis International Airport is in a highly-developed area southwest of Indianapolis, Indiana (Fig. 1). Mitigation relating to the extension of a runway in 1992 resulted in studies aimed at determining the habitat used by Indiana myotis in the surrounding area. Additional details about the mitigation effort, the overall bat community, and the site are available in Sparks et al. (1998) and Whitaker et al. (2004).

This colony is on the edge of Indianapolis in a rapidly-developing area. It is not known when this colony first occurred on the study site, but it was detected in 1994. Thus, this colony has persisted at least 14 years, located between four multi-lane divided highways and a major freight airport, while the surrounding area was developed into warehouses and subdivisions (Fig. 1). As such, this study provides a unique opportunity to explore the impacts of urbanization.

METHODS

We captured bats in 9 m multi-tier 50 denier mistnets with 38 mm mesh set at 10 permanent sites along the East Fork of White Lick Creek and within woodlots near known roosts (Sparks et al. 1998; Whitaker et al. 2004). Eighteen of the Indiana myotis captured were fitted with 0.49 g radio-transmitters (Holohil Systems, Ltd., Ontario, Canada, and Titley Electronics, New South Wales, Australia). These transmitters allowed us to track bats to their roost trees. We returned to these trees at dusk to count bats when they emerged. Emergence counts provided our main source of information about roosting and movement patterns of Indiana myotis. In addition to conducting such counts at trees while they were in use by radio-tagged bats, we also returned to these trees to conduct follow-up counts. In 1997 we completed 14 such counts on a tree in the primary woods used by Indiana bats during this period. We refer to this ~30 ha woodlot as Sodalis Woods (Fig. 1). The main tree was discovered in 1996 by earlier consultants and was likely also in use in 1994 when the consultants tracked bats to Sodalis Woods, but they were unable to obtain permission to enter the woodlot. Because this tree was the main roost for the bats, we conducted intensive emergence counts of this roost in 1998 (56 counts) and 1999 (60 counts) and as many counts as possible on other known roost trees. These emergence counts provided us with a minimum number of bats in the population throughout a given summer.

During emergence counts, observers would arrive 30 min before sunset to observe bats emerging. Counts would continue until no bats had been observed exiting the roost for at least 10 min. To help count the bats and to distinguish between bats returning to the roost and bats exiting, we often used a night vision scope (ITT F5000 or ITT Night Mariner 220 series night vision viewer [Roanoke, Virginia]), thermal imager (FLIR ThermaCam PM575, North Billerica, Massachusetts), binoculars, and a radio receiver (when radio-tagged bats were present).

RESULTS AND DISCUSSION

Fluctuation in numbers.—Callahan et al. (1997) in Missouri, Kurta and colleagues in Michigan (Foster & Kurta 1999; Kurta et al. 1993, 2002), and Gardner et al. (1991) in Illinois, showed that one or more primary trees may be used by Indiana myotis, but that alternate trees also are commonly used, usually by smaller numbers of bats (Kurta & Kennedy

