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THE INDIANA MYOTIS (*MYOTIS SODALIS*) ON AN ANTHROPOGENIC LANDSCAPE: NEWPORT CHEMICAL DEPOT, VERMILLION COUNTY, INDIANA

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ABSTRACT. Indiana myotis (*Myotis sodalis*) caught on Newport Chemical Depot, Vermillion County, Indiana used four primary and two alternate roosts, all within 6.3 km of one another, supporting the hypothesis of a fission-fusion social system. Roosting with larger numbers of individuals may be advantageous when thermoregulatory demands are high, while roosting with fewer individuals may help reduce parasitism and place individuals closer to foraging areas. Roosts and capture sites were scattered across a landscape dominated by agriculture and development, requiring that bats cross open lands and roads. One roost was on the edge of a 0.7 ha woodlot, adjacent to a four-lane divided highway. Movement across open spaces among habitat patches may readily occur because the species is adapted to a natural interspersion of open and wooded habitats. Loss or conservation of small or isolated wooded tracts within the core range may harm or benefit the species, and this effect may be proportionally greater than in portions of the range where wooded lands are plentiful.

Keywords: Anthropogenic, habitat, Indiana myotis, maternity roosts, *Myotis sodalis*, Newport Chemical Depot, radiotelemetry

The range of the Indiana myotis (*Myotis sodalis*) includes much of the eastern United States. The eastern portion of the range has more woodlands, larger woodland tracts, and less fragmentation, but fewer Indiana myotis than the western portion (Brack et al. 2002). Despite smaller wooded tracts, fragmented by agriculture and development, the Indiana myotis is more common in the core summer range of northern Missouri, southern Iowa, Illinois, northern Indiana, southern Michigan, and southwestern Ohio. Within the core range, only 24% of the land area in counties with records of reproductive Indiana myotis is forested (Gardner & Cook 2002). In the core range, reproductive individuals and maternity colonies have been found in small upland woodlots, many of which were grazed (cows, sheep, and pigs) and repeatedly high-graded for lumber, and in narrow riparian strips (USFWS 1999). Nevertheless, most studies of the Indiana myotis have focused on natural aspects of the habitats and ignored anthropogenic aspects of the landscape and habitat, and the implications that use of these areas has for management and conservation of the species. An exception is the studies at the Indianapolis airport (Sparks et al. 2005; Whitaker et al. 2004).

Kurta et al. (2002) showed that the Indiana myotis exhibits a social organization similar to the fission-fusion groups of many primates. Group size in primates is often limited by scarcity of food and availability of safe sleeping quarters; hamadryas baboons (*Papio hamadryas*) break into small groups to forage but congregate by hundreds on a few cliffs at night, while patas monkeys (*Erythrocebus patas*) disperse to sleep individually in trees relatively inaccessible to predators (Kummer 1979). Sussman (1979) cautioned that even among primates there is no simple relationship between social structure and phylogeny or ecology, so the fission-fusion social structure is best explained by the animals taking advantage of both group and independent living. For the Indiana myotis, the advantage of a maternity colony may be conservation of energy for thermoregulation; there may be a limited availability of thermally suitable roosts with adequate solar exposure (Carter & Feldhamer 2005; Humphrey et al. 1977; Kurta et al. 2002), and thermoregulatory demands of individuals may be less when in a group than

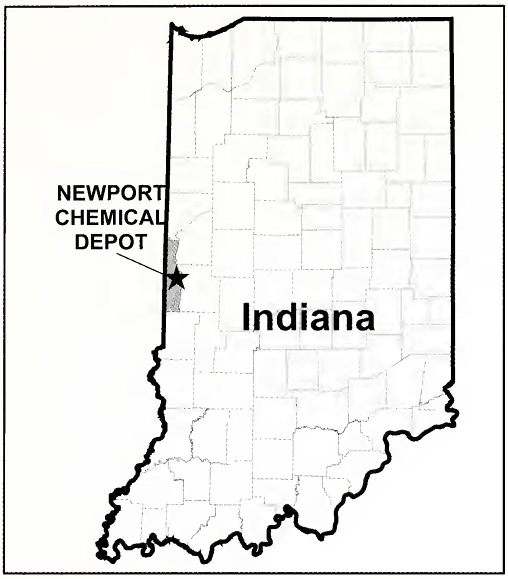

Figure 1.—Location of the Newport Chemical Depot in Vermillion County, Indiana.

when roosting singly (Tuttle 1975). In contrast, living in groups may increase risk of predation (Sparks et al. 2003), large colonies may be more susceptible to parasite infestations (Krutzsch 1955), and more bats are at risk when roost trees fall over. Typically, foraging for a dispersed or patchy resource, such as non-swarming insects, is by individuals or small groups; and use of roosts with fewer bats may place individuals closer to foraging areas.

