FORAGING BEHAVIOR AND HABITAT USE OF RED BATS IN MIXED MESOPHYTIC FORESTS OF THE CUMBERLAND PLATEAU, KENTUCKY

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Abstract—Although the red bat (*Lasiurus borealis*) is a common forest-dwelling bat, limited information is available on the foraging requirements and habitat use of this species. We radiotracked red bats on the Cumberland Plateau in eastern Kentucky during July and August 1996, and May, July and August 1997. We estimated size of foraging areas and evaluated use of habitats available within foraging areas. We placed transmitters on 10 females and nine males. Size of foraging areas ranged from 113 to 850 hectares for females, and 134 to 925 hectares for males; however, most radiotagged males moved considerable distances among nights and changed foraging areas frequently. Size of foraging areas and commuting distance varied temporally, with bats exhibiting slightly larger foraging areas and longer commuting distances in late summer compared to early summer. The maximum distance bats were recorded foraging away from the day roost ranged from 1.2 to 5.5 kilometers for females, and 1.4 to 7.4 kilometers for males. Red bats were located in non-forested habitats and aquatic habitats at proportions slightly higher than the availability of these habitats. The red bat appears to be a generalist species that can tolerate a range of habitat conditions, foraging temporally and spatially over many habitats.

INTRODUCTION

Although bats represent a large percentage of the mammals in deciduous forests (Barbour and Davis 1969) and account for 25 percent of all mammal species (Altringham 1996), the importance of bats as part of forest ecosystems in North America only recently has received much attention (Barclay and Brigham 1996). Studies on the ecology of bats in forests in western North America have been completed (Brigham and others 1997, Grindal and Brigham 1998, Kalcounis and Brigham 1998, Ormsbee and McComb 1998, Rabe and others 1998), but data for only a few species of bats in eastern North America exist (Krusic and others 1996). Most studies emphasize threatened and endangered species, particularly bats that roost in caves during all or part of the year (e.g., Adam and others 1994, Humphrey and others 1977, Tuttle 1979).

Despite the general longevity (Paradiso and Greenhall 1967) and early sexual maturity (Tuttle and Stevenson 1982) of insectivorous bats in North America, most species are monestrous and raise only one young per year (Hill and Smith 1984). An exception to this general rule are the tree-dwelling bats of the genus *Lasiurus* that have litters of usually 3-4 young (Barbour and Davis 1969, Constantine 1966, Mumford 1973). The alteration of significant amounts of forest habitat could impact populations of tree-dwelling bats to where bats presumed to be common, such as the red bat (*Lasiurus borealis*), become imperiled. Red bats are known to roost and forage in habitats such as open fields or urban areas (Constantine 1966, Mumford 1973); however, research has not addressed foraging requirements of red bats in areas where large, contiguous tracts of forest exist. The objectives of this study were to determine the location, size, and habitat of foraging areas used by red bats.

METHODS

Description of Study Areas

Research took place in the Cumberland Plateau physiographic province in eastern Kentucky. The region covers ca. 28,500 square kilometers consisting of rugged, forested terrain, locally interspersed with sandstone cliffs (McGrain 1983). Research was conducted in the northeastern portion of the Cumberland province in Carter and Elliott counties (NCP), and in the southeastern corner of the province in Breathitt, Knott, and Perry counties (SCP). Forests in both areas are classified as mixed mesophytic forest (Braun 1950). Research sites represent mature, second-growth forest that largely was undisturbed by silvicultural activities and contained mature stands of timber (i.e., an average d.b.h. ≥ 25.4 centimeters; Personal communication. 1996. Paul Kalisz, Professor of Silviculture, University of Kentucky, Lexington, KY 40546-0073).

In NCP large tracts of unbroken mature, second-growth forest, 400 to 3,200 meters wide and 8 to 20 kilometers long, were present along tributaries that run into the Little Sandy River or Grayson Lake. Grayson Wildlife Management Area, adjacent to Grayson Lake, consisted of 4,190 hectares and supported a large contiguous tract of mature, second-growth forest. Upland areas of fragmented forest, agricultural lands, pastures, and residential areas surrounded the forested-tributaries and Grayson Wildlife Management Area. Dominant forest vegetation in the area consisted of yellow-poplar (*Liriodendron tulipifera*), black walnut (*Juglans nigra*), and white oak (*Quercus alba*) on the north and east slopes (Weisenberger and others 1965). Black oak (*Q. velutina*) scarlet oak (*Q. coccinea*), and hickories (*Carya* spp.) dominated the south and west slopes, and chestnut oak (*Q. prinus*), scarlet oak, and patches of shortleaf (*Pinus echinata*) and pitch (*P. rigida*) pine were common on the upper slopes and ridges

