

Large Filing Separator Sheet

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(CONTINUED)

During hibernation, Indiana bats arouse naturally, as do all hibernating mammals (Thomas et al. 1990). Several researchers have observed that Indiana bats arouse during hibernation (Hall 1962, Myers 1964, Hardin and Hassell 1970, Henshaw 1970). Hicks and Novak (2002) noted that in an Indiana bat hibernaculum in New York, there were long periods of little or no bat movement, with occasional bouts of activity. Generally, a rhythm of approximately one arousal every 12 to 15 days for hibernating bats is considered typical, but considerable variation has been observed (Speakman and Thomas 2003). Hardin and Hassell (1970) observed that the average time between movements of tagged Indiana bats during hibernation was 13.1 days, but noted that some movements may not have been detected. Further, some bats may arouse and not move; therefore, movement may not be a reliable indicator of arousal (Dunbar and Tomasi in press). The frequency of arousal varies during the hibernation period. During the later stage of hibernation (i.e., spring), bats arouse more often and may move towards the entrance of the cave. In Barton Hill mine (New York) in early April, Indiana bat clusters shifted roost sites as the bats moved toward a "staging area" near the entrance; numbers within clusters also became more variable (A. Hicks, New York State Department of Environmental Conservation, pers. comm., 2002). Clawson et al. (1980) observed Indiana bats responding to cave wall temperatures in a study of five hibernacula in Missouri. Indiana bats roosted in deeper cave passages in the fall, moved to colder roosts (primary roosting areas) in mid-winter as the rock temperatures declined, and returned to warmer roost sites in the spring before emerging. Human disturbance can increase the frequency of arousal in hibernating bats (see discussion in Overutilization for Commercial, Recreational, Scientific, or Educational Purposes: Disturbance of Hibernating Bats section). Microclimate factors in hibernacula can also influence the frequency of arousal (see discussion in the Hibernacula Microclimate section).

Spring Emergence

The timing of annual spring emergence of Indiana bats from their hibernacula may vary across the range, depending on latitude and weather (Hall 1962). Based on trapping conducted at the entrances of caves in Indiana and Kentucky, Cope and Humphrey (1977) observed that peak spring emergence of female Indiana bats was in mid-April, while most males were still hibernating. The proportion of females active at the entrance of hibernacula decreased through April, and by early May none remained. Peak emergence of males occurred in early May, and few were left hibernating by mid-May. LaVal and LaVal (1980) made similar observations at Missouri hibernacula; females started emerging in late March to early April, and outnumbered males active at hibernacula entrance during that period. By the end of April, few females remained, and males dominated the sample of bats captured at hibernacula entrances. At the Mt. Hope mine complex in New Jersey, peak spring emergence of females was in early April, and emergence of males peaked at the end of April (Scherer 2000). Exit counts from several hibernacula in southern Pennsylvania and Big Springs Cave in Tucker County, West Virginia, suggest that peak emergence from hibernation is mid-April for these two areas (Butchkoski and Hassinger 2002, Rodrigue 2004). Spring surveys of the interior of Barton Hill mine in New York documented substantial numbers of Indiana bats through April and into mid-May; however, by the end of May, only one-tenth of the population remained (A. Hicks, pers. comm., 2005).

In spring when fat reserves and food supplies are low, migration provides an additional stress and, consequently, mortality may be higher immediately following emergence (Tuttle and

Stevenson 1977). This increased risk of mortality may be one reason why many males do not migrate far from the hibernacula (Brack 1983, Gardner and Cook 2002, Whitaker and Brack 2002). Movements of 4-16 km (2.5-10 mi) by radiotagged male Indiana bats were reported in Kentucky, Missouri, and Virginia (Hobson and Holland 1995, Rommé et al. 2002). However, other males leave the area entirely upon emergence in spring and have been captured throughout various summer habitats (Kurta and Rice 2002, Whitaker and Brack 2002).

Female Indiana bats may leave immediately for summer habitat or linger for a few days near the hibernaculum. Once en route to their summer destination, females move quickly across the landscape. One female released in southeastern New York moved 56 km (35 mi) in approximately 85 minutes (Sanders et al. 2001). Radiotelemetry studies in New York documented females flying between 16 and 48 km (10 and 30 mi) in one night after release from their hibernaculum, arriving at their maternity sites within one night (Sanders et al. 2001; Hicks 2004; S. von Oettingen, USFWS, unpublished data, 2005). One radiotagged female bat released from Canoe Creek Mine in Pennsylvania traveled approximately 97 km (60 mi) in one evening (C. Butchkoski, pers. comm., 2005). A female Indiana bat from a hibernaculum in Luzerne County, Pennsylvania, traveled 90 km (56 mi) to her summer habitat in Berks County, Pennsylvania, in two nights (Butchkoski and Turner 2006).

Indiana bats can migrate hundreds of kilometers from their hibernacula. Twelve female Indiana bats from maternity colonies in Michigan migrated an average of 477 km (296 mi) to their hibernacula in Indiana and Kentucky, with a maximum migration of 575 km (357 mi); Winhold and Kurta 2006). Gardner and Cook (2002) also reported on long-distance migrations for Indiana bats traveling between their summer ranges and hibernacula. Shorter migration distances are also known to occur. Indiana bats banded (during summer) at multiple locations in Indiana have been found in hibernacula only 55 to 80 km (34 to 50 mi) from their summer range (L. Pruitt, USFWS, pers. comm., 2006). Some banded female Indiana bats from maternity colonies in Mammoth Cave National Park have been found hibernating in nearby caves (J. MacGregor, pers. comm., 2006). Recent radiotelemetry studies of 70 spring emerging Indiana bats (primarily females) from three New York hibernacula found that most of these bats migrated less than 64 km (40 mi) to their summer habitat (A. Hicks, pers. comm., 2005; S. von Oettingen, USFWS, unpublished data, 2005).

Little information is available to determine habitat use and needs for Indiana bats during migration. Recent spring emergence telemetry studies in New York and Pennsylvania are beginning to document migratory routes in the northeast (A. Hicks, pers. comm., 2005; C. Butchkoski, pers. comm., 2005; J. Cheng, Bat Conservation and Management, pers. comm., 2005).

Summer Life History and Behavior

Reproductive females arrive at their summer habitats as early as mid-April in Illinois, New York, and Vermont (Gardner et al. 1991a, Britzke 2003, Hicks 2004). Humphrey et al. (1977) reported that Indiana bats first appeared at their maternity roost sites in early May in Indiana, with substantial numbers arriving in mid-May. However, Whitaker et al. (2005b) counted 25 bats emerging from a primary Indiana bat maternity roost tree (used in previous years) in central Indiana on April 9, and smaller numbers of bats have been observed emerging from known

Indiana bat roosts on this study area as early as late March (Whitaker et al. 2005a). Indiana bats from hibernacula in southern Indiana and Kentucky enter southern Michigan as early as late April, although most do not arrive until the middle or end of May (Kurta and Rice 2002). Most Indiana bats from hibernacula in New York fly directly to their summer range in Vermont and southeastern New York beginning in mid-April (Britzke 2003, Hicks 2003).

Less is known about male migration patterns. Some males summer near their hibernacula (Whitaker and Brack 2002). Some males disperse throughout the range and roost individually or in small numbers in the same types of trees (although males often use smaller trees and are more likely to roost in live trees; see discussion in the Summer Habitat section) and in the same areas as females (Kurta and Rice 2002).

Nonreproductive females may also roost individually or in small numbers, including in the same trees as reproductive females (A. Kurta, Eastern Michigan University, pers. comm., 2005). Relatively little is known about the summer habits of males and nonreproductive females; therefore, the following section is primarily focused on summer life history of reproductive females.

