SUMMER HABITAT USE AND HOME-RANGE ANALYSIS OF THE ENDANGERED INDIANA BAT

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The Indiana bat (*Myotis sodalis*) was officially listed as an endangered species in 1967 by the U.S. Fish and Wildlife Service. Despite this protective status, populations have continued to decline throughout much of the eastern United States (Clawson 2002). Even with reasonable protection in place at the remaining major Indiana bat hibernacula, the roosting and foraging ecology of the Indiana bat continues to be impacted throughout its range by habitat alteration caused by stream channelization, conversion of forests to agricultural land, surface-mining and urban development, and prey reduction caused by landscape-wide insecticide use (Conlin 1976, Garner and Gardner 1992, O'Shea and Clark 2002, Schmidt et al. 2002). Although winter hibernacula protection is better understood, obtaining knowledge of summer habitat requirements of Indiana bats has proved difficult, hindering effective conservation and protection of the species. Of the 2 largest data gaps, summer roosting and foraging ecology, radiotelemetry studies to document roost habitats have been the most successful in yielding quantifiable information across much of the species' range (Kurta et al. 1996, Menzel et al. 2001, Butchkoski and Hassinger 2002, Gumbert et al. 2002, Ford et al. 2002, Kurta et al. 2002, Carter 2003, Owen et al. 2003). However, because of the difficulty associated with monitoring the home range and habitat use of a small, highly vagile animal such as the Indiana bat, few studies have attempted to quantify the home range and habitat use of this species. Much of what is known about the foraging habitat use of Indiana bats has been gleaned from anecdotal accounts or observations from the periphery of the species' range rather than its core distribution (Murray and Kurta 2004). A more detailed understanding of summer foraging habitat for both female and male Indiana bats in midwestern, agriculture-dominated landscapes typical of most of the species' summer range is vital for effective Indiana bat conservation and management.

Although several researchers have performed descriptive and cursory examinations of the foraging habits of Indiana bats (Humphrey et al. 1977, Brack 1983, Hobson and Holland 1995), none have quantitatively analyzed foraging habitat selection or summer home-range size. Because the core of the Indiana bat summer range occurs in largely agricultural landscapes where forests are highly fragmented and reduced, ongoing forest management practices as well as other land use or land conversion activities can have negative impacts on the foraging and roosting habitat of this endangered species. Without a better understanding of the foraging habitat selection of Indiana bats in these landscapes, it is impossible to make informed predictions about the potential impact of current and future land use practices on this species.

Indiana bats have been found foraging along forested riparian areas in Indiana, Missouri, and Kentucky, (Humphrey et al. 1977, LaVal and LaVal 1980, Kessler et al. 1981, Brack 1983) and in upland woodland patches in Indiana and Missouri (Mumford and Cope 1958, Easterla and Watkins 1969, LaVal et al. 1977, LaVal and LaVal 1980, Brack 1983). However, the use and importance of these habitat types in agriculture-dominated midwestern landscapes remain unclear. We radiotagged male and female Indiana bats in Illinois and examined their movements and habitat

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use during the summer months. Our objectives were to determine the home-range size of male and female Indiana bats in a mixed agricultural, wooded midwestern landscape and to quantify habitat preference of male and female Indiana bats by comparing the habitats used to those present in the landscape. Based on previous research on other bat species including Rafinesque's big-eared bat (*Corynorhinus rafinesquii*), northern yellow bat (*Lasiurus intermedius*), Seminole bat (*Lasiurus seminolus*), eastern red bat (*Lasiurus borealis*), and eastern pipistrelle (*Pipistrellus subflavus*), we hypothesized that males would have larger home ranges than the females (Krishon et al. 1997, Menzel et al. 2000). Additionally, we hypothesized that the home ranges of both sexes would encompass a greater proportion of forested and riparian habitats than expected based on each habitat's availability in the study area.

Study Area

The fieldwork for our study was conducted from May through August in 1987 and 1988 on the Fishhook Creek Watershed in Pike and Adams counties, Illinois, USA. The area is located in the Till Plains section of the Central Lowland physiographic province (Fenneman 1938). Several Priority III hibernacula are located within Pike and Adams counties and Priority I and II hibernacula are located nearby in adjacent counties in Illinois and across the Mississippi River in Missouri (Gardner and Cook 2002). During fieldwork, land use consisted of a mix of agricultural land (43%), forested areas (33%), grasslands (23%), riparian areas (0.8%) and roads (0.2%). From a landscape perspective, the area was heavily fragmented with medium-sized woodlots and agricultural fields. Forest patches were connected through wooded corridors; however, these corridors were narrow and fragmented. Agricultural areas were dominated by corn (*Zea mays*), soybean (*Glycine max*), wheat (*Triticum aestivum*) row-crop production, hay meadows, and livestock pastures. Upland forest consisted of Central Hardwood associations including shagbark hickory (*Carya ovata*), slippery elm (*Ulmus rubra*), white ash (*Fraxinus americanus*), black locust (*Robinia pseudoacacia*), white oak (*Quercus alba*), shingle oak (*Q. imbricaria*), northern red oak (*Q. rubra*), and swamp white oak (*Q. bicolor*). Riparian areas around streams, ponds, and bottomland swamps were dominated by silver maple (*Acer saccharinum*), box elder (*A. negundo*), cottonwood (*Populus deltoides*), slippery elm, black walnut (*Juglans nigra*), and American sycamore (*Plantanus occidentalis*).