The purpose of this study was to examine capture and roost sites of the Indiana myotis associated with Newport Chemical Depot, Vermillion County, Indiana, a landscape dominated by agriculture and development. Use of the area is examined in light of the fission-fusion theory of social organization and in terms of conservation of the species.

METHODS

Study areas.—This study was completed on Newport Chemical Depot, formerly the Newport Army Ammunition Plant, in Vermillion County, Indiana (Fig. 1), approximately 3 km southwest of the city of Newport and about 112 km west of Indianapolis. Newport Chemical Depot covers approximately 2873 ha, of which 770 ha are forested. Parts of the study extended outside the borders of Newport Chemical Depot. The study area is located at the interface of two natural regions: the Grand Prairie Section of the Grand Prairie Natural Region and the Entrenched Valley Section of the Central Till Plain Natural Region (Homoya et al. 1985). The Grand Prairie Section is characterized by dark, fertile, loamy soils, and as the name implies, included a great variety of natural prairie communities before European settlement. The Entrenched Valley Section, as the name implies, is identified by deeply entrenched valleys along major drainages. The Wabash River is the dominate drainage in this area. Except in specialized cliff and ravine communities, the hardwood forest communities are essentially the same as in most of the Tipton Till Plain Section, also a part of the Central Till Plain Natural Region. Upland forests, bottomland forests, and flatwoods are the major natural communities, although prairies, gravel-hill prairies, fens, marshes, savannas, cliffs, and seep springs are also present. The boundary between the two natural sections is not abrupt, but rather is a mosaic of prairie (typically converted to agriculture, although Newport Chemical Depot has 91 ha of restored prairie) and oak timber lands.

Bat captures and radiotelemetry.—Bats were captured with mist nets between 15 May and 15 August in 1987 (1 net night and 1 bat trap night), 1994 (12 sites; 12 net nights), 1997 (4 sites; 12 net nights), 1998 (10 sites; 18 net nights), and 2003 (4 sites; 18 net nights). The two areas where bats were caught in 1997 were netted in 1998, and all areas netted in 2003 were the same as those netted in 1997. Netting was completed with nets 6–20 m long and 2–6 m high. Netting was initiated at dusk and continued until between midnight and 0200 h.

Bats were removed from the net and identified to species. Mass, sex, age, right forearm length, and reproductive condition were recorded. In 1997, radiotransmitters were attached to two pregnant female Indiana myotis; and in 2003 two lactating females and a juvenile were fitted with transmitters (Holohil Systems, Ltd., Ontario, Canada and Titley Electronics, Pty., Ltd., Ballina, Australia). Transmitters weighed approximately 0.43 g and were attached dorsally between the scapulae using a non-toxic surgical adhesive (Skin-Bond® cement; Smith and Nephew, Inc., manufacturer). Bats were released at the point of capture. Bats with transmitters were tracked to day roosts using Wildlife Materials Inc. (Carbondale, Illinois) model series TRX 1000 and 2000 receivers for 1–5 days following transmitter attachment. Roost tree locations, species, dbh, condition (live or dead), and amount of exfoliating bark were recorded. Each roost tree was watched at dusk 1–5 nights to count the number of bats exiting the roost. Roost emergence counts were completed in summer 1998 at the two roost trees found in 1997. Roosts used by multiple bats and/or on several visits were classified as primary roosts, while roosts used by a single bat were considered alternate roosts.

Net sites and roost trees were located with hand-held GPS units (Gamin model 12) during studies in 2003, but during prior studies sites were located by placing them on USGS 7.5 minute topographic maps while in the field. Roost height was considered as the level at which bats emerged for their evening exodus, and was visually estimated. Canopy closure at the roost was also estimated visually.