Maternity Colony Formation

After arriving at their summer range, female Indiana bats form maternity colonies. Indiana bat maternity colonies can vary greatly in size. It is difficult to enumerate colony size because colony members are dispersed among various roosts at any given time (Kurta 2005). Most estimates of colony size are based on counts of bats emerging from known Indiana bat maternity roosts. Estimating colony size based on emergence counts requires the researcher to make assumptions. First, based on the date of the counts, researchers generally assume that emerging bats are adult female Indiana bats (if counts occur prior to dates when young typically become volant), or that young-of-the-year bats are included in the count. There are documented cases of adult male bats in maternity roosts, but it is considered unlikely that large numbers of male bats occupy maternity roosts. Second, the assumption is made that all bats emerging from the roost are Indiana bats, although this assumption is generally not tested. There are documented cases of more than one species of bats using the same maternity roost, either simultaneously, or within the same season. Third, assumptions must be made regarding what proportion of the colony may have been counted during emergence counts. Counts based on multiple nights at multiple known roost sites over the course of the maternity season provide better estimates than a single count at a single tree. However, even a single count at a primary maternity roost tree provides an estimate of minimum colony size.

Although most documented maternity colonies contained 100 or fewer adult females (Harvey 2002), as many as 384 bats have been reported emerging from one maternity roost tree in Indiana (Whitaker and Brack 2002). Whitaker and Brack (2002) indicated that average maternity colony size in Indiana was approximately 80 adult female bats. The mean maximum emergence count after young began to fly (measured in 12 studies) was approximately 119 bats (Kurta 2005), suggesting that 60 to 70 adult females were present (assuming that most adult females successfully raise one pup to volancy).

Barclay and Kurta (in press) suggested five potential explanations for the establishment of maternity colonies in cavity- and bark-roosting bats: 1) high-quality roosts may be limiting in some areas, 2) foraging efficiency--members of a colony communicate regarding good foraging areas, 3) reduced predation risk, 4) thermoregulatory advantages--roosting in a large group may be a mechanism for reproductive females to reduce thermoregulatory costs by clustering, and 5) water conservation by reducing evaporative water loss. (However, see Kerth et al. 2001 for a discussion of why foraging efficiency is unlikely to explain coloniality in species of bats in which members of the colony do not forage together). The relative importance of these benefits of coloniality is not known, but the thermoregulatory advantages of colonial roosting have been clearly demonstrated. Female bats in late pregnancy and their pups are poor thermoregulators (Speakman and Thomas 2003), and prenatal and postnatal growth are controlled by the rate of metabolism and body temperature (Racey 1982). Humphrey et al. (1977) demonstrated the importance of roost temperature in the growth and development of young Indiana bats. Barclay and Kurta (in press) concluded that "the weight of evidence suggests that roost microclimate and its impact on thermoregulation are the primary factors involved in roost selection by forest-dwelling bats," although experimental tests of this hypothesis are lacking. In addition to selecting favorable roost sites, clustering (in maternity roosts) is another mechanism used by bats to maintain roost temperatures favorable for prenatal and postnatal development. Thus, colonial roosting is a life history strategy adopted by Indiana bats (like many other temperate-zone bats) to improve reproductive success (Barclay and Harder 2003).

Maternity Roosts

Indiana bat maternity roosts can be described as primary or alternate based upon the proportion of bats in a colony consistently occupying the roost site (Kurta et al. 1996, Callahan et al. 1997, Kurta et al. 2002). In Missouri, Callahan (1993) defined primary roost trees as those with exit counts of more than 30 bats on more than one occasion; however, this number may not be applicable to small-to-moderate sized maternity colonies (Kurta et al. 1996). For smaller maternity colonies, determining the number of "bat days" over one maternity season (one bat day = one bat using a tree for one day) may be a better technique for distinguishing primary from alternate roosts (Kurta et al. 1996).

Maternity colonies typically use 10 to 20 trees each year, but only one to three of these are primary roosts used by the majority of bats for some or all of the summer (Callahan 1993, Callahan et al. 1997). Before the young are capable of flight (volant), the composition of a colony at a primary roost is fluid, as individual bats leave and return (Barclay and Kurta in press). Kurta et al. (2002) observed that certain roost trees were occupied by a "quasi-stable number of Indiana bats for days or weeks" at a time. However, during this time, individuals (based on radiotelemetry observations) consistently moved into and out of the trees.

Alternate roosts are used by individuals or a small number of bats and may be used intermittently throughout the summer or used on only one or a few days. All roost trees eventually become unusable—by losing bark, falling over, or through competition with other animals—and these events can often occur suddenly and without warning (Gardner et al. 1991a, Kurta and Foster 1995, Belwood 2002). The use of alternate roosts may be a way of discovering new primary

roosts since Indiana bats must maintain an awareness of suitable replacements in case of an emergency (Kurta et al. 1996, 2002). Thus, "primary" roosts are a function of bat behavior (aggregation) and roost physical characteristics (e.g., large size). Studies documenting roost trees used by individuals in a colony identified a range in the number of alternate roosts. For example, based on Callahan's (1993) definition, Watrous (unpublished data, 2005) documented 12, 9 and 14 alternate roost trees for three colonies in the Lake Champlain Valley of Vermont and New York.

Indiana bats appear to have a fission-fusion society as demonstrated by frequent roost changing (Kurta et al. 2002, Kurta 2005). Barclay and Kurta (in press) explain "that in this type of a society, members frequently coalesce to form a group (fusion), but composition of that group is in perpetual flux, with individuals frequently departing to be solitary or to form smaller groups (fission) for a variable time before returning to the main unit." It may be possible that some bats select individuals with whom to roost and avoid roosting with others (Barclay and Kurta in press). Although many members of a colony may reside in one tree at any one time, other members roost elsewhere as solitary individuals or in small subgroups of fluctuating composition. Such a fission-fusion society has been suggested for other species of forest bats, as well (Kerth and König 1999, O'Donnell 2000, Kurta et al. 2002, Willis and Brigham 2004).

On average, Indiana bats switch roosts every two to three days, although reproductive condition of the female, roost type, and time of year affect switching (Kurta et al. 2002, Kurta 2005). Lactating females may change roosts less often than pregnant or post-lactating females. Bats roosting under exfoliating bark may change more often than bats roosting in crevices (Kurta et al. 1996, 2002; Gumbert et al. 2002; Carter 2003; Kurta 2005). Roost switching occurs less often in the spring, most likely due to colder night temperatures that may induce extended torpor (Gumbert et al. 2002, Britzke et al. 2006).

Night Roosts

Indiana bats use night roosts (Butchkoski and Hassinger 2002, Kiser et al. 2002, Ormsbee et al. in press), although there is limited research on where and why they night roost. Adults of both sexes as well as juveniles use night roosts (Kiser et al. 2002). Indiana bats may night roost for a variety of reasons, including (but not limited to) resting, aiding in digestion, protection from inclement weather, and conservation of energy (Ormsbee et al. in press). Night roosting may occur at the bat's day roost in conjunction with nocturnal tending of its young or during inclement weather, or, more often, at sites not generally used as day roosts (Ormsbee et al. in press). Indiana bats night roost in trees (Butchkoski and Hassinger 2002, Murray and Kurta 2004), bridges (Mumford and Whitaker 1982, Kiser et al. 2002), caves (Gumbert et al. 2002), and bat houses (Butchkoski and Hassinger 2002).

Reproduction

Females give birth to a single young in June or early July (Easterla and Watkins 1969, Humphrey et al. 1977, Kurta and Rice 2002) while in their maternity roosts. As previously discussed, maternity colonies reduce thermoregulatory costs, which, in turn, increases the energy available for birthing and raising young (Barclay and Harder 2003). There are no documented occurrences in which a female Indiana bat has successfully given birth and raised a pup alone without communal benefits of a maternity colony. A study by Belwood (2002) shows

asynchronous births extending over two weeks within one colony. This asynchrony results in great variation in size of juveniles (newborn to almost adult size young) in the same colony.

In Indiana, lactating females have been recorded from June 10 to July 29 (Whitaker and Brack 2002). Lactation begins at birth and continues through early volancy of young. Young Indiana bats are volant within 3-5 weeks of birth (Mumford and Cope 1958, Easterla and Watkins 1969, Cope et al. 1974, Humphrey et al. 1977, Clark et al. 1987, Gardner et al. 1991a, Kurta and Rice 2002, Whitaker and Brack 2002). Young born in early June may fly as early as the first week of July (Clark et al. 1987), others from mid-to-late July. Once the young Indiana bats are volant, the maternity colony begins to disperse. The use of primary maternity roosts diminishes, although the bats may stay in the maternity roost area until migrating to their respective hibernacula. Bats become less gregarious and the colony uses more alternate roosts (Kurta et al. 1996), possibly because there is no longer the need for the adult females to cluster for thermoregulation and to nurture their young. However, as many as 69 bats have been observed exiting a primary roost tree in central Indiana in late September (D. Sparks, Indiana State University, pers. comm., 2006).