Methods

We captured Indiana bats using double-stacked mist nets (38 mm mesh) ranging in length from 5.5 to 18.3 m. We placed the nets adjacent to roosts, over-stream corridors and other flyways, and beneath forest canopies throughout the study area (Gardner et al. 1989). For each Indiana bat we captured, we recorded sex, age, reproductive condition, mass, and length of forearm. We attached 0.72-g radiotransmitters (BD2A, Holohil Systems Ltd., Carp, Ontario, Canada) to male and female Indiana bats using Skin Bond® brand surgical cement (Pfizer Hospital Products Group, Inc., Largo, Florida, USA). The transmitter to body mass ratio achieved was similar to that achieved in other radiotelemetry habitat studies conducted on bat species including the Indiana bat (Kurta and Murray 2002, Kurta et al. 2002, Rommé et al. 2002, Winklemann et al. 2003). Transmitters were attached to the mid-sagittal dorsal surface midway between the scapulae and the tail.

We conducted fixed-station tracking on Indiana bats to determine their home-range size and habitat use. We used model TRX-1000S tracking receivers (Wildlife Materials Inc., Carbondale, Illinois, USA) and 172-3FB 3-element Yagi antennas (AF Antronics, Inc., White Heath, Illinois, USA) to located tagged bats. Under optimal conditions, line-of-site signals were received from distances up to 3 km over rolling, partially forested terrain; however, a receiving range of 1 km was more common. We monitored signals with a null/peak antenna configuration from each of 3 stations positioned in a triangular fashion surrounding the foraging area of the bats. Bearings were taken simultaneously every 5 minutes, synchronized, and verified via radio communication between stations. Indiana bats were tracked until shedding of the transmitter package (approx 7 nights). In addition to nightly telemetry to determine foraging habits, day-roost trees of these bats were located and analyzed in a separate study (Gardner et al. 1991, Carter et al. 2002).

We entered the coordinates of the fixed telemetry stations along with all compass bearings taken from each station into the computer program LOCATE to obtain the Universal Transverse Mercator (UTM) coordinates of each foraging location. To calculate the home range of each bat, we plotted location coordinates in the Animal Movement Analysis Extension (Hooge and Eichenlaub

1997) in ArcView® (Environmental Systems Research Institute, Redlands, California, USA). We calculated home ranges only for individuals for which we had collected >30 foraging locations (Seaman 1999). We used the adaptive kernel method (ADK) for determining each bat's home range, and each home range was based on the 95% confidence interval to exclude outliers.

We created a habitat map of the study site from a 1991 LANDSAT 4 thematic mapper image provided by the Illinois Department of Natural Resources (IDNR; Champaign, Illinois, USA). The image was georeferenced onto a UTM grid and was further processed by clustering using PCI, Inc. software's ISODATA algorithm. In addition, we included ancillary data from the Illinois Wetlands Inventory data, Natural Resources Conservation Service county crop compliance data, National Aerial Photography Program 1988 color infrared and black and white photographs, and digital vector roads, streams, and railroads to further classify land cover classes. A comparison between the LANDSAT satellite imagery used and Digital Orthophoto Quadrangle files from 1987 and 1988 indicated no significant change in the land cover of the study area during the intervening years. Five classification categories were identified: agriculture, grassland, forest, roads, and riparian areas.