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(Weisenberger and others 1965). Mesic and riparian vegetation of the lower slopes and creek bottoms was dominated by American beech (*Fagus grandifolia*), eastern hemlock (*Tsuga canadensis*), American sycamore (*Platanus occidentalis*), sweet birch (*Betula lenta*), and thickets of rhododendron (*Rhododendron maximum*).

Robinson Forest, located in the southeastern portion of the Cumberland Plateau physiographic province (SCP), is a 5,984-hectare tract of mature, second-growth forest 70 to 80 years old, with occasional wildlife clearings 1 to 2 hectares in size (Overstreet 1984). The area surrounding Robinson Forest was almost entirely surface-mined land; thus, Robinson Forest, served as an island of forest enclosed within a disturbed landscape. Dominant tree species included yellow-poplar, scarlet oak, white oak, black oak, American beech, chestnut oak, northern red oak (*Quercus rubra*), mockernut hickory (*Carya tomentosa*), eastern hemlock, American sycamore, and pitch pine (Overstreet 1984). Upland and ridge tops were dominated by oaks, hickories, and pines. Mesic and riparian vegetation consisted primarily of American beech, American sycamore, eastern hemlock, and white oak.

Capture and Handling Procedures

Mist nets, 5.5 or 9.1 meters wide, were placed across streams, trails, road-rut ponds, and small upland ponds to capture red bats. Bats were removed from the net, their age, sex and reproductive condition was determined, and they were weighed to the nearest 0.5 gram. Age was determined based on the time of year and the closure of the cartilaginous, epiphyseal growth plates in the finger bones (Anthony 1988).

Radiotransmitters (Type LB-2, 172-173 megahertz, Holohil Syst., Ontario, Canada) weighing 0.51 gram, with whip antennae 17.5 centimeters in length, were placed on 19 red bats (10 females and nine males). Radiotransmitters were attached using surgical cement between the scapulae on the upper back of the bat. A small section of hair was clipped between the scapulae to ensure proper bonding between the transmitter and the skin, and to lengthen the period that the transmiter remained on the bat. Each bat was held with the transmitter in place for ca. 5 minutes until the cement hardened before being released. Radiotagged bats were monitored continuously for 30 minutes following release to insure that each bat was able to fly properly and to identify any complications.

Radiotelemetry Procedures

Red bats were tracked in the NCP in July and August in 1996 and 1997, and in the SCP in May and August 1997. Telemetry stations were established at various high points in close proximity, i.e., 400 to 1,000 meters, to diurnal roost sites. Field personnel, equipped with a TRX 1000s receiver (Wildlife Materials, Inc., Carbondale, IL), a 3-element yagi antenna, and a compass, maintained contact using two-way radios. Once field personnel located a signal, azimuths were obtained simultaneously from stations at 2- to 3-minute intervals until either the bat perched in a night roost or the signal was lost. Azimuths were taken simultaneously from two or three stations, depending on the location of the bat and the movement of personnel to alternate stations to improve signal reception. Azimuths were plotted immediately at a base station on laminated 7.5-minute topographic maps to determine the location of a bat.

Data Analyses

A minimum of 40 locational crosses was used to calculate a foraging area estimate of a bat, as size of foraging areas of red bats was not found to increase beyond this sample size (Hutchinson 1998). The Calhome Software package (Kie and others 1996) was used to analyze spatial resolution on bat foraging locations, with estimates of foraging area size calculated using the adaptive kernel method. We used the adaptive kernel method because it is a nonparametric technique suitable for smaller sample sizes, does not require the assumption of normality, and is robust to changes in spatial resolution (Hansteen and others 1997). The adaptive kernel method calculates the size of a foraging area based on the intensities of locational crosses within areas, and is less biased by outliers than other existing methods (Worton 1989).

Habitat use and availability were determined by placing foraging area polygons and locational crosses over 7.5-minute topographic maps. Habitats were grouped into the following categories: forested habitat, non-forested habitat, such as clearings, agricultural land and human development, and aquatic habitat, including streams, ponds and lakes. The percentage of each habitat available and the number of radiolocations in each habitat was determined within the foraging area of each red bat for which $\geq$ 40 locational crosses were obtained.