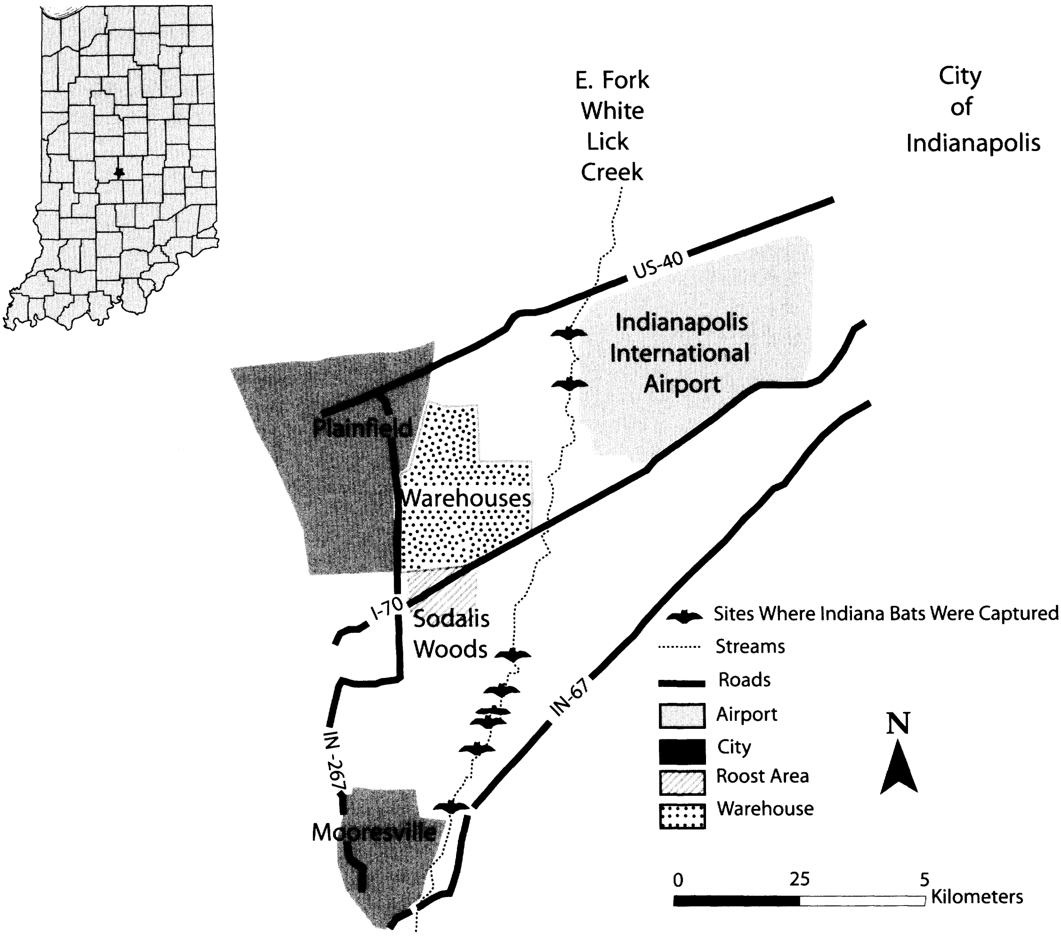

Figure 1.—Relationship of the study area to the Indianapolis International Airport. Artificial roost structures were placed within the area outlined with the four highways that surround (US Highway 40, Indiana Highway 67, and Indiana Highway 267) and bisect (Interstate Highway 70) the study area. The stippled area represents the developed area associated with Indianapolis and surrounding suburbs.

2002). During the present study, we detected use of 4 alternate roosts in 1997, 12 in 1998, 12 in 1999, and 2 in 2001. Four of these were used in at least two years.

Numbers of bats fluctuated widely within and between roosts (Fig. 2), even during counts made within days of each other. Most roosts were apparently used for only short periods. Some roosts, however, were consistently used for multiple days and even across multiple years.

Classification of roosts.—During this project we detected use of five primary roosts (Table 1) and 30 alternate roosts. The shagbark hickory (*Carya ovata*) in Sodalis Woods that was initially located by consultants in 1996 was the main tree used throughout the study by up to 146 bats at one time. This tree was used until it fell in winter of 2001–02, after which the behavior of the bats changed substantially (Sparks 2003). A large cottonwood (110.5 cm dbh), located 2.3 km south of the main shagbark, functioned as a second primary roost from its discovery in August of 1997 until the bark was blown off in June 1998. This roost was in continuous use from the time the bats returned from hibernation (by up to 64 bats) until it was blown over. Thus, we also recognize this tree as a primary Class I roost. Beginning in summer 2000, we began radio-tracking bats to a series of large, dead cottonwoods in Pioneer Park, in Mooresville, Indiana (6 km south of Sodalis Woods). We recognize these trees as primary Class II roosts because, although they were occasionally occupied by large numbers of bats (up to 36 bats during this study and 68 in 2002), all were also unused for most of each field season. Each of these roosts continued to be used by the bats after the current study concluded in 2001.