Habitat characterization.—To complete an analysis at the landscape scale, net sites where Indiana myotis were caught and roost locations were placed on 1998 3.75 minute Digital Orthophoto quarter quadrangle aerial photography obtained from the USGS. The 1998 photography was compared to versions of USGS mapping used during earlier years of the study to ensure consistency. Aerial photographs were placed in ArcView™ geographic information system software. Habitat within 1.6 and 4 km of each primary and alternate maternity tree was characterized to 1 of 5 habitat types, based on the Anderson et al. (1967) land cover classification system: agriculture (including grasslands), developed, forested, scrub-shrub, and water. The 4 km radius was used because it is frequently applied during regulatory concerns for the species and represents a distance equal to or greater than the average of most documented movements. The 1.6 km radius was used for comparison and was a distance sometimes used for regulatory issues in the past. Areas of each habitat type were tabulated using GIS.

RESULTS

No Indiana myotis were caught in 1987 or 1994, 4 (3 females and 1 male) were caught in 1997; 4 in 1998 (2 females and 2 males); and 3 in 2003 (2 lactating females and a juvenile).

Capture and roost sites.—Indiana myotis were captured at three sites: 2 bats at both Sites II and III in 1997, 3 bats at Site I and 1 bat at Site III in 1998, and 2 bats at Site II and 1 bat at Site III in 2003 (Fig. 2). Distances among capture sites were 3.1–5.9 km (Table 1). In 1997, Indiana myotis were radio-tracked to two primary roosts, #213 and #380 (Fig. 2), monitored in 1997 and 1998. In 2003 Indiana myotis were tracked to two primary (#407C and #708) and two alternate roosts (#407A and #407B; Fig. 2). Roost #708 was in the same woodlot and near roost tree #380, but that roost could not be precisely relocated in 2003. Distances among primary roosts were 2.8–5.5 km, while distances among all roosts were <0.1–5.5 km (Table 1). Distances among all capture sites and all roosts were <0.1–6.3 km ($\bar{X}$ = 3.2; *SD* = 2.7).

All roosts were behind exfoliating bark; all primary roost trees were dead and the two alternate roost trees were living (Table 2). Roost #213, a sugar maple (*Acer saccharum*), had been girdled in 1993 for timber stand improvement. Canopy closure over primary roosts (0–15%) was less than over alternate roosts (45–90%). Primary roost trees were larger ($\bar{X}$ = 53.3 dbh; *SD* = 31.2) than alternate roost trees (30 and 35 cm dbh).

Primary roost trees housed 9–50 bats during the period 1 June–25 July. In 1997, the number of bats in two roosts increased from 33 on 28 June, probably shortly before parturition, to 50 on 31 July when young are volant, although some adult females may have roosted at alternate locations by this later date. Similarly, the number of bats in roost #380 increased from 7 to 13 during the period 23 June–17 July 1998. Roosts #708 and #407C (9–11 bats and 21–35 bats, respectively) were observed in 2003 when young would have been volant, and some females may have left maternity roosts.

Roost #213 was along the southern edge of a 331 ha woodland that was part of a woodland corridor along Jonathon Creek. Primary roosts #380 and #708 were along the southern edge of a 331 ha woodlot surrounded by agricultural lands and roads (U.S. Route 63 to the east and a two-lane paved road to the north). Across the two-lane road and extending north was a wooded unnamed drainage.