Statistical summaries are based on the mean and standard error of the mean. All statistical tests were made using the Mann-Whitney U test (Hollander and Wolfe 1973).

RESULTS

The mean body mass of radiotagged adults was 12.9 $\pm$ 0.59 (SE) grams, while juveniles averaged 9.83 $\pm$ 0.60 (SE) grams (table 1). Body mass of adult females (14.1 $\pm$ 0.68 (SE) grams) was significantly greater ($U = 2.0$; $P = 0.006$) than for adult males (10.9 $\pm$ 0.40 (SE) grams). Three radiotagged females were pregnant, and two other adult females were in various stages of lactation. Female #606 roosted with two non-volant young, and female #745 roosted with two volant young. The post-lactating female (#745) was observed on several occasions leaving the roost shortly after her young emerged. Four males had descended testes, and the remaining bats showed no sign of reproductive activity.

No radiotagged adult red bats appeared to exhibit difficulty with flight after release. Commonly, radiotagged bats flew a short distance (ca. 50 to 100 meters) from the processing station to roost, and remained for 5 to 20 minutes. The bats probably were adjusting to the handling process and the added burden of the transmitter. After the initial adjustment period, the bats exhibited normal foraging habits and often foraged until we left the study area for the night, usually around 0100 hours. Twelve bats were radiotracked for a

Table 1—Sex, age, body mass, reproductive status, and tracking success of radiotagged red bats

Bat no.	Sex	Age	Mass	Status	Date of attachment	No. locations
			g			
389	F	A	14.5	Not active	7/09/97	120
430	F	A	13.5	Not active	7/21/97	46
432	M	A	11.0	Testes	7/25/97	59
451	M	J	11.0	Not active	8/05/97	0
504	F	A	15.0	Not active	8/11/97	24
521	M	A	11.0	Not active	8/11/97	0
546	F	A	11.0	Not active	8/12/97	74
575	F	A	11.5	Not active	8/12/97	54
606	F	A	14.5	Lactating	7/11/96	123
622[a]	M	J	9.5	Not active	7/24/96	0
645[a]	M	J	9.0	Not active	7/24/96	0
622[a]	M	A	12.5	Testes	7/30/96	0
645[a]	M	A	10.5	Testes	8/06/96	49
745	F	A	12.5	Post-lactating	8/09/96	40
845	M	A	11.0	Testes	8/09/96	0
883	M	A	9.5	Not active	5/20/97	41
944	F	A	14.0	Pregnant	5/20/97	66
963	F	A	16.5	Pregnant	5/20/97	53
984	F	A	18.0	Pregnant	5/20/97	46

[a] Indicates transmitter used on > 1 red bat.

sufficient period (Mean = 7.75 nights) to obtain an estimate of foraging area size.

Eighty-two percent of the azimuths resulted in locational crosses. Adult females, particularly those that were pregnant, lactating or post-lactating, were easier to monitor than adult males and often used the same foraging area for five to 12 nights (table 2). If a bat remained in the area, we usually observed little variation in the location of crosses obtained after the first three to four nights. Female bats that were not reproductively active exhibited foraging patterns more typical of adult males. All red bats were difficult to monitor in August.

The shape of foraging areas typically was bivariate and there was substantial overlap in the foraging areas (fig. 1). The foraging areas of bats contained their diurnal roost sites in all but one instance (#645) and most foraging areas included a permanent water source. Two bats (#606, #645) had foraging areas that were transected by secondary or major roadways and the foraging areas of all bats contained either forested trails or seldom used gravel or paved roads. Bats #645 and #430 each had two distinct foraging areas, separated by distances of 4 kilometers and ca. 75 meters, respectively.

The overall size of foraging areas of red bats, pooling females and males, was 334 ± 82.1 (SE) hectares (table 2). No difference ($U = 11.0$; $P = 0.29$) was observed in the mean size of foraging areas for bats in the NCP and the SCP. Males (Mean = 450 ± 242 (SE) hectares) used a foraging area almost 1.5 x larger than females (Mean = 295 ± 82.1 (SE) hectares), but this difference was not significant ($U = 9.0$; $P = 0.46$).