The question arose as to why the bats were using these large cottonwoods so far from the main roost in Sodalis Woods; and, to date, we have not developed a definitive answer. The cottonwoods had all the characteristics of excellent primary Class I roosts. All were large dead trees with sloughing bark and substantial solar exposure. We had thought that perhaps this colony was beginning to separate into two colonies, but even in summer 2005 we still detected some bats making trips between the two roosting areas. Another possibility was that these trees served as reserve trees that could be used in case of loss of the main tree. However, the bats did not move into these trees when the main tree fell in winter 2001–2002 but, instead, selected a variety of roosts in subsequent years. They eventually settled on another shagbark hickory tree near Sodalis Woods (Sparks 2003) and a series of bat-boxes along the East Fork of White Lick Creek (Ritzi et al. 2005; Whitaker et al. 2006). Another possibility was that the Mooresville site provided better access to an early spring foraging area (when these roosts receive the most extensive use), whereas foraging later in the summer was better near Sodalis Woods.

Emergence counts conducted on the primary roosts typically did not detect all of the bats that were known to be present at the site (i.e., the maximum previous count), and these were illustrated as "missing" bats in Fig. 2. We suspect that most of these missing bats were located in the other primary roost, although we also suspect many of these bats were occupying alternate roosts on those nights. In fact, the greatest challenge we faced while conducting emergence counts was ignoring bats that were emerging from other nearby trees–particularly in Sodalis Woods. Later research indicated that Sodalis Woods was also occupied by five other species of bats (Whitaker et al. 2004), but we suspect that many of these unrecorded emergences were Indiana myotis. Thus, in a woodlot dominated by shagbark and shellbark hickory (*Carya laciniosa*), and containing a Primary Class I Roost, such as Sodalis Woods, many or most suitable trees probably serve at times as alternate roosts.

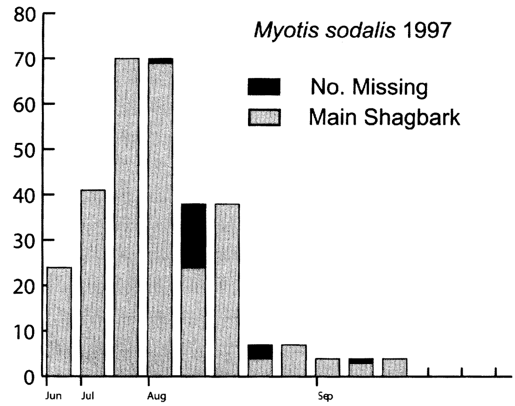

Figure 2.—1997. Numbers of bats counted as they emerged from the primary shagbark (gray) and number missing (black) in 1997. The numbers indicated as missing were known to be present at the site based on previous or later counts but were not among the bats from the trees counted on those specific dates, and were therefore presumed to be in alternate roosts or roosts not counted on those days. (No data are available from April through early June 1997.)

Re-use between seasons.—During this study, we also detected use of 30 alternate roosts. Four of these were occupied by 26–47 bats on only a single night and were not occupied again. A fifth roost was occupied by up to 8 bats on 4 occasions. We tentatively recognized these as alternate Class I roosts. The rest were used by small numbers of bats (1–10) and only four were occupied in two or more of the five years of this study. These are recognized as alternate Class II roosts. All but three alternate roosts were located in Sodalis Woods; and these three were located near the second primary Class I roost along the East Fork of White Lick Creek. Thus, alternate roosts at this site were typically located within 100 m of primary roosts. We were also certain that there were many alternate roosts that we did not detect.