Although the preceding discussion provides a seasonal framework for Indiana bat reproduction, the timing of reproductive events is somewhat weather-dependent (Grindal et al. 1992, Lewis 1993, Racey and Entwistle 2003). Adverse weather, such as cold spells, increases energetic costs for thermoregulation and decreases availability of insect prey (the available energy supply). Bats may respond to a negative energy balance by using daily torpor, and some females may not bear a pup in years with adverse weather conditions (Barclay et al. 2004). In females that maintain pregnancy, low body temperatures associated with daily torpor slow chemical reactions associated with fetal and juvenile growth and milk production and may cause annual and individual variation in the time when young are born and how quickly young develop.

Site Fidelity

Research indicates that Indiana bats exhibit site fidelity to their traditional summer maternity areas. Numerous studies have documented female Indiana bats annually returning to the same home range to establish maternity colonies (Humphrey et al. 1977; Gardner et al. 1991a, 1991b; Gardner et al. 1996; Callahan et al. 1997; Whitaker and Sparks 2003; Whitaker et al. 2004). While use of new roosts that become available within established home ranges has been documented, pioneering of new maternity colonies has not been documented. We presume that the species is capable of forming new maternity colonies, but neither the mechanism nor circumstances under which the Indiana bat pioneers maternity colonies has been documented.

Roost trees, although ephemeral in nature, may be occupied by a colony for a number of years until they are no longer available or suitable. Roost tree reoccupation of 2 to 6 years has been documented in a number of studies (Gardner et al. 1991b; Whitaker et al. 2004; Barclay and Kurta in press; K. Watrous, University of Vermont, pers. comm., 2005).

Maternity colonies of Indiana bats also appear to be faithful to their foraging areas within and between years (Cope et al. 1974; Humphrey et al. 1977; Gardner et al. 1991a, 1991b; Murray and Kurta 2004; Sparks et al. 2005b). Available data also suggest that individual Indiana bats are faithful to their foraging areas between years. Gardner et al. (1991a, 1991b) observed that

individual females returned to the same foraging areas year after year, irrespective of whether they were captured as juveniles and recaptured and tracked as adults or captured as adults and then followed. In Indiana, one female Indiana bat was radiotracked in two different years and both roosting and foraging habits were found to be remarkably consistent between years (Sparks et al. 2005b). In Michigan, Murray and Kurta (2002, 2004) recaptured 41 percent (12 of 29) of banded females when mist netting at the same area in subsequent years. Further studies of this colony reported use of a wooded fenceline as a commuting corridor for at least nine years (Kurta 2005, Winhold et al. 2005).

Fall Migration

Maternity colonies begin disbanding during the first two weeks in August, although some large colonies may maintain a steadily declining number of bats into mid-September (Humphrey et al. 1977, Kurta et al. 1993b). It should be noted that in some cases, bats emerging from documented Indiana bat roosts later in the season were determined to be another species (A. Hicks, pers. comm., 2005). Even in northern areas, such as Michigan, a few Indiana bats may remain into late September and early October; these late migrants may be young-of-the-year (Kurta and Rice 2002). Members of a maternity colony do not necessarily hibernate in the same hibernacula, and may migrate to hibernacula that are over 300 km (190 mi) apart (Kurta and Murray 2002, Winhold and Kurta 2006).

Food Habits

Indiana bats feed on flying insects, with only a very small amount of spiders (presumably ballooning individuals) included in the diet. Four orders of insects contribute most to the diet: Coleoptera, Diptera, Lepidoptera, and Trichoptera (Belwood 1979, Brack 1983, Brack and LaVal 1985, Lee 1993, Kiser and Elliot 1996, Kurta and Whitaker 1998, Murray and Kurta 2002, Whitaker 2004). Various reports differ considerably in which of these orders is most important. Terrestrial-based prey (moths and beetles) were more common in southern studies, whereas aquatic-based insects (flies and caddisflies) dominated in the north. Presumably, this difference indicates that southern bats foraged more in upland habitats, and northern bats hunted more in wetlands or above streams and ponds. These differences in diet are consistent with observations of foraging animals in various studies. However, apparent geographic differences are confounded by differences in survey techniques, in sex or age of animals studied, in availability and use of habitats, and in composition of the local bat community (i.e., presence of potential competitors) (Murray and Kurta 2002, Brack in press).

Hymenopterans (winged ants) also are abundant in the diet of Indiana bats for brief, unpredictable periods corresponding with the sudden occurrence of mating swarms. Although not as dramatic, seasonal occurrence of Asiatic oak weevils in the diet indicates use of an abundant resource available only for a limited part of the season (Brack 1983, Brack and Whitaker 2004). Consistent use of moths, flies, beetles, and caddisflies throughout the year at various colonies suggests that Indiana bats are selective predators to a certain degree, but incorporation of ants into the diet also indicates that these bats can be opportunistic (Murray and Kurta 2002). Hence, Brack and LaVal (1985) and Murray and Kurta (2002) suggested that the Indiana bat may best be described as a "selective opportunist," as are a number of other *Myotis* species (Fenton and Morris 1976).

At individual colonies, dietary differences exist between years, within years by week, between pregnancy and lactation, and within nights (Murray and Kurta 2002). Although some authors ascribe various adaptationist reasons for these differences, it is difficult to explain why different studies are not consistent in their results. For example, Belwood (1979) reported an increase in moth consumption during lactation, but Kurta and Whitaker (1998) reported a decrease. Kurta and Whitaker (1998) stated that caddisfly consumption remained constant throughout the season, whereas Brack (1983) reported a decrease. Murray and Kurta (2002) found a significant increase in moth consumption by one colony during lactation in one year but not in the following year. These inconsistencies within and among studies suggest that diet of Indiana bats, to a large degree, may reflect availability of preferred types of insects within the foraging areas that the bats happen to be using, again suggesting that they are selective opportunists (Murray and Kurta 2002).

Foraging Behavior

The Indiana bat is a nocturnal insectivore. It emerges shortly after sunset and begins feeding on a variety of insects that are captured and consumed while flying (Sparks et al. 2005b). At two maternity colonies—one in Michigan and one in Illinois—Indiana bats began emerging from the roost to forage around 19 minutes after sunset, with peak emergence around 21 to 26 minutes after sunset (Viele et al. 2002). In western Illinois, emergence averaged 21 minutes after sunset and peaked 30 to 45 minutes after sunset (Gardner et al. 1991b). There may be considerable variation in emergence times within a colony that is not related to light level, ambient temperature, or number of bats residing in the colony (Gardner et al. 1991a, Viele et al. 2002). Emergence occurs later in relation to sunset near the summer solstice and closer to sunset in spring and late summer (Viele et al. 2002). In Indiana, bats emerged 38–71 minutes after sunset throughout the season, but emergence was earlier when young became volant, i.e., the time of exit was inversely related to the number of bats exiting the roost (Brack 1983). After juveniles become volant, they typically leave the roost for foraging after adults have departed (Kurta et al. 1993b). In Virginia, as autumn progressed, nightly activity started earlier in the evening in relation to sunset (Brack 2006).

Thirteen foraging areas were identified that were used by pregnant and lactating Indiana bats in southern Michigan: five were used only by pregnant bats, four were used only by lactating bats, and four were used by both pregnant and lactating bats (Murray 1999, Murray and Kurta 2004). Individual females visited one to four foraging areas each night. When two or three bats were radiotracked simultaneously, they seldom used the same foraging area and were found in different areas over 5 km (3 mi) apart.

Indiana bats usually forage and fly within an air space from 2 to 30 m (6 to 100 ft) above ground level (Humphrey et al. 1977). Most Indiana bats caught in mist nets are captured over streams and other flyways at heights greater than 2 m (6 ft) (Brack 1983, Gardner et al. 1989). In autumn, observations of light-tagged bats suggest that Indiana bats do not typically fly close to the ground or water (Brack 1983).