Reproductively active females had a mean foraging area size of 176 ± 28.0 (SE) hectares compared with a mean foraging area size for non-reproductive females of 444 ± 161 (SE) hectares, but the difference was not significant ($U = 5.0$; $P = 0.20$). During late summer, foraging areas of females appeared to increase (table 2). Although females remained in the proximity of their diurnal roost sites in late summer, they occasionally made forays out of the range of receivers. These females, all non-reproductive, usually returned within 45 minutes.

The maximum distance that bats were recorded foraging away from the day roost ranged from 1.2 to 5.5 kilometers for females, and 1.4 to 7.4 kilometers for males (table 2). Bats traveled somewhat further to foraging sites in the NCP than the SCP. When the distance traveled by red bats was examined temporally, bats monitored in late summer (August) were detected an average of 5.02 kilometers from the roost, whereas remaining bats traveled an average of 1.55 kilometers from the roost.

The foraging area polygons of red bats consisted of 87.2 percent forested habitat, 11.8 percent non-forested areas,

Table 2—Estimates of foraging area size and maximum distances traveled from day roosts of radiotagged red bats[a]

Bat no.	Study area	Days monitored	Foraging area	Maximum distance
			Ha	*Km*
389	NCP	12	193	1.4
430	NCP	2	179	1.3
432	NCP	4	291	2.7
606	NCP	12	262	1.7
645	NCP	8	925	7.4
745	NCP	7	120	5.5
546	SCP	6	554	3.3
575	SCP	9	850	3.9
883	SCP	9	134	1.4
944	SCP	10	116	1.2
963	SCP	6	113	1.2
984	SCP	8	192	1.5

[a] Includes only bats for which ≥ 40 locational crosses were obtained.

and 1.0 percent aquatic habitat (table 3). The bats were recorded foraging over forested habitat 78.3 percent of the time, non-forested areas 16.0 percent of the time, and aquatic habitat 5.7 percent of the time. In the NCP where the landscape was more fragmented, 76.8 percent of the foraging area of red bats was forested and bats spent 68.6 percent of their foraging time over those habitats. The total foraging area of red bats in the SCP was 97.5 percent forested habitats and the bats used these areas 88.0 percent of the time. Aquatic habitats accounted for ≤ 1 percent of the total habitat within all foraging areas of red bats, yet accounted for 5.0 percent and 6.5 percent of the foraging locations of bats in the NCP and SCP, respectively.

DISCUSSION

The characteristics of the landscape appeared to dictate the habitats that red bats used as foraging habitat. Although forested habitat predominated in both study areas, red bats also used other habitats such as grazing lands, agricultural fields, cemeteries, street lights and other human residential areas, especially in the more fragmented NCP. These data are consistent with those obtained for red bats in other locations where this species was frequently detected foraging in non-forested habitat (Hickey and Fenton 1990; Hickey and others 1996; McCracken and others 1997).