1997: Few data were available on alternate roosts in 1997, since work began late (June) in that year. Four alternate roosts were used in that year, three shagbark hickories in the woods north of Sodalis Woods, plus a shake garland on a sycamore tree (*Platanus occidentalis*) beside the primary Class I roost in a cottonwood.

1998: Twelve alternate roost trees were used in 1998. Three of these were the same three

Table 1.—Information on primary roost trees used by Indiana myotis at the Indianapolis International Airport, 1997 through 1999. Three alternate roost trees (trees used by small numbers of bats and intermittently) were used in 1997, and the same three were also used in 1998 and 1999. Nine additional alternate roosts were used in 1998 and 1999, all new roosts in 1998 and 1999. See text for details on alternate roosts.

	DBH (cm)	Height (m)	
1997			
Primary Class I Roost Trees (trees used by large numbers of bats on a daily basis)			Alternate Roost Trees
Shagbark hickory; Sodalis Woods This tree was used throughout all three years.	59.3	17.8	Total 4 alternate roosts: 3 shagbark hickories in woods north of Sodalis Woods, plus a shake garland.
Cottonwood, 2.24 km SSE Sodalis Woods This tree was used in 1997 and through late June 1998, when it fell.	110.5	28.3	
1998			
Primary Class I Roost Trees			Alternate Roost Trees
Same two primary roosts, the main shagbark and the cottonwood, that had been used in 1997, the cottonwood until it fell in June, 1998.			Twelve alternate roosts: same 3 hickories as in 1997 DBH measuring 32.4, 39.6, and 64.8 cm. Nine other trees were:
Primary Class II Roost Trees (trees used by large numbers of bats, but intermittently)			shagbark hickories: 37.0, 29.6, 31.3
MV1 Cottonwood at Mooresville	78.5	19.5	shellbark hickories: 41.2, 33.2
MV2 Cottonwood at Mooresville	43.6	18	mockernut hickory: 36.6
MV3 Cottonwood at Mooresville	37.2	20.1	sugar maple: 9.6
			honey locust: 41.5
			white oak: 52.2
1999			
Primary Class I Roost Trees			Alternate Roost Trees
Same shagbark hickory was the single tree consistently used			Total 12 alternate trees: same 3 shagbarks as used in 1997, 1998. Nine other trees were:
			shagbark hickories: 64.8, 39.6, 34.0, 32.4, 29.7, 28.7, 28.5 (for 2 we had no measurements)
			American elm: 44.5
			slippery elm: 42.7

shagbark hickory trees in Sodalis Woods that had been used in 1997. The nine other trees were three shagbark hickories (*Carya ovata*), two shellbark hickories (*Carya laciniosa*),, one mockernut hickory (*Carya tomentosa*), one sugar maple (*Acer saccharum*), one honey locust (*Gleditsia triacanthos*), and one white oak (*Quercus alba*). The maple tree was very small (dbh = 9.6 cm) and used only by one male.

1999: There were again 12 alternate roost trees used in 1999. The same three shagbark hickory trees used in 1997 and 1998 were again used. One bat exited on 3 June from the first, one bat exited on 4 June and 1 August from the second, and three and five bats exited from the third alternate tree used in both 1997 and 1998. Fifteen counts were made on the other 9 trees, 7 shagbark hickories, an American elm, and a slippery elm.

Bats used alternate roosts throughout the summer season, April until October. Four pregnant females, five lactating females, two non-reproductive females, and seven juveniles (two females, five males) were tracked to alternate trees in 1998 and 1999. The number of bats occupying alternate roosts varied greatly, from just one bat up to 47 bats.