Linear distances between roosts and foraging areas for females range from 0.5 to 8.4 km (0.3 to 5.2 mi), although most distances were less than half the maximum distance (Murray and Kurta 2004, Sparks et al. 2005b). For example, one individual at a colony in Indiana moved 8.4 km

(5.2 mi) between roosts and foraging area; however, the mean distance of 41 bats from the same colony was 3.0 km (1.9 mi). In Canoe Creek, Pennsylvania, an area with significant changes in elevation, reported distances between roost and foraging areas ranged from 2.4 to 4.5 km (1.5 to 2.8 mi) with an average distance of 3.4 km (2.1 mi) (Butchkoski and Hassinger 2002). Murray and Kurta (2004) and Sparks et al. (2005b) speculate that the variations in distances to foraging areas were due to differences in habitat type, interspecific competition, and landscape terrain. For more information on foraging habitat, see the Summer Landscape Structure and Macrohabitat: Foraging Habitat section.

Home Range

Indiana bats occupy distinct home ranges, particularly in the summer (Garner and Gardner 1992). However, relatively few studies have determined the home ranges of Indiana bats, and these studies based their calculations on a small number of individuals. Further, direct comparison of the home range estimates between studies is difficult due to different methodologies used in collecting the data, inconsistency in terminology, and different methods of calculating home range size (Lacki et al. 2006). Home range size varies between seasons, sexes, and reproductive status of the females (Lacki et al. 2006). Standardized methodology and terminology as well as additional research will be necessary in order to further refine home range estimates.

Kiser and Elliot (1996) identified minimum foraging areas for 15 Indiana bats (14 males, 1 female) at a hibernaculum in Kentucky. Their estimates ranged from approximately 28 to 267 ha (69 to 734 acres) (excluding the cave in the estimate), with a mean of 156 ± 101 ha (385 ± 249 acres). Rommé et al. (2002) calculated a mean home range near a hibernaculum in Missouri of 667 ± 994 ha ($1,648 \pm 2,456$ acres) for spring and fall (based on pooled data for nine bats—male and female) and $1,584 \pm 1,424$ ha ($3,825 \pm 3,518$ acres) for fall home range (based on three males). In Virginia, Brack (2006) calculated average active areas for three females and eight males near a hibernaculum as 250 ± 100 ha (618 ± 247 acres) ($n=11$) using mean convex polygons and 361 ± 259 ha (892 ± 640 acres) ($n=10$) using adaptive kerneling (core areas).

Menzel et al. (2005) tracked seven female and four male Indiana bats from May to August in Illinois. No significant differences in home ranges between males and females were observed and home range estimates were subsequently grouped. Menzel et al. (2005) determined the mean summer home range size of the 11 Indiana bats to be 145 ha (357 acres). Watrous (in press) calculated a mean home range of 83 ha (205 acres) for 14 female Indiana bats in Vermont.

Hibernation Habitat

During winter, Indiana bats are restricted to suitable underground hibernacula. The majority of these sites are caves located in karst areas of the east-central United States; however, Indiana bats also hibernate in other cave-like locations, including abandoned mines in several states, a railroad tunnel in Pennsylvania, and even a hydroelectric dam in Michigan. Hall (1962) observed that Indiana bats find and occupy newly available hibernating sites very quickly. In some areas, such as Illinois and New York, the largest and most rapidly growing populations occur in abandoned mines (Hicks and Novak 2002, Kath 2002). Pilot Knob Mine in Missouri

was occupied by Indiana bats after mining ceased in the 1890s; by the 1950s, Pilot Knob Mine held the largest population of Indiana bats in Missouri (>100,000 bats) and still has the largest population in the state (Hall 1962, Myers 1964, Clawson 2002). Rapid population growth has also occurred at caves where measures have been implemented to restore hibernacula in cases where previous alterations and/or disturbance made the cave unsuitable or marginally suitable for hibernation. For example, the population at Wyandotte Cave in Indiana grew from a low of 500 bats in 1955 to a current population of over 50,000 bats in response to restoration efforts and measures to eliminate disturbance of hibernating bats. At Saltpetre Cave in Kentucky, the population grew from 475 in 1999 to over 6,000 in 2005 in response to measures that were implemented to restore the microclimate and protect hibernating bats from disturbance. Only a small percentage of caves (and mines) within the range of the Indiana bat provide the conditions required for successful hibernation (USFWS 1983); for recovery, it is essential to conserve and manage those sites with suitable microclimate, and to restore suitable microclimate to sites that have been altered.

Hibernacula Microclimate

Ambient Temperature during Torpor

Most Indiana bats hibernate in caves or mines where the ambient temperature remains below 10°C (50.0°F) but infrequently drops below freezing (Hall 1962, Myers 1964, Henshaw 1965, Humphrey 1978), and the temperature is relatively stable (Tuttle and Kennedy 2002). Tuttle and Kennedy (2002) compared mid-winter temperatures at major hibernacula and reported that populations hibernating where temperatures were between 3° and 7.2°C (37.4° and 45°F) remained stable or increased, while populations hibernating at temperatures above or below this range were unstable or had declined. However, Brack et al. (2005a) reported that hibernacula temperatures below 5°C (41.0°F) are too cold because they observed that in hibernacula in Indiana the highest concentrations of Indiana bats were found at sites with mid-winter temperatures of 6° to 7°C (42.8° to 44.6°F).

Researchers studying hibernacula temperature have used different temperature monitoring instruments and techniques, making it difficult to compare results of studies. For example, among long-term (>2 years) datasets, Henshaw (1965) left thermometers inside hibernacula and measured maximum and minimum temperatures once every two weeks; Brack and his colleagues usually measured temperatures near hibernating clusters of Indiana bats during occasional cave visits (e.g., Brack et al. 1984, Brack et al. 2003, Whitaker et al. 2003); and Tuttle and Kennedy (2002) took near-continuous temperature readings using dataloggers left inside hibernacula. Standard (and thus comparable) protocols for quantifying the thermal profiles of hibernacula used by Indiana bats over ecologically meaningful periods (e.g., >5 years) have not been established, but continuous monitoring using dataloggers is currently the most useful approach. Any protocol for monitoring with dataloggers should be designed to maximize the likelihood that temperature measurements are taken in all areas of a hibernaculum used by bats during winter. Ideally, temperature measurements from dataloggers would be temporally correlated to remotely-sensed information (e.g., images from infrared cameras) on the actual whereabouts of individuals or colonies within the hibernaculum. The second factor complicating the analysis of temperature data gathered by different researchers working in different geographic areas is the relationship between temperature and the degree of gregariousness exhibited by Indiana bats.

Several researchers have noted an inverse relationship between ambient roost temperature and the size of hibernating clusters formed by Indiana bats (Clawson et al. 1980, Brack et al. 1984), i.e., larger clusters are typically found at colder sites, whereas smaller clusters are found in warmer sites. Thus, studies that focus on characterizing temperatures of hibernacula with large, dense colonies of hibernating bats (e.g., Priority 1 caves; Tuttle and Kennedy 2002) may be biased toward colder temperatures and studies of sites with relatively smaller numbers and dispersed clusters of Indiana bats may be biased toward warmer temperatures. Behavioral thermoregulation, in the form of clustering, likely allows Indiana bats to hibernate at a wider range of ambient temperatures than would be possible for noncolonial species, but the effect of clustering density is difficult to measure.

Discussion about the “optimum” range of temperatures for hibernation by Indiana bats relies heavily on temperature data collected inside hibernacula where large numbers are (or in some cases, were) known to hibernate. Such data are correlative and should be treated cautiously. For example, certain hibernating populations may be using available, rather than optimal, habitat. The assumption that the largest colonies aggregate in the most optimal conditions is likely an oversimplification (Henshaw 1970). Furthermore, intra-specific differences in thermal physiology between geographic regions have been observed in vespertilionid bats during warmer months (Willis et al. 2005) and such differences may persist into the winter. Without a clearer picture of the factors influencing the energy and water balance of Indiana bats under different microclimate conditions, the precise range of optimal hibernacula conditions will remain equivocal.