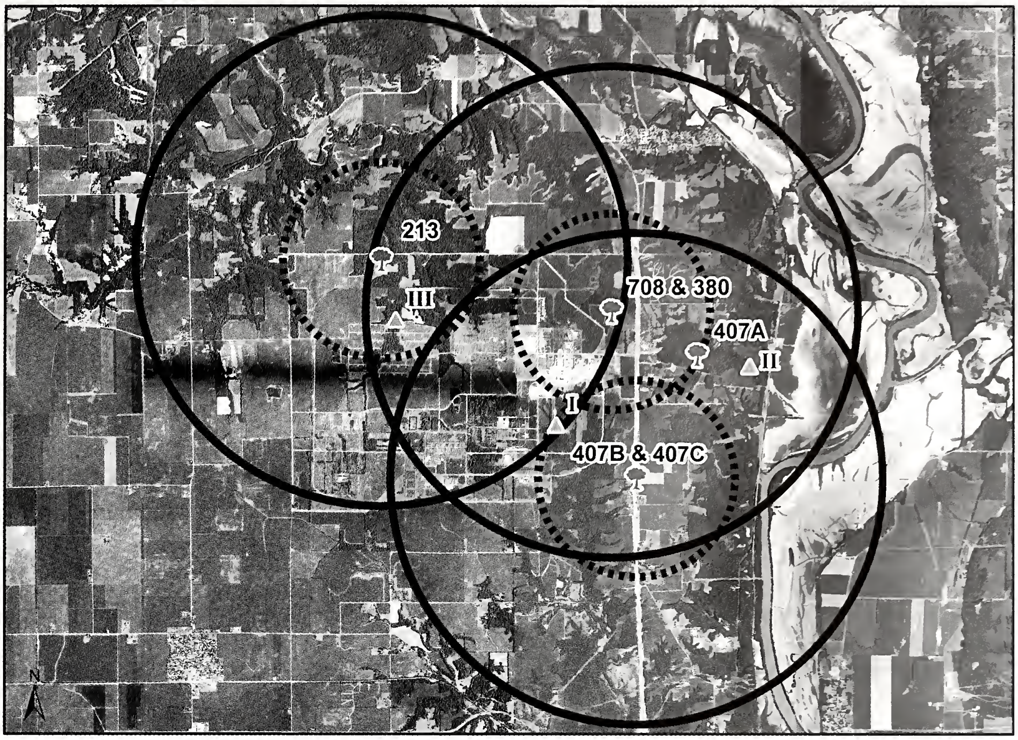

Figure 2.—Aerial photograph of capture sites (I–III, denoted with closed triangles), roost trees (denoted by a tree icon and labeled with a numeral), and the surrounding landscape on Newport Chemical Depot, Vermillion County, Indiana. The circles formed by dotted and solid lines are 1.6 km and 4.0 km around primary maternity roosts.

Roost #380 was a slippery elm (*Ulmus rubra*) 51 cm dbh and roost #708 was an American elm (*Ulmus americana*) 34 cm dbh (Table 2), while dominate trees near them were 25–30 cm dbh American elm, black locust (*Robinia pseudoacacia*), and black walnut (*Juglans nigra*).

Primary roost #407C and alternate roost #407B were in a small (0.7 ha) isolated woodlot. It was bounded on the west by a four-lane divided highway (U.S. Route 63) and by agriculture fields to the north, east, and south. The closest woody habitat was a brushy fence row of small trees west of Highway 63. The width of cleared highway right-of-way was about 30 m. The fence row, ultimately attached to the Little Raccoon Creek drainage, crossed open field for 660 m. Alternatively, the distance southwest to a wooded drainage of Little Raccoon Creek was about 180 m.

Alternate roost #407B bordered the U.S. Route 63 right-of-way and primary roost

Table 1.—Distances (km) among mist net capture sites (I, II, and III) and roosts (numerals prefaced by a # sign). Superscripts designate roosts as primary (P) or secondary (S).

	Site I	Site II	Site III	#213	#380/#708	#407A	#407B
Site II	3.3						
Site III	3.1	5.9					
#213^P	3.8	6.3	1.1				
#380/#708^P	1.9	2.5	3.6	3.8			
#407A^S	2.5	0.9	5.0	5.4	1.6		
#407B^S	1.6	2.6	4.7	5.5	2.7	2.2	
#407C^P	1.6	2.6	4.7	5.5	2.8	2.2	<0.1

Table 2.—Characteristics of and numbers of bats exiting four primary (multiple bats) and 2 alternative roost (single bat) trees used by Indiana myotis at Newport Chemical Depot, Vermillion County, Indiana.