Number of colonies.—Although at least two primary roosts were present during most of this study, it appears that these roosts were occupied by one colony. Evidence was as follows: 1) Radio-tagged bats moved from the roosting area in Sodalis Woods to roosting areas along the East Fork of White Lick Creek in 1997, 1999, 2000 and 2001; 2) Following the loss of the cottonwood roost in a thunderstorm in June of 1998, the number of bats using the main roost in Sodalis Woods increased substantially, with two counts of over 100 in the next few days; 3) The number of bats using the two main roosts was negatively correlated (Spearman's $R = -0.764$, $P = 0.017$, $df = 8$), meaning that the bats were high in one tree and low in the other, once the number of bats peaked for the year in 1998. This suggested that the bats regularly were moving between the two trees; 4) Although individual bats moved between roosts, the number of bats in any single roost was highly variable as predicted by the fission/fusion model of bat sociality (Kurta et al. 2002); 5) Although individual bats frequently made use of alternate roosts, most (11 of 17) at least occasionally used a primary roost.

Seasonality of roost use.—Tracking started too late to determine bat arrival dates in 1997 (Fig. 2), but the last bats were detected leaving the primary roost on 10 September. In 1998, the first Indiana myotis was recorded in Sodalis Woods on 5 April (Fig. 3) when one bat emerged from the main tree. The first bat observed emerging from the second primary roost (the cottonwood) was on 11 April 1998 (Fig. 4). In 1999, bats were first observed on 19 April when 11 bats exited from the main roost in Sodalis Woods; the last three bats that year exited on 13 October. Sharp decreases in the number of bats using this roost were noted in late August (Figs. 3, 4) in all years, although bats continued to use the main roost well past 15 August, the end of the "window" used for locating maternity colonies of Indiana myotis. In 1997, there were still 38 bats in the roost on 18 August (54.2% of the largest population), and three to seven bats remained between 27 August and 10 September. No bats were observed during three emergence counts after 20 September. It appeared that the last bats left the tree in 1997 between 10–13 September. In 1998, bats were present in the main shagbark hickory throughout August, ranging from 42–118 individuals, except 25 August, when only one bat emerged, and 27 August, when none emerged. In September, fewer bats were present until 11 September (18–35 bats per night). Subsequent reductions occurred with no more than six bats on any night through 8 October, when the last bat was seen to emerge. In 1999, 124 bats were counted on 15 August, but bats then rapidly declined. On 19 August, 51% were still present, on 2 September (32%), on 5 September (11.3%), and on 30 September (2%), and 13 October (2%). No bats were seen after 13 October.

Population demographics.—Although bats routinely moved between roosts, there was a dramatic increase in the number of bats in early- to mid-July, representing the addition of volant juveniles. In 1997 a maximum of 41 bats emerged prior to volancy of young (2 July), whereas a maximum of 70 bats emerged after 30 July. In 1998, we counted 76 bats on 22 June, and a maximum of 139 bats following volancy of the young. In 1999, 104 bats were counted on 20 May, and 146 following volancy of the young. While these numbers cannot be considered exact, they do provide a relative measure of reproductive success of the colony in 1997–1999, especially since all females in a colony presumably become pregnant and produce a single young. These data suggested that approximately 71% (29/41), 83% (63/76), and 41% (42/104) of the bats in the main tree successfully fledged young in the years 1997 to 1999, respectively. Also, the maximum number of bats both before and after fledging increased in both years after 1997. Although we cannot totally exclude the possibility that the bats were becoming more concentrated in the main tree, the data suggested this colony was increasing from 1997 to 1999.

In addition to variation due to bat behavior, interactions with a pair of red-bellied woodpeckers, *Melanerpes carolinus*, living in the roost tree in Sodalis Woods in 1999 caused occasional disturbance (Sparks et al. 2003, 2005a). This may have been a threat as indicated by relatively low emergence counts on 25 and 27 May (31 bats), 2 June (0 bats), and 4 June (17 bats). Prior to this disturbance, as many as 104 bats were seen to emerge (20 May; Fig. 4). However, the number of bats emerging from this tree increased again after the woodpeckers left. By 11 June, the number of bats using the primary tree had reached 87, and 102 bats by 25 June.