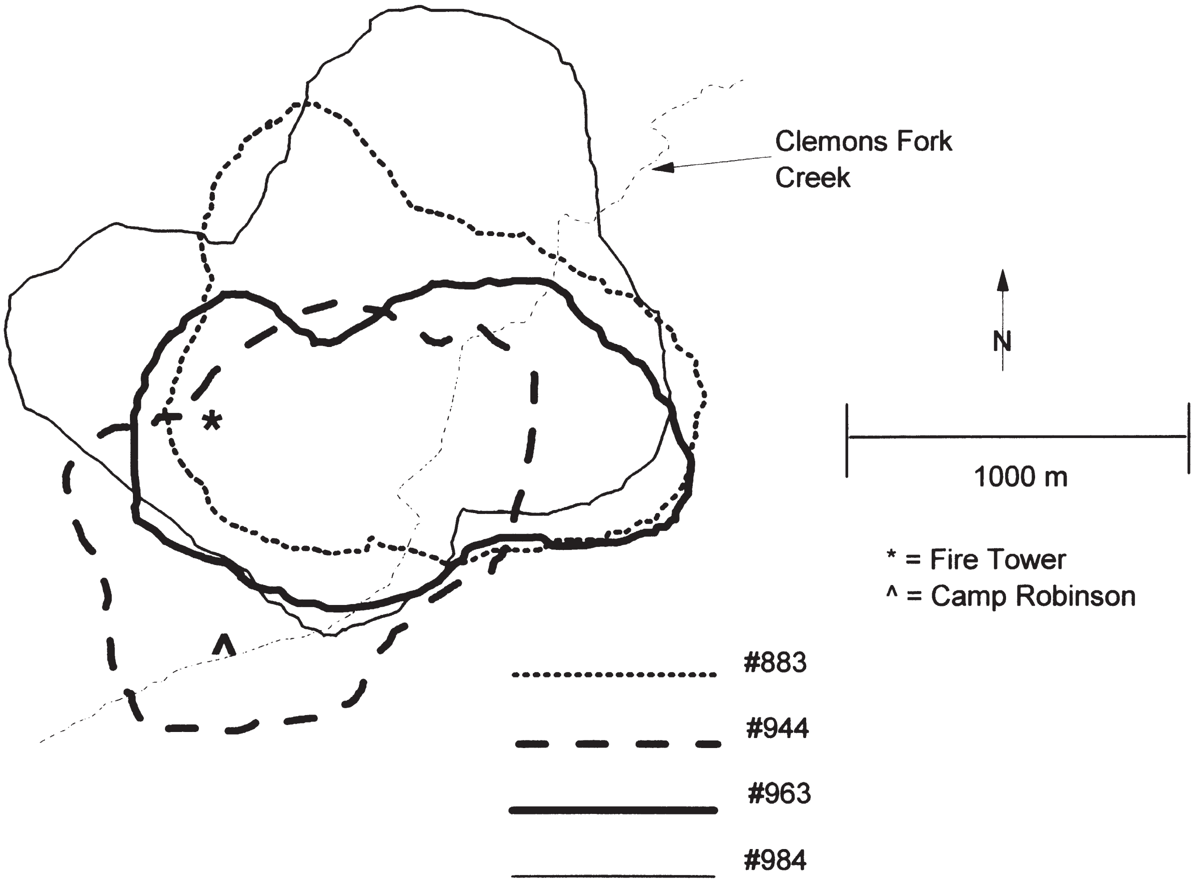

Figure 1—Foraging area polygons for four radiotagged red bats showing overlap in use of available habitat.

Table 3—Comparison of habitat available within foraging area polygons to the percentage of locational crosses by habitat (in parentheses) of radiotagged red bats in eastern Kentucky[a]

Bat no.	Study area	Forested habitat	Non-forested habitat	Aquatic[b] habitat
		- - - - - - - -	*Percent*	- - - - - - - -
389	NCP	99.0 (95.8)	0.0 (1.7)	1.0 (2.5)
430	NCP	79.0 (56.5)	20.0 (36.9)	1.0 (6.6)
432	NCP	90.0 (67.8)	9.0 (30.5)	1.0 (1.7)
606	NCP	64.0 (57.7)	35.0 (36.6)	1.0 (5.7)
645	NCP	76.0 (71.4)	23.0 (20.4)	1.0 (8.2)
745	NCP	53.0 (62.5)	46.0 (32.5)	1.0 (5.0)
546	SCP	98.0 (92.0)	1.0 (4.0)	1.0 (4.0)
575	SCP	98.0 (87.0)	1.0 (3.7)	1.0 (9.3)
883	SCP	98.0 (92.7)	1.0 (4.9)	1.0 (2.4)
944	SCP	95.0 (75.8)	4.0 (16.7)	1.0 (7.5)
963	SCP	98.0 (86.8)	1.0 (1.9)	1.0 (11.3)
984	SCP	98.0 (93.5)	1.0 (2.2)	1.0 (4.3)

[a] Includes only bats for which ≥ 40 locational crosses were obtained.
[b] Availability of water in foraging area estimated to be ≤ 1.0 percent for all red bats monitored.

Because red bats selectively foraged over water at proportions greater than the availability of this habitat in the landscape, a source of permanent water in the vicinity of roosting sites of red bats apparently is important. However, in the NCP where large bodies of water were present, i.e., Grayson Lake and the Little Sandy River, red bats were seldom detected foraging over these sites. The majority of locational crosses of red bats over water occurred while the bats were foraging over small streams during the first 30 to 45 minutes after emergence. Mumford and Whitaker (1982) reported that red bats needed bodies of water for drinking and observed this species foraging over small pools of water ca. 1.2 x 1.8 meters in size and as shallow as 2.5 centimeters in depth. A small permanent source of water transected the foraging areas of all but two of the red bats monitored.