Roost	Tree species	Status	dbh (cm)	% of bark exfoliated	% canopy closure	Height of roost (m)	Date observed	No. of bats
#213	*Acer saccharum*	Dead (girdled in 1993)	98	>25	0	7.6	6 June 1997	22
							11 June 1997	21
							18 June 1997	20
							28 June 1997	33
							31 July 1997	50
							1 June 1998	9
							26 June 1998	16
							17 Aug. 1998	0
#380	*Ulmus rubra*	Dead	51	>25	0	≈6.0	11 June 1997	16
							22 June 1998	5
							23 June 1998	7
							17 July 1998	13
							9 Sept. 1998	0
#407A	*Carya ovata*	Live	30	Yes*	45	6.1	21 July 2003	1
#407B	*Gleditsia triacanthos*	Live	35	Yes*	90	7.6	22 July 2003	1
#407C	*U. americana*	Dead	30	Yes*	10	12.2	23 July 2003	21
							24 July 2003	23
							25 July 2003	35
#708	*U. americana*	Dead	34	Yes*	15	10.7	21 July 2003	11
							22 July 2003	9
							23 July 2003	9
							24 July 2003	9
							25 July 2003	10
	Mean		46.3		26.7	8.4		14.8
	SD		26.5		35.2	2.5		12.3

* Exfoliation was observed but not recorded as a percent.

Table 3.—Percentages of five types of habitat within 1.6 and 4.0 km of primary roost trees.

Habitat type	1.6 km		4.0 km	
	X̄	*SD*	X̄	*SD*
Agriculture	44.0	5.4	46.6	3.1
Developed	11.0	6.8	11.4	0.8
Forest	39.5	17.1	35.6	3.0
Scrub shrub	5.4	6.3	5.6	0.2
Water	0.1	0.1	0.8	0.7

#407C was about 20 m east of the right-of-way, both on the west edge of the woodlot. The transmittered bat switched between the two roosts during daylight hours. Dominant trees near roosts #407B and #407C were 25–30 cm dbh honeylocust (*Gleditsia triacanthos*), black walnut, and sugar maple; primary roost #407C was 30 cm dbh and alternate roost #407B was 35 cm dbh (Table 2).

Landscape habitat characterization.—Habitat within 1.6 and 4.0 km of primary roosts was similar (Table 3). Developed lands were about 11% of the landscape and agricultural lands were about 45% of lands near primary roosts. Forested lands were 35–40% of the landscape. Within 1.6 km of a roost, about 321 ha (*SD* = 139) of wooded habitat was available, and within 4.0 km about 1811 ha (*SD* = 154) was available, however, because of overlap among areas (Fig. 2), total available woodlands was 0.6% less than individually within 1.6 km, and 49% less within 4.0 km (i.e., collective availability within 4.0 km of all three roosts was 3693 ha). Combined, scrub shrub and water were about 6% of the landscape.

DISCUSSION

The presence of multiple roost trees and multiple capture sites productive over a seven-year period, all within close proximity to one another, and movements of bats among roost trees within this area is strong evidence that a single maternity colony is using this area, and these data support the hypothesis of Kurta et al. (2002) that the Indiana myotis has a fission-fusion social organization. In Michigan, Kurta et al. (2002) found that members of one nursery colony used roosts up to 9.2 km apart over a four-year period, up to 8.2 km during a single season, and individual bats moved 5.8 km in a single night and 7.8 km in four days. At the Indianapolis International Airport during the period 1997–2001, a single nursery colony used four primary and 24 alternate roosts in a much larger area than that studied at Newport Chemical Depot (JOW pers. obs.). At Newport Chemical Depot we found four primary and two alternate roosts within 5.5 km of each another during three summers over a seven-year period. Thus, members of a maternity colony of the Indiana myotis roost singly, in small communal roosts, and in large communal roosts.

Many studies of the Indiana myotis emphasize natural features of forested areas where roosts are found (Callahan et al. 1997; Carter & Feldhamer 2005; Kurta et al. 2002), although at a landscape scale, these areas are dominated by human activities. Studies addressing the influence of humans on the habitat used by this bat are few (Sparks et al. 2005). Within the core summer range, woodlands are fragmented by agriculture and urbanization; only 24% of land in counties with records of reproductive Indiana myotis is forested (Gardner & Cook 2002). Only 20% of Indiana is forested (Tormoehlen et al. 2000) and many counties in the northern two-thirds of the state are <10% forested (Schmidt et al. 2000). Habitat of the Newport Chemical Depot study area, about 35–40% forested, was nevertheless fragmented, with bats using isolated woodland parcels. Before European settlement, the core range (including the study area) was a mosaic of woods and prairies, oak-dominated savannahs, and wetlands including marshes and open swamps (Brugam & Patterson 1996; Homoya et al. 1985; Nuzzo 1985). Thus, woodlands were naturally fragmented in the past, while today fragmentation is a result of agriculture and development.