Primary roosts: Four trees would have been recognized as primary roosts (used by 30 or

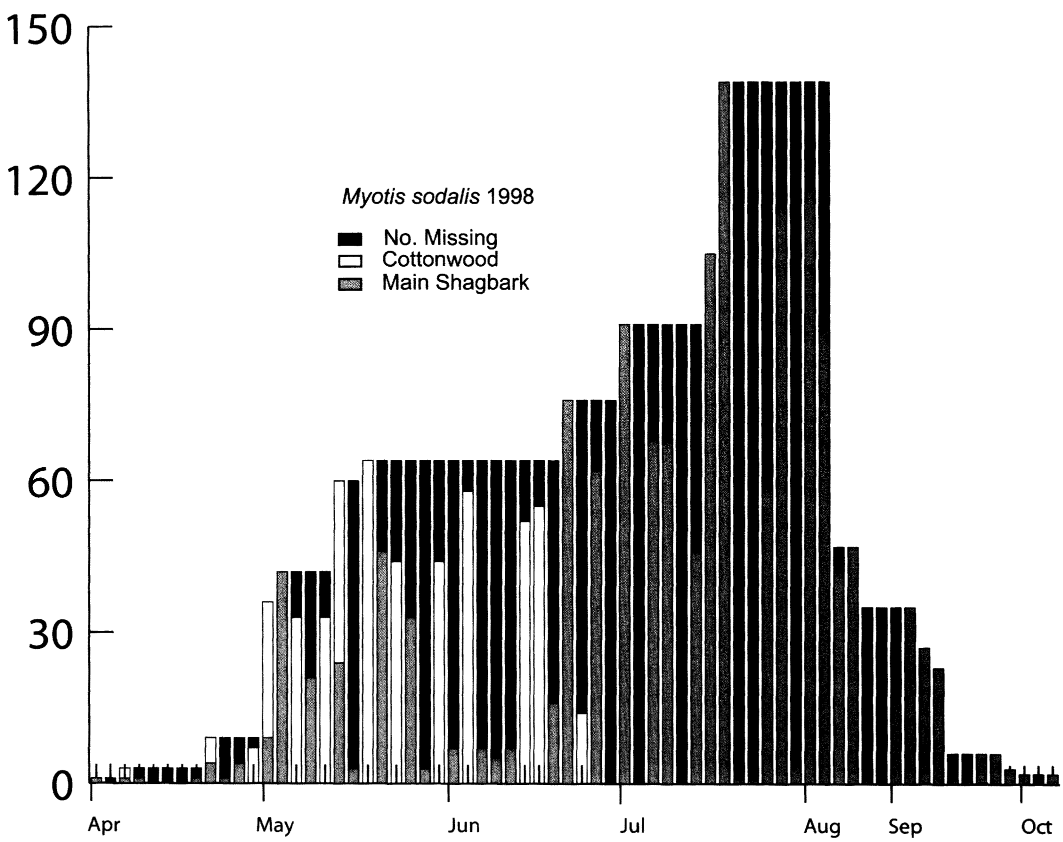

Figure 3.—1998. Numbers of bats counted as they emerged from the primary shagbark (gray), primary cottonwood (white) and number missing (black) in 1998. The numbers indicated as missing were known to be present at the site based on previous or later counts but were not among the bats from the trees counted on those specific dates, and were therefore presumed to be in alternate roosts or roosts not counted on those days. The cottonwood lost its bark in a storm in late June 1997.

more bats on two or more nights) by Callahan et al. (1997). However, we recognized two of these as primary Class I roosts, i.e., used on a daily basis. The other two we termed primary Class II roosts, as these were used on an intermittent basis.

The main roost tree throughout this study was the large dead shagbark hickory in Sodalis Woods. All other primary roosts through 2001 occurred along the East Fork of White Lick Creek south of Sodalis Woods, and all were large cottonwood trees. Besides the main roost, the bats used at least one primary roost along the East Fork of Lick Creek in every year except 1999, and these roosts all were less intensively used than the roost in Sodalis Woods.