There are few quantitative data pertaining to energy use by Indiana bats during hibernation. In laboratory experiments, Henshaw (1965) measured energy expenditure by Indiana bats as a function of ambient temperature. During torpor, Indiana bats consumed the least amount of energy at 5°C, with energy use increasing at temperatures of both -5°C and 10°C (23.0°F and 50.0°F). However, Henshaw (1965) did not quantify energy expenditure by Indiana bats at intermediate temperatures (i.e., 1° to 4°C and 6° to 9°C (33.8° to 39.2°F and 42.8° to 48.2°F)). T. Tomasi (Missouri State University, unpublished data, 2006) collected metabolic data for Indiana bats hibernating in a laboratory at 1°, 3°, 5°, 7°, and 9°C (33.8°, 37.4°, 41.0°, 44.6°, 48.2°F) and his preliminary analysis showed a significant effect of temperature on the metabolic rate of individual bats (n=13). Lowest metabolic rates were measured for bats in the 5°C (41.0°F) treatment. V. Brack (pers. comm., 2004; Brack 2005) raised concerns regarding laboratory experiments that measure the efficiency of hibernation at various temperatures without considering the energetic costs and frequency of arousals. He suggested that the energy savings of torpor at a low versus high ambient temperature (e.g., 3°C versus 8°C (37.4°F versus 46.4°F)) may be outweighed by the increased cost of arousal, the increased cost of maintenance of normothermic body temperatures during arousal, and the secondary effects of metabolic inhibition (e.g., oxidative stress, reduced immunocompetence; Geiser 2004). Patterns of energy use by hibernating Indiana bats over a range of ambient temperatures could be quantified in the laboratory (including the cost of arousal and maintenance of normothermic body temperatures during arousal). Tomasi (pers. comm., 2006) proposes to collect additional data to evaluate the energetic cost of arousal at various temperatures (to be analyzed in conjunction with data on the metabolic rates of Indiana bats hibernating at those temperatures). Further study is also needed to better understand how clustering affects heat loss and rewarming of hibernating Indiana bats.

Decreased thermal conductance (Kurta 1985) and increased radiant heat gain experienced by bats in a cluster (Geiser and Drury 2003) may significantly decrease their energy expenditure during arousal from low ambient temperatures.

Water Balance and Winter Activity of Hibernating Bats

Little is known about the water balance of hibernating Indiana bats. Henshaw (1965, 1970) measured evaporative water loss by Indiana bats and noted that, as with other species, water loss was a function of the vapor pressure deficit of ambient air; bats lost more water as the humidity of air decreased. Although Indiana bats apparently experience less evaporative water loss during hibernation than little brown bats (Henshaw 1970, Brenner 1973), extensive laboratory research on the latter species offers insight into the importance of air moisture on hibernation by species of *Myotis*. Thomas and Cloutier (1992) observed that at relative humidity levels below 99.3 percent (air temperature 2° to 4°C), evaporative water loss rates of little brown bats exceeded metabolic water production under laboratory conditions. The implication of this research is that the lower the humidity in a hibernaculum, the more frequently a bat hibernating at that site will need to arouse and replenish water supplies. Researchers have suggested that the need for water is a major factor influencing the arousal frequency of hibernating bats (Speakman and Racey 1989, Thomas and Geiser 1997, Speakman and Thomas 2003), and Indiana bats have been observed drinking during arousals (Hall 1962, Myers 1964). Considering that arousals account for approximately 75 to 85 percent of winter fat depletion (Thomas 1995, Speakman and Thomas 2003), humidity of the hibernacula could play a major role in both the water and energy balance of hibernating bats. Although quantitative field studies are limited, several early researchers noted that Indiana bats arouse frequently during hibernation (Hall 1962, Myers 1964, Hardin and Hassell 1970, Henshaw 1970). It is possible that arousal frequency in Indiana bats, and thus energy use and probability of survival, is partially a function of the humidity of the hibernacula. Laboratory measurements of arousal frequency as a function of water vapor pressure deficit in Indiana bats have not been made. Temperature may also play a role in the arousal frequency of hibernating Indiana bats, but targeted studies are lacking. Hicks and Novak (2002) observed infrequent arousals between late January and mid-May at a cold (-1.1°C to 3.3°C) (30.0° to 37.9°F) hibernaculum occupied by 700 to 1000 Indiana bats, but similar data from warmer sites or larger colonies are not available.

Henshaw (1965) reported air movement in most of the Indiana bat and little brown bat hibernacula that he studied. Although air circulation can have a dramatic influence on energy expenditure (through convective heat loss) and water balance (through transdermal water loss; Bakken and Kunz 1988), few quantitative data on air movement in hibernacula used by Indiana bats are available.

Structure of the Hibernaculum

Myers (1964) observed that some caves are more attractive to bats and that larger caves invariably offer a greater variety of habitats. Caves that historically sheltered the largest populations of hibernating Indiana bats were those that provided the largest volumes and structural diversity, thus ensuring stable internal temperatures over wide ranges of external temperatures, with a low likelihood of freezing (Tuttle and Kennedy 2002). Caves that meet temperature requirements for Indiana bats are rare. Specific cave and mine configurations

determine levels of temperature and humidity and, thus, suitability for Indiana bats (Humphrey 1978, Tuttle and Stevenson 1978, LaVal and LaVal 1980, Tuttle and Kennedy 2002).

In many hibernacula in the central and southern United States, roosting sites are near an entrance but may be deeper in a cave or mine, if that is where cold air flows and is trapped (Tuttle and Stevenson 1978; R. Clawson, Missouri Department of Conservation, pers. comm., 1996). The best hibernation sites in the central or southern United States provide a wide range of vertical structure and a cave configuration that provides temperatures ranging from below freezing to 13°C (55.4°F) or above. These hibernacula tend to have large volume and often have large rooms or vertical passages below the lowest entrance. Large volume helps buffer the cave environment against extreme changes in outside temperature, and complex vertical structure offers a wide range of temperatures and, therefore, diversity of roosting sites. Low chambers allow entrapment of cold air that is stored throughout summer, providing arriving bats with relatively low temperatures in early fall (Tuttle and Kennedy 2002).

In central and southern portions of the winter range, the best caves for hibernation consistently have multiple entrances that permit "chimney-effect" airflow. In winter, due to barometric pressure, cold outside air enters one or more lower entrances while warmer air rises and exits the cave through entrances that are at least a few feet higher in elevation. The chimney effect cools the cave more than a single entrance allows (Humphrey 1978, Tuttle and Kennedy 2002). In contrast, aboveground temperatures are lower in the north, and successful hibernation sites in northern hibernacula typically are further back from entrances and not in areas with strong chimney effect airflow, which may lead to subfreezing temperatures in areas between the entrances in small caves (M. Tuttle, Bat Conservation International, pers. comm., 1999).

Fall and Spring Roosts near Hibernacula

Limited work has been done on roosting habitats of Indiana bats in spring and fall, and most data are associated with areas near hibernacula on the Daniel Boone National Forest in Kentucky (Kiser and Elliot 1996, Gumbert et al. 2002). These studies show that Indiana bats use roosting sites in the spring and fall that are similar to sites selected during summer, i.e., bats typically roost under exfoliating bark, with occasional use of vertical crevices in trees. Species of tree also are similar to summer sites, although various pines (*Pinus* spp.) commonly are occupied in spring and fall. During this time, Indiana bats tend to roost more often as individuals than in summer. Roost switching occurs every two to three days and Indiana bats show fidelity to individual trees and roosting areas, within and among years. Various trees used by the same individual tend to be clustered in the environment, and roost trees most often are in sunny openings in the forest created by human or natural disturbance.

During autumn, when Indiana bats swarm and mate at hibernacula, male bats roost in nearby trees during the day and fly to the cave at night. In Kentucky, Kiser and Elliott (1996) found male Indiana bats roosting primarily in dead trees on upper slopes and ridgetops, within 2.4 km (1.5 mi) of their hibernaculum. During September, in West Virginia, male Indiana bats roosted within 5.6 km (3.5 mi) of their cave, in trees near ridgetops, and often switched roost trees from day to day (C. Stihler, West Virginia Division of Natural Resources, pers. comm., 1996). One Indiana bat in Michigan roosted 2.2 km (1.4 mi) away from the hibernaculum during fall swarming, and another chose trees at a distance of 3.4 km (2.1 mi) (Kurta 2000).