Regardless of the cause, the Indiana myotis is adapted to using a fragmented landscape, which would necessitate crossing open, unforested areas. Relying upon radiotelemetry, Murray & Kurta (2004) found that members of a colony of Indiana myotis followed a tree line rather than cross an open agricultural area. They interpreted this as a reluctance of the species to cross open lands. In this study, it is obvious bats crossed a variety of open lands, including agricultural lands and a divided four-lane highway. Brack (1983) reported light-tagged individuals crossing open pastures. One author of this paper (VB) has caught Indiana myotis in a variety of open habitats including over a ditch (channelized stream) in an open agricultural bottom land in southern Illinois, in open pipeline corridors in predominately wooded areas of New York, and over open roads in many portions of the range. We suspect bats follow tree lines, fly over ditches in open fields, and follow openings through woodlands because they use these landscape features for navigation.

Indiana bats have been caught, observed, and radio-tracked foraging in open habitats (Brack 1983; Clark et al. 1987; Gumbert 2001; Hobson and Holland 1995; Humphrey et al. 1977; Sparks et al. 2005), which is supported with studies of food habits, including at least one incidence of a Hessian fly (*Mayetolia destructor*, a pest on wheat) in the diet (D. Sparks pers. comm.). In Indiana, individuals foraged most in habitats with large foliage surfaces, including woodland edges and crowns of individual trees (Brack 1983). Woodlands with open canopies, including wooded pastures and recently logged areas, provide a greater foliage area for foraging than woodlands with a closed canopy. Woodland openings provide more insects than woodland interiors (Tibbels & Kurta 2003). Many woodland bat species forage most along edges, an intermediate amount in openings, and least within forest interiors (Grindal 1996).

It might seem that Indiana bats should avoid open areas in order to avoid predators such as owls. However, owls seldom prey on bats (Sparks et al. 2000). Instead, they prey mostly on small and medium-sized mammals, hunting by listening for sounds made as they move about on the ground. Possibly the few bats eaten by owls are disabled or are on the ground. If owls use eyesight to capture bats, then bats should avoid open areas at times of greater lunar illumination. However, to date there is no evidence of such avoidance by bats from temperate regions (Parsons et al. 2003).

The Indiana myotis roosts in trees with sloughing bark that are typically large, often dead or dying, and typically exposed to solar heating. Three of four primary roosts on Newport Chemical Depot were on the southern edge of woodlands and the fourth was on a western edge. Thus, the sun would warm all primary roosts; and canopy closure was minimal. Kurta et al. (1993) found that all of eight roosts were exposed to direct sunlight throughout the day, and both Kurta et al. (2002) and Carter & Feldhamer (2005) documented numerous roosts exposed to abundant solar radiation.

Managers of publicly-owned wooded lands, federal and state forests, parks, wildlife management areas, and Dept. of Defense facilities have developed management plans to conserve wooded habitat for this endangered bat. Within the fragmented landscape of the core range, preservation of wooded drainages and isolated woodlots will benefit the species. While beneficial, conservation of large tracts in the core range is difficult because open areas are in agriculture and expensive to acquire. However, conservation areas need not be large or contiguous to benefit the bat. Creating small wooded areas and enlarging existing small areas within proximity to one another, should benefit the species, and in some cases may be the only way that enough habitat can be maintained on the landscape to support a colony. In contrast, much of the eastern portion of the range of the Indiana myotis is heavily wooded, and yet the species is less common. Brack et al. (2002) noted that more trees do not mean more bats; and in the eastern United States, removal or replacement of smaller tracts of woodland in areas of abundance may affect the species less.

In summary, in many portions of Indiana, the Indiana myotis uses isolated woodlots and wooded drainages on an agricultural landscape. Use of several roosts by a maternity colony supports the hypothesis of a fission-fusion social system. Movement across open spaces among habitat patches may readily occur because the species is adapted to a natural interspersion of open and wooded habitats. Loss or conservation of small or isolated wooded tracts within the core range may harm or benefit the species disproportionately more than in other portions of the range.

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