Despite their use of aquatic and non-forested habitats, red bats foraged in forested habitat more often than the other habitats available, but used forests at proportions less than their availability in the landscape. This was especially true for bats in the SCP where large disturbed habitats in the form of reclaimed strip mines and numerous upland ponds were nearby, but were never used as foraging areas. Instead, red bats remained in contiguous forest almost 90 percent of the time. Barclay (1984) observed similar patterns for red bats in Manitoba. He found that red bats used forested ridges 75 percent of the time they were foraging and spent much less time foraging in the other habitats.

We observed substantially larger foraging areas of red bats than previously reported (Hickey and Fenton 1990; McCracken and others 1997). In these studies, red bats centered their foraging activity around street lights and, in one study, averaged 127 minutes/night foraging around lights (Hickey and Fenton 1990). The echolocation calls of red bats foraging around street lights may be homed in on by other red bats in search of prey (Hickey and Fenton 1990). Although more than one red bat was seen occasionally foraging around street lights, we never observed two radiotagged bats using street lights at the same time despite substantial overlap in the foraging areas of red bats monitored simultaneously (fig. 1). The red bats monitored in the Cumberland Plateau physiographic region of eastern Kentucky did not exploit the prey densities around street lights in rural areas to the extent hypothesized by Furlonger and others (1987).

By recording azimuths every 2 to 3 minutes, the possibility exists that our data are affected by autocorrelation (White and Garrott 1990). Autocorrelation leads to a biased underestimate of foraging area size (Hansteen and others 1997, White and Garrott 1990). Extending the length of time between azimuths will correct for autocorrelation, but will also lead to a reduction in sample size (Hansteen and others 1997). Given the length of time that the transmitters were likely to remain active (ca. 1 to 2 weeks), we felt that sample size was a more important consideration in our study. Further, our estimates of foraging area size of red bats were larger than any reported in the literature (Hickey and Fenton 1990, McCracken and others 1997); therefore, it is unlikely that autocorrelation, if present, altered the conclusions drawn from this study.

The maximum distance red bats foraged away from their roosting sites was slightly greater for bats in the fragmented landscape of the NCP than for bats inhabiting the contiguous forests of the SCP. These distances increased in late summer, likely coinciding with the breakup of family units as suggested by Constantine (1966). Kunz (1982) proposed that roost lability, especially among tree-roosting species of bats, results in decreased commuting costs to foraging areas; however, the distances that red bats were recorded traveling from roosting sites to feed were comparable in length to those recorded for cliff-roosting bats, i.e., *Corynorhinus* species, on the Cumberland Plateau of eastern Kentucky (Adam and others 1994, Hurst 1997). Based on Kunz (1982), we anticipated shorter commuting distances for red bats than were observed for cliff-roosting species, because of a higher availability of potential roosting sites for red bats. Because red bats traveled long distances to feed and often used large foraging areas, roost lability probably was not a factor influencing commuting cost or foraging area size in the red bats that we radiotracked. Instead, we propose that commuting cost and foraging area size in red bats were a function of the seasonal cycle and the reproductive status of individual bats. The location of foraging areas ultimately may be determined by the presence of preferred diurnal roosting sites.

Because all bats in which ≥ 40 locational crosses were obtained met the 5 percent load-carrying rule for transmitter mass (Aldridge and Brigham 1988), we believe that these data accurately depict the foraging behavior of red bats. All radiotagged red bats exhibited normal foraging patterns within 20 minutes after release, with the exception of two juvenile males in July 1996. We found adult males to be much more difficult to track than adult females, with increased movements for bats radiotagged after 24 July in both years. Saugey and others [In Press] reported similar problems in radiotracking male red bats back to roosting sites in Arkansas, referring to the roosting pattern of males as "vagabond."

CONCLUSIONS

Although there is considerable plasticity in the selection and use of foraging habitat by red bats, the extensive use of forests by this species suggests that large blocks of contiguous forest provide suitable habitat. Shorter commuting distances for red bats in the less fragmented SCP and the complete absence of radiotagged bats in the heavily disturbed habitat (i.e., surface-mined lands) nearby, indicate that some deforested areas and habitat fragments may provide less than optimal habitat conditions for this species. Studies comparing the survivorship and fecundity of red bats inhabiting forested and fragmented landscapes, including agricultural and surface-mined lands, are warranted.

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