In summary, two primary Class I and three primary Class II roosts were used at some time in the period from 1997–1999. The main tree was a shagbark hickory, while the other four trees were cottonwoods. Average dbh of these five trees was 65.8 cm, SD = 29.6 cm, range 37.2–110. Their average height was 20.7 m, SD = 4.3 m, range 17.8–28.3 m.

Alternate roosts: Alternate roosts, by definition, were used by few bats. Tree species used as alternate roosts (Table 1) were 15 shagbark hickories, 3 shellbark hickories, and 1 each of the following: sugar maple (*Acer saccharum*), mockernut hickory (*Carya tomentosa*), honey locust (*Gleditsia triacanthos*), slippery elm (*Ulmus rubra*), American elm (*Ulmus americana*), white oak (*Quercus alba*). Also, an artificial roost in an American sycamore was used. Primary roost trees were significantly larger than alternate trees in terms of diameter (65.8 cm, SD = 12.2, n = 5; as compared to

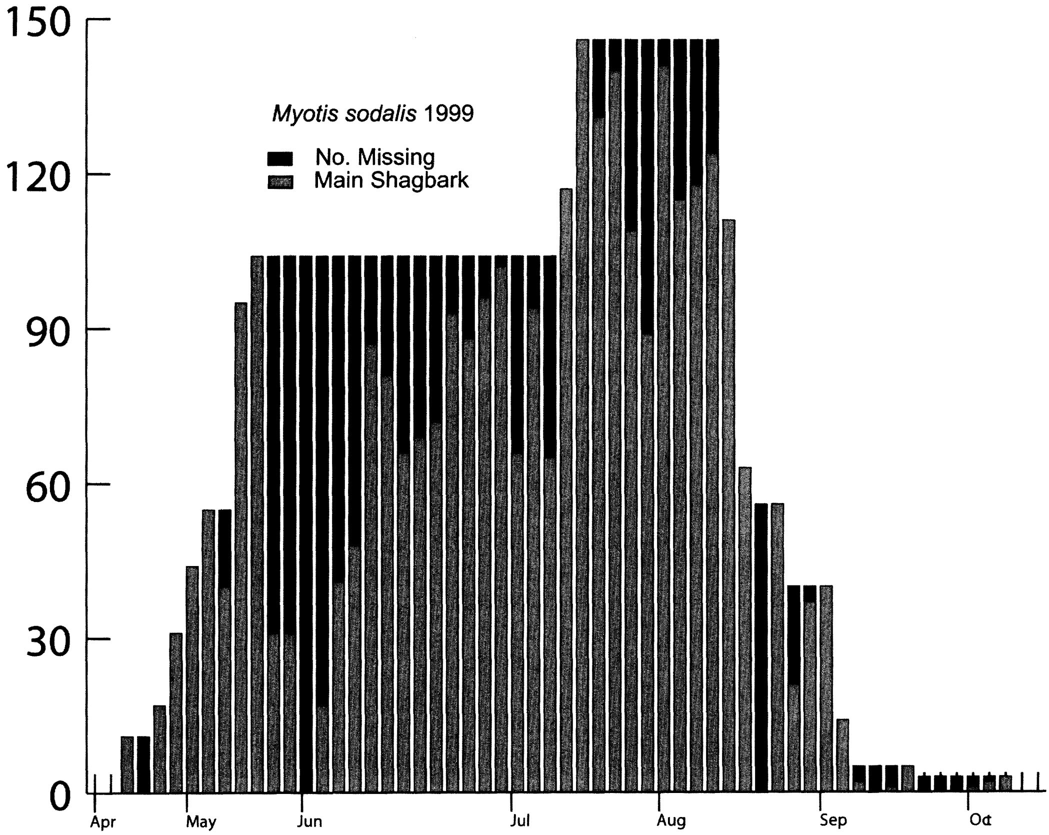

Figure 4.—1999. Numbers of bats counted as they emerged from the primary shagbark (gray) and number missing (black) in 1999. The numbers of bats indicated as missing were known to be present at the site on previous or later counts but were not among the bats from the trees counted on those specific dates, and were therefore presumed to be in alternate roosts or roosts not counted on those days.