Summer Habitat

Microhabitat

Bark or Crevice

In summer, female Indiana bats usually roost under slabs of exfoliating bark, and they occasionally use narrow cracks within trees (Callahan 1993; Kurta et al. 1993a, 1993b, 2002; Carter 2003; Britzke et al. 2006). For example, longitudinal crevices that formed when trees were snapped by a tornado were used as primary roosts in Michigan (Kurta et al. 2002). Although other species of bats frequently occupy tree hollows that were created by rot or woodpeckers (Barclay and Kurta in press), such cavities are rarely used by maternity colonies of Indiana bats. Even a "hollow" sycamore (*Platanus occidentalis*) that was used by Indiana bats in Illinois (Kurta et al. 1993b) was a crevice in the bole and not a rot-related or woodpecker-induced cavity (A. Kurta, pers. comm., 2006).

Species of Tree

At least 33 species of trees have supplied roosts for female Indiana bats and their young (Table 5), and 87 percent are various ash (*Fraxinus*; 13 percent), elm (*Ulmus*; 13 percent), hickory (*Carya*; 22 percent), maple (*Acer*; 15 percent), poplar (*Populus*; 9 percent), and oak (*Quercus*; 15 percent). At one time, it appeared that oak and hickory were used more commonly at southern sites (Callahan et al. 1997, Gardner et al. 1991b), whereas elm, ash, maple, and cottonwood were occupied more often in northern areas (Kurta et al. 1996, 2002; Whitaker and Brack 2002). Recent work, however, shows Indiana bats occupying ash and elm in southern Illinois (Carter 2003) and hickories in Vermont (Palm 2003), so type of tree seems related more to local availability of trees with suitable structure than to broad regional preferences for particular species of tree. Nonetheless, some common trees, such as American beech (*Fagus grandifolia*), basswood (*Tilia americana*), black cherry (*Prunus serotinus*), box elder (*A. negundo*), and willows (*Salix* spp.) have rarely or never been used, suggesting that they typically are not suitable, especially as primary roosts.

Most (97 percent) roost trees of female Indiana bats at maternity sites are deciduous species, except for a few coniferous trees recently discovered in the Great Smoky Mountains (Harvey 2002, Britzke et al. 2003) and in New England (Palm 2003). Although this may indicate a preference for deciduous trees, it more likely reflects availability. Many other species of bats roost in conifers (Barclay and Kurta in press), and Indiana bats consistently use coniferous trees at some sites during autumn swarming (Gumbert et al. 2002).

Many species of tree apparently make suitable roosts (Table 5), but some species are preferred under certain circumstances. Kurta et al. (1996), for example, demonstrated a preference by Indiana bats for green ash (*F. pennsylvanica*) over silver maple (*A. saccharinum*) in Michigan, and Carter (2003) showed that Indiana bats chose green ash and pin oak (*Q. palustris*) more often than expected based on availability in Illinois. Both studies occurred at sites with very high snag densities. However, if suitable trees are less abundant, other factors that influence roost selection (e.g., canopy cover, exposure to wind, distance to foraging sites) may mask preferences displayed by bats in areas of superabundant roosts.

Living or Dead Trees

Most trees occupied by female Indiana bats in summer are dead or nearly so. Indiana bats sometimes are found under bark on large dead branches within a living tree or on a dead trunk of a living tree with multiple trunks. Indiana bats also occasionally roost under the naturally peeling bark of living trees, most often shagbark (*C. ovata*) and shellbark hickories (*C. laciniosa*) and occasionally white oak (*Q. alba*) (Callahan et al. 1997, Sparks 2003, Brack et al. 2004). These trees may be used especially as alternate roosts during exceptionally warm or wet weather (Humphrey et al. 1977, Callahan et al. 1997). Carter (2003), however, suggests that living trees are used as alternates only when suitable dead trees are not available.

Size of Tree

Roost trees vary in size (Tables 6 and 7). Although minimum diameter reported so far is 6.4 cm (2.5 in) for a tree used by males (Gumbert 2001) and 11 cm (4.3 in) for one occupied by females (Britzke 2003), such small trees have not been documented as primary roosts. Average diameter of roost trees (primary and alternate) is 62, 55, and 41 cm (24, 22, and 16 in) for Indiana, Missouri, and Michigan, respectively (Callahan et al. 1997, Kurta and Rice 2002, Whitaker and Brack 2002). Differences in average diameter among states likely reflect differences in species of tree contained in each sample—the Indiana sample is dominated by cottonwood; Missouri, by oak and hickory; and Michigan, by ash. The smallest mean diameter in Table 6 (28 cm or 11 in) is for five trees in Pennsylvania; however, the primary roost for this colony was a building, and no tree sheltered more than four bats (Butchkoski and Hassinger 2002).

Larger-diameter trees presumably provide thermal advantages and more spaces for more bats to roost. As with most tree-roosting bats (Hayes 2003, Barclay and Kurta in press), female Indiana bats probably select trees, especially primary roosts, that are larger in diameter than nearby, apparently suitable, but unoccupied trees (Kurta et al. 1996, 2002; Britzke et al. 2003; Palm 2003; Sparks 2003). Nevertheless, whether a statistical difference in diameter is detected between roost and randomly selected trees is partly dependent on the definition of a “suitable” or “available” tree. Differences between roosts and random trees have been found when the minimum diameter of available trees is set at 4.5, 10, or 15 cm (2, 4, or 6 in) (Kurta et al. 1996, 2002; Palm 2003; Sparks 2003) but not at 18.5 or 25 cm (7 or 10 in) (Callahan et al. 1997, Carter 2003). Inclusion of small trees in the pool of randomly selected trees seems justified, because there are numerous instances of one or more Indiana bats using them; hence, they are “available” to the bats.

Average heights of roost trees range from 16 to 26 m (52 to 85 ft) (Tables 6 and 7). Variation in height among studies likely reflects species differences in the sample of roost trees but also in the manner in which the trees died. For example, roost trees at one site in Michigan were killed slowly by inundation and had an average height of 25 m (82 ft), whereas roosts at a second site were broken in a wind storm and averaged only 18 m (59 ft) (Kurta et al. 1996, 2002). Minimum tree heights are 3 m (10 ft) for an alternate roost (Carter 2003) and 3.7 m (12 ft) for a primary roost (Callahan 1993). Absolute height of the roost tree probably is less important than height relative to surrounding trees, because relative height can affect the amount of solar radiation impinging on the tree (e.g., Kurta and Rice 2002), ease of finding the tree, and ease of safely approaching the roost in flight (Barclay and Kurta in press, Hayes 2003).

Among 16 studies, mean height of the exit, which also is assumed to be the height of the roosting area, was 5 to 16 m (16 to 52 ft), although the mean more commonly ranged from 7 to 10 m (23 to 33 ft) (Table 6). Nevertheless, minimum exit height for a primary roost is 1.8 m (6 ft); for an alternate roost it is only 0.6 m (2 ft) (Callahan 1993). Height of the exit is correlated with height of the tree (Kurta et al. 2002).

Other Factors Affecting Access and Sunlight

In addition to height, other factors influence the amount of sunlight striking a roost tree and simultaneously impact the ease and safety of access for a flying bat (Barclay and Kurta in press). For example, roosts of the Indiana bat, especially primary roosts, typically are found in open situations, although definitions of "open" vary (Gardner et al. 1991b; Kurta et al. 1993b, 1996, 2002; Callahan et al. 1997; Carter 2003; Palm 2003; Sparks 2003). The immediate vicinity of a roost, especially a primary roost, often is open forest, or roosts may occur along the edge of a woodlot, in gaps within a forest, in a copse of dead trees, as part of a wooded fenceline, in grazed woodlands, or in pastures with scattered trees. When present in denser forests, primary roost trees often extend above the surrounding canopy (e.g., Callahan et al. 1997). Roosts occasionally occur in low-density residential areas with mature trees (e.g., Belwood 2002).