We used a Wilcoxon test to determine whether the home-range size differed between study years and sex and used MANOVA to determine whether habitat use differed between study years and sex. We used the Euclidean distance-based analysis (DA) method to conduct our habitat-use analysis (Conner and Plowman 2001). The DA approach was chosen because of its ability to incorporate edge and fragmented habitats into the habitat use analysis (Conner et al. 2002). Additionally, the use of DA reduces the effect of telemetry and Type 1 errors commonly associated with other habitat analysis methods such as compositional analysis (Bingham and Brennan 2004). Because of the fragmented nature of the study area and the errors commonly associated with tracking volant species, we felt this habitat analysis method was most appropriate for this study. We defined the lateral extent of the study area as the distance between the center of all bat home ranges and the foraging point located the greatest distance from the center of the study area. Within this area, we used ArcView® to calculate the Euclidean distances between the bat locations and the nearest representative of each habitat type. We paired each foraging location with a randomly located point within the study area, and we calculated a Euclidean distance from each foraging and random location to each habitat type in the study area. Based on these Euclidean distances, we created a vector of ratios using the distances of foraging and random locations. We used a MANOVA to determine whether the ratios differed from 1.0, indicating that use of the habitat by the Indiana bats we tracked was not random. We used a paired *t*-test to determine which habitat types were not used in proportion to their abundance in the study area. Last, we used a series of pairwise *t*-tests to evaluate the relative rankings (or order of preference) of each habitat type in the study area. We performed all statistical analyses using SAS statistical software (SAS Institute 1990) and statistical significance was determined at $P \leq 0.05$.

Results

We tracked and determined the home ranges of 7 females and 4 male Indiana bats from May to August 1987–1988. We found no significant difference in home-range size between male and female bats ($z = -1.42$, $P = 0.156$) or between study years ($z = 0.72$, $P = 0.4183$); thus, data for males and females were pooled prior to analysis. The mean number of telemetry locations used to calculated each bat's home range was 66 (range = 33–149). The mean home-range size for the Indiana bats we tracked was 144.7 ha ($n = 11$, SE = 18.4; females = 161.1 ha; males = 115.9 ha; Table 1). Based on telemetry error testing, our telemetry bearing error was ± 2° and our error polygon was 0.12 ha.

Table 1. Summer home-range sizes of male and female Indiana bats (*Myotis sodalis*) in Pike and Adams counties, Illinois, USA, May–Aug 1987 and 1988.

Bat	Sex	Reproductive status	No. locations	Home-range size ADK[a] (ha)
083	Female	Lactating	74	179.1
263	Female	Lactating	96	88.9
342	Female	Post-lactating	149	205.5
363	Female	Lactating	52	258.8
444	Female	Lactating	40	162.8
484	Female	Lactating	63	171.4
501	Female	No data	33	61.4
Mean	Female		72.4	161.1
182	Male	Non-scrotal	31	130.0
244	Male	Non-scrotal	37	60.7
383	Male	Non-scrotal	82	117.3
462	Male	Non-scrotal	72	155.6
Mean	Male		55.5	115.9
Mean	All		66.3	144.7

[a] ADK = 95% adaptive kernal.

Table 2. Ranking matrix of Indiana bat habitat use in Illinois, USA, 1987–1988. Numbers are *t*-statistics (*P*-values) associated with pairwise comparisons of corrected distances to habitat.

Agriculture	Grassland	Forest	Road	Water
Agriculture	2.51 (0.03)	4.26 (0.002)	5.58 (0.001)	3.62 (0.005)
Grassland	−2.51 (0.03)	4.18 (0.002)	5.74 (0.001)	2.63 (0.03)
Forest	−4.26 (0.002)	−4.18 (0.002)	1.50 (0.17)	−1.19 (0.26)
Road	−5.58 (0.001)	−5.74 (0.001)	−1.50 (0.17)	−1.96 (0.08)
Water	−3.62 (0.005)	−2.63 (0.03)	−1.19 (0.26)	1.96 (0.08)

The average distance between an Indiana bat foraging location and the nearest agricultural land, grassland, forest, road, and riparian habitat was 72.8 m, 39.5 m, 30.7 m, 539.6 m, and 626.5 m, respectively. The average distance between randomly selected locations and the nearest agricultural land, grassland, forest, road, and riparian habitat was 48.4 m, 35.8 m, 83.4 m, 1960.1 m, and 1039.8 m, respectively. A comparison of these distances indicates that the foraging locations were not sex specific and that bats we tracked did not forage randomly across the study area ($F_{5,6}$ = 77.67, *P* < 0.0001). For example, the bats we tracked foraged significantly closer to forested habitats (t_{10} = −9.68, *P* < 0.0001), roads (t_{10} = −22.06, *P* < 0.0001), and riparian habitats (t_{10} = −2.36, *P* = 0.0398) than expected based on the relative availability of these habitat types in the study area. Additionally, the bats we tracked foraged significantly further from agricultural lands (t_{10} = 2.38, *P* = 0.0389) than would be expected if the bats foraged randomly across the study area. Finally, a comparison of the distance between foraging and randomly selected locations and grasslands indicates that the bats we tracked neither selected nor avoided this habitat type (t_{10} = 0.71, *P* = 0.4922).