37.8, SD = 12.2, $n = 21$ respectively) and height in meters (47.0, SD = 22.3, $n = 5$; as compared to 21.7, SD = 7.8, $n = 22$). Both differences were significant ($t = 3.42$, 24 *df*; $P < 0.002$; and 4.47, 25 *df*, $P < 0.002$ respectively).

The use of different primary and alternate roosts elicits the question of how bats find each other at different roosts. It is clear from mist-netting that they do not fly in groups. However, they are obviously communicating in some way. We suspected that some of the "foraging" behavior we have detected at dawn (Sparks et al. 2005b) was bats flying through woodlots containing roosts. We suggest that these bats may be attracted to roost trees by vocalizations emanating from these trees.

Similarity to other regions.—Behavior of the bats in this study in a developed area was similar to that observed in previous studies (Britzke et al. 2003; Callahan et al. 1997; Gardner et al. 1991; Humphrey et al. 1977; Kurta et al. 1993). Over the three years, Indiana myotis at Indianapolis Airport used at least five primary (two Primary Class I, three primary Class II) and 24 secondary or alternate roosts. Primary roosts were large, dead trees with substantial solar exposure. Some roosts were used on a daily basis, whereas others were used much less frequently. Secondary roosts included trees that closely resembled primary roosts in forest interiors, with more canopy cover, thus allowing less sunlight in. Indiana myotis were loyal to a fairly small area (Sodalis Woods), but they made occasional switches between roosts in Sodalis Woods and Pioneer Park (a distance of 6 km). Bats arrived in mid-April, numbers stabilized by mid-May, juveniles began flying in early July, numbers in the main roost declined precipitously after 15 August, and the last bats left by mid-October.

Callahan et al. (1997) argued, and we agree, that both primary and alternate potential roost trees were beneficial to Indiana myotis. There is clearly much roost-switching in this species. The primary roost trees are the most important roosts, but alternate roost trees may be used to help ameliorate climatic conditions, to serve as roosts away from the primary roosts, and perhaps to allow separation of females and young. The characteristics of alternate roost trees are not as stringent as those of primary trees. They can have less sun, less sloughing bark and can be smaller (pers. obs.). However, it would seem likely or desirable that some alternate trees approach the characteristics of primary trees, and thus could serve as primary trees in case of loss of a primary tree. Destruction of roost trees is undoubtedly part of a natural process. Thus we agree with Callahan et al. (1997) that a continuous supply of roost trees is critical to the persistence of this species. Management practices that would benefit Indiana bats would be to favor the creation and retention of habitat that provides a continuous supply of good primary roost trees. The bats use more than one primary tree, and move as necessary.

The bat colony under study used mostly one main roost tree for at least six years from 1996 (and perhaps from 1994) until the tree fell in the winter of 2001–2002. However, numerous other roost trees have been used and the bats have been able to survive well, as indicated by their increasing adult populations, with minima of 41, 76, and 104 individuals in 1997, 1998, and 1999, respectively.

Some conservation efforts that were beneficial to this bat in this rapidly-developing area near the city of Indianapolis were the purchase and setting aside of existing woodlots, development of wetlands, and planting of new forests. The management plan calls for all these habitats to provide long-term roosting and foraging habitat. Already these conservation efforts have provided valuable foraging habitat for the bats (Sparks et al. 2005b). These same conservation efforts have here benefited other species of bats, and also other vertebrates as well (Walters et al. 2007; Duchamp et al. 2004; Foster et al. 2004; Ritzi et al. 2005; Sparks et al. 2005c; Whitaker et al. 2004).

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