Mean values of canopy cover are highly variable among studies, ranging from <20 to 88 percent (Tables 6 and 7). Reports of roost trees in closed-canopy forests (e.g., Gardner et al. 1991b reported that 32 of 48 roost trees examined in Illinois occurred within forests with 80 percent to 100 percent canopy closure) may appear to conflict with statements that primary roosts are generally located in areas with high solar exposure. There are several points to consider in evaluating this apparent discrepancy. First, some variation undoubtedly is related to differences in methodology, because virtually every study measures canopy cover in a different way. Second, roosts found in closed-canopy forests, particularly primary roosts, are often associated with natural or man-made gaps (e.g., openings created when nearby trees fall, riparian edges, trail or forest road edges). Although the forest may be accurately described as closed canopy, the canopy in the immediate vicinity of the roost tree may have an opening that allows for solar radiation to reach the roost. Indiana bat roosts have been created by the death of a single large-canopy tree (A. King, USFWS, pers. comm., 2005).

Regional differences in roost characteristics also account for some of the variability in canopy cover in the vicinity of Indiana bat roost sites. For example, average values for canopy cover may be higher in areas where many living shagbark hickories are used as alternate roosts (e.g., Palm 2003), compared with sites where most roost trees are dead and leafless (e.g., Kurta et al. 1996, 2002). In addition, Indiana bats may use sites that are more shaded during warm weather (e.g., Callahan et al. 1997). Sites in northern areas (e.g., Kurta et al. 1996) or at high altitudes (e.g., Britzke et al. 2003) are exposed to cooler temperatures, so use of highly shaded roosts probably is less common in these areas and may be restricted to periods of unusually warm weather, which may not occur every year. For example, a colony of 30 Indiana bats in Michigan used a tree with 58 percent canopy cover and an open southern exposure, but all bats shifted to a nearby tree with 90 percent canopy cover after a prolonged period of abnormally high ambient temperature (>32°C or 89.6°F) (L. Winhold, pers. comm., 2005). In a typical year, however, Indiana bats generally do not use such highly shaded sites in Michigan (Kurta et al. 1996, 2002).

Table 5. Species of tree and type of roosting site used by Indiana bats, based on studies conducted through 2004 (from Kurta 2005).

Scientific Name	Common Name	Type of Roost ^a	Number of trees used by adult		Percent of trees used by adult		Number of trees used by adult		Percent of trees used by adult		References ^b
			females and young	males	females and young	males	females and young	males	females and young	males	
<i>Acer rubrum</i>	Red maple	B, C	7		1.8	13		5.4			2, 4, 9, 12, 13, 16, 17
<i>Acer saccharinum</i>	Silver maple	B	25		6.4	1		0.4			5, 6, 8, 13, 18, 19
<i>Acer saccharum</i>	Sugar maple	B, C	18		4.6	2		0.8			1, 2, 8, 16-20
<i>Acer</i> sp.	Unidentified maple	B	9		2.3	0		0.0			13
<i>Betula alleghaniensis</i>	Yellow birch	?	2		0.5	0		0.0			2, 16
<i>Betula lenta</i>	Sweet birch	B	1		0.3	0		0.0			3
<i>Carya cordiformis</i>	Bitternut hickory	B	3		0.8	1		0.4			8, 11, 18, 19
<i>Carya glabra</i>	Pignut hickory	B	0		0.0	3		1.3			12, 17
<i>Carya laciniosa</i>	Shellbark hickory	B	4		1.0	0		0.0			18, 19
<i>Carya ovata</i>	Shagbark hickory	B	78		19.8	22		9.2			2, 5, 6, 8-13, 16-21
<i>Carya tomentosa</i>	Mockernut hickory	?	0		0.0	7		2.9			9
<i>Celtis occidentalis</i>	Northern hackberry	B	1		0.3	0		0.0			18, 19
<i>Cornus florida</i>	Flowering dogwood	?	0		0.0	4		1.7			9
<i>Fagus grandifolia</i>	American beech	?	1		0.3	0		0.0			2
<i>Fraxinus americana</i>	White ash	C	1		0.3	0		0.0			5
<i>Fraxinus nigra</i>	Black ash	B	4		1.0	3		1.3			13
<i>Fraxinus pennsylvanica</i>	Green ash	B, C	46		11.7	4		1.7			2, 6, 13, 18, 19
<i>Gleditsia triacanthos</i>	Honeylocust	B	2		0.5	0		0.0			7
<i>Juglans cinerea</i>	Butternut	B	1		0.3	0		0.0			20
<i>Juglans nigra</i>	Black walnut	B	1		0.3	0		0.0			18, 19
<i>Liriodendron tulipifera</i>	Tulip tree	B	1		0.3	6		2.5			9, 15
<i>Ostrya virginica</i>	Hophornbeam	B	1		0.3	0		0.0			20
<i>Oxydendrum arboreum</i>	Sourwood	?	0		0.0	9		3.8			9, 12
<i>Pinus echinata</i>	Shortleaf pine	B	2		0.5	70		29.3			3, 9
<i>Pinus rigida</i>	Pitch pine	B	1		0.3	6		2.5			3, 9
<i>Pinus</i> sp.	Unidentified pine	B	1		0.3	4		1.7			3, 10, 21
<i>Pinus strobus</i>	White pine	B, C	8		2.0	0		0.0			16, 20
<i>Pinus virginiana</i>	Virginia pine	?	0		0.0	15		6.3			9, 12
<i>Platanus occidentalis</i>	Sycamore	C	2		0.5	0		0.0			14, 18, 19

<i>Populus deltoides</i>	Cottonwood	B, C	25	6.4	0	0.0	5, 6, 8, 13, 18, 19, 21
<i>Populus</i> sp.	Unidentified poplar	B	5	1.3	0	0.0	20
<i>Populus tremuloides</i>	Trembling aspen	B	5	1.3	0	0.0	2, 16
<i>Quercus alba</i>	White oak	B	15	3.8	18	7.5	5, 8, 9, 17, 21
<i>Quercus coccinea</i>	Scarlet oak	?	0	0.0	5	2.1	9, 12
<i>Quercus falcata</i>	Spanish oak	?	0	0.0	1	0.4	9
<i>Quercus imbricaria</i>	Shingle oak	B	0	0.0	1	0.4	8
<i>Quercus palustris</i>	Pin oak	B	8	2.0	0	0.0	6
<i>Quercus prinus</i>	Chestnut oak	?	0	0.0	6	2.5	9
<i>Quercus rubra</i>	Red oak	B	30	7.6	9	3.8	3, 4, 5, 8-10, 12, 13, 21
<i>Quercus</i> sp.	Unidentified oak	B	3	0.8	0	0.0	20
<i>Quercus stellata</i>	Post oak	B	3	0.8	2	0.8	8
<i>Quercus velutina</i>	Black oak	B	0	0.0	2	0.8	9, 17
<i>Robinia pseudoacacia</i>	Black locust	B, C	12	3.1	0	0.0	2, 20
<i>Sassafras albidum</i>	Sassafras	B, Ca	0	0.0	2	0.8	8
<i>Tilia americana</i>	Basswood	B	1	0.3	0	0.0	20
<i>Tsuga canadensis</i>	Eastern hemlock	B	3	0.8	0	0.0	2, 3, 20
<i>Ulmus americana</i>	American elm	B	35	8.9	14	5.9	2, 4, 8, 9, 13, 16-22
<i>Ulmus rubra</i>	Slippery elm	B, C	9	2.3	9	3.8	4, 7, 8, 9, 13, 21
<i>Ulmus</i> sp.	Unidentified elm	B	8	2.0	0	0.0	6
Unidentified		B	11	2.8	0	0.0	2, 6, 13
Total			393	100.0	239	100.0	

^a Type of roost: B = under bark; C = in crevice; and Ca = in cavity. Not all references indicated specifically which species of tree provided a bark vs. a crevice roost.