Pairwise comparisons of the distances between each habitat type and Indiana bat locations indicates that the bats we tracked foraged significantly closer to forests, grasslands, roads, and riparian areas than agricultural lands (Table 2). They also foraged significantly closer to forests, roads, and riparian habitats than grasslands (Table 2). A ranking of the habitats based on each habitat's use shows that, proportionately, roads were used the most followed by, in order of preference, forests, riparian areas, agricultural lands, and grassland habitats.

DISCUSSION

Rommé et al. (2002) recently conducted a telemetry study on 6 Indiana bats in the Ozark Plateau physiographical province of Missouri. The males they tracked had larger home ranges (255 ha) than the male Indiana bats we tracked in Illinois (116 ha). Conversely, the females they tracked had smaller home ranges (113 ha) than the females we tracked (161 ha). Difference in the home-range estimator used, the time the study was conducted, or the study location may have resulted in the differences in the home-range sizes between the studies. Rommé et al. (2002) used a minimum convex polygon estimation of home range, whereas we used the adaptive kernel estimator. Moreover, their estimate of the home-range size of female Indiana bats was based on only 2 individuals and a total of 27 telemetry locations, perhaps explaining the discrepancy from a sample size standpoint (Seaman 1999). Our study was conduced during the summer maternity season, whereas Rommé's study was conducted in the spring and fall. Lastly, the study site in Missouri probably is somewhat more xeric than our study site in Illinois. Bat activity commonly is correlated with insect abundance, and bats often forage in riparian areas where insect densities are high (Grindal 1996). Murray and Kurta (2002) found that aquatic insects comprise a large portion of the diets of Indiana bats in the northern part of the species' range. The abundance of riparian and bottomland hardwood habitats in our study area may have resulted in the concentration of insects in specific areas across the landscape, permitting the Indiana bats we tracked to meet their foraging requirements without having to travel great distances across the study area.

Humphrey et al. (1977) used fluorescent bands in Missouri to compare relative levels of Indiana bat foraging activity among vegetation community types. The tagged Indiana bats foraged exclusively in forested riparian habitats; no tagged bats were observed foraging in upland forests, pastures, cornfields, upland hedgerows, or along treeless creek banks. Brack (1983) also used chemoluminescent tags in Missouri to compare the proportion of Indiana bat sightings in several forested and open habitats to that expected based on the availability of each habitat in the study area. Although most of the foraging he observed occurred in upland forests, his statistical analyses comparing habitat availability and use indicated that Indiana bats did not preferentially forage in, or avoid, riparian habitats. However, Brack did find that forested areas were selected over open areas (e.g., pastures, old fields) by foraging Indiana bats. Our results quantitatively confirm the results of previous studies indicating that Indiana-bat foraging activity is commonly concentrated in forested areas rather than over grassland or agricultural areas.

Recently, Murray and Kurta (2004) radio-tracked Indiana bats in Michigan to determine patterns of nocturnal activity. Although they did not quantitatively identify foraging habitat, they did report that the Indiana bats they tracked spent a considerable amount of time foraging over forested and riparian areas despite the fact that the study area consisted primarily of agricultural land (Murray and Kurta 2004). Our findings support those of Murray and Kurta (2004) and highlight the importance of forested habitat to Indiana bats in agricultural landscapes.

Our results also indicate the potential importance of linear landscape features such as riparian corridors and roads to Indiana bats. The Indiana bats we tracked used these corridors preferentially over other landscapes such as agricultural land and grasslands. It is possible that these bats are using linear landscape features as foraging habitat, as well as traveling corridors between their roosts and foraging areas. The relatively high use of roads by the bats we tracked suggests that these linear landscape features may create foraging habitat on a smaller scale by creating vertical edges in riparian habitats. Corridors are beneficial to bats because they reduce the energetic demands associated with flight, provide needed landscape orientation clues, and commonly contain more accessible prey (Verboom and Huitema 1997, Murray and Kurta 2004). Additionally, forested habitats along corridors commonly serve as windrows that reduce wind speed and thereby increase insect abundance (Lewis 1970). The Indiana bats we tracked may have selectively foraged over waterways and along road corridors because of the low energy costs associated with flying in these areas of relatively little structural complexity and because of the abundance of insects commonly associated with these linear landscape features. Finally, we observed that, although these corridors provide important vertical structure for foraging bats, an increase in these corridors would further fragment the landscape.

Management Implications.—Our data illustrates the importance of forested habitats and riparian areas for Indiana bats. Because of the fragmented nature of Indiana bat habitat in the Midwest, natural resource managers and landowners in this region should contemplate how land use changes will impact the connectivity of forested riparian areas. Forest management activities in central Illinois, while still just a temporal disturbance rather than conversion, may not be well tolerated by Indiana bats as forested habitats in the region are relatively rare. Although the home range of the Indiana bat is relatively small, the scarcity of large contiguous forest patches in the Midwest makes the management and conservation of most remaining stands important.

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