^b References are: 1, Belwood 2002; 2, Britzke 2003; 3, Britzke et al. 2003; 4, Butchkoski and Hassinger 2002; 5, Callahan 1993; 6, Carter 2003; 7, Cheng 2003; 8, Gardner et al. 1991b; 9, Gumbert 2001; 10, Harvey 2002; 11, Humphrey and Cope 1977; 12, Kiser and Elliott 1996; 13, Kurta and Rice 2002; 14, Kurta et al. 1993b; 15, A. Kurta, pers. comm., 2004; 16, Palm 2003; 17, Schultes 2002; 18, Sparks 2003; 19, D. Sparks Indiana State University, pers. comm., 2004; 20, K. Watrous, pers. comm., 2004; 21, Whitaker and Brack 2002; and 22, L. Winhold, Eastern Michigan University, pers. comm., 2004.

Table 6. Means or ranges (n) for roost parameters of adult female and/or young Indiana bats in various studies conducted through 2004 (from Kurta 2005). All means were rounded to the nearest whole number to facilitate comparison. Means were taken from the indicated references or calculated based on tabulated data contained in each reference.

Location/parameter	Diameter of tree (cm)	Height of tree (m)	Height of exit or roosting area (m)		Bark remaining (%) ^a	Canopy cover (%)	Reference
			area (m)	area (m)			
Illinois	39 (47)	18 (47)	10 (47)	10 (47)	47 (47)	36 (47)	Carter, 2003
Illinois	37 (48)						Gardner et al., 1991b
Illinois	56 (1)	16 (1)	5 (1)				Kurta et al., 1993b
Indiana							Humphrey et al., 1977
Indiana	47 (27)	23 (27)	9 (25)				Sparks, 2003
Indiana	62 (17)						Whitaker and Brack, 2002
Michigan	41 (23)	25 (23)	10 (23)				Foster and Kurta, 1999; Kurta et al. 1996
						0-20	
						(23) ^b	
Michigan	42 (38)	18 (38)	10 (34)			31 (35)	Kurta et al. 2002; A. Kurta, pers. comm., 2004
Michigan	43 (3)	26 (3)	16 (3)		60 (3)	54 (3)	L. Winhold, pers. comm., 2004
Missouri	54 (38)				73 (21)	67 (38)	Callahan, 1993; Callahan et al., 1997
New York, Vermont ^c	46 (31)	19 (34)					Britzke, 2003
New York, Vermont	48 (50)	21 (50)	7 (18)				K. Watrous, pers. comm. 2004
Pennsylvania	28 (5)	20 (5)	8 (5)		51 (5)		Butchkoski and Hassinger, 2002
North Carolina,	46 (8)	18 (8)			46 (18)		Britzke et al., 2003
Tennessee							
Ohio	38 (2)	21 (1)					Belwood, 2002
Vermont	50 (20)				77 (13)	88 (20)	Palm, 2003
Average \pm SE ^d	45 \pm 2	20 \pm 1	9 \pm 1		59 \pm 5	50 \pm 10	
Number of studies	15	11	8		6	6	
Number of trees	359	231	141		88	128	

^a Total bark on tree, not just loose and peeling.

^b A liberal value of 20% was used when calculating the overall mean.

^c Trees were located primarily in April and early May; all other studies were mid-May to mid-August.

^d Calculations of overall average and SE used the unweighted means from the various studies. Weighting each study, based on the number of trees, gave very similar results.

Table 7. Means (n) for roost parameters and roosting behavior of adult male Indiana bats in various studies conducted through 2004 (from Kurta 2005). All means were rounded to the nearest whole number to facilitate comparison. Means were taken from the indicated references or calculated based on tabulated data in each reference.

Location/ parameter	Diameter of tree (cm)	Height of tree (m)	Height of exit or roosting area (m)	Bark remaining (%) ^c	Canopy cover (%)	Reference
Illinois	32 (18)					Gardner et al., 1991b
Indiana	38 (12)	25 (1)		25 (12) ^b	49 (12)	Brack et al., 2004; Whitaker and Brack, 2002
Iowa	43 (1)	20 (1)	13 (1)			Chenger, 2003
Kentucky ^c	31 (169)	15 (169)			58 (169)	Gumbert, 2001; Gumbert et al., 2002
Kentucky	31 (8)			61 (8)		Kiser and Elliot, 1996
Michigan	37 (9)	21 (9)	9 (9)			Kurta and Rice, 2002
Ohio	32 (14)	16 (14)		56 (14)	81 (14)	Schultes, 2002
Pennsylvania	20 (2)	18 (2)	9 (2)	53 (2)		Butchkoski and Hassinger, 2002
Average \pm SE ^d	33 \pm 2	18 \pm 1	10 \pm 1	57 \pm 1	63 \pm 10	
Number of studies	8	5	3	3	3	
Number of trees	219	189	12	25	128	

^a Total bark on tree, not just exfoliating, unless otherwise noted.

^b Amount of exfoliating bark; not used in calculation of mean.

^c Data collected from April through October; all others apparently were mid-May to mid-August. Data from Gumbert (2001) are confounded slightly with trees used by adult females (7.6% of bats located were female) and by multiple counting of trees (9.2%) used in more than one season (spring, summer, autumn).

^d Calculations of overall average and SE used the unweighted means from the various studies. Weighting each study, based on the number of trees, gave very similar results.

Access by a flying bat and amount of sunlight striking the roost could be affected negatively by presence on the trunk of living or dead vines, such as wild grape (*Vitis* spp.) or Virginia creeper (*Parthenocissus quinquefolia*). In Michigan, all roost trees ($n = 76$) lacked vines at or above the roosting area, although no comparison was made with randomly selected trees (Kurta and Rice 2002; A. Kurta, pers. comm., 2005). A roost shaded by poison ivy (*Rhus radicans*) was observed in New York (V. Brack, pers. comm., 2006).

Amount of Bark Remaining

Amount of bark remaining on a tree is another parameter that often is measured, although not always in the same way. Some biologists record the total amount of bark remaining on a tree, whether the bark is suitable for roosting or not (e.g., Callahan et al. 1997), whereas other researchers record only the amount of exfoliating bark under which a bat might roost (e.g., Gardner et al. 1991b; Kurta et al. 1996, 2002). The two techniques must be distinguished because they mean different things—total bark indicates stage of decay, whereas exfoliating bark indexes roosting opportunities; consequently, the two methods can yield different results. For example, a randomly selected tree that recently died may be covered totally by bark and yield a value of 100 percent; however, the same tree would be totally unsuitable for roosting, because all bark is still tight to the trunk. Although there is potential for confusion, neither the amount of total bark nor the amount of exfoliating bark is useful as a predictor of current occupancy by Indiana bats (Kurta et al. 1996, 2002; Callahan et al. 1997; Gumbert 2001; Britzke et al. 2003; Carter 2003; Palm 2003).

Primary vs. Alternate Roosts

Despite the number of studies of Indiana bats, few reports have statistically compared the attributes of primary roosts and alternate trees. In Missouri, primary trees were more likely to be in open situations, as opposed to the interior of the woods, and more likely to be dead trees, rather than living shagbark hickories; alternate roosts, in contrast, were more variable and could be either interior or open trees (Callahan et al. 1997). No other statistical differences were found between primary and alternate trees (Callahan et al. 1997). In Michigan, both primary and alternate roosts typically were in open sites, and there was no statistical difference between primary and alternate roosts in tree height, exit height, canopy cover, solar exposure, or amount of bark (Kurta et al. 1996, 2002). In addition, mean diameter did not differ, although diameter of primary trees was less variable than that of alternate roosts in Michigan (Kurta et al. 2002).

One proposed function of frequent roost switching by tree-living bats is that individuals are evaluating new trees for future use (Barclay and Kurta in press). Hence, primary roosts likely were alternate roosts initially, although most alternate roosts never become primary roosts. If so, an inability to detect statistical differences between primary and alternate roosts is understandable, because primary roosts represent a small subset of all sites that were evaluated by the bats. Alternate roosts probably are more variable in most parameters than are primary roosts (Callahan et al. 1997; Kurta et al. 2002), although most reports do not address the degree of variation.

A Summary of Characteristics of a Typical Primary Roost

Individual Indiana bats have been found roosting in a large number of types of trees and situations, but it is possible to summarize the essential characteristics of a typical primary roost.

A typical primary roost is located under exfoliating bark of a dead ash, elm, hickory, maple, oak, or poplar, although any tree that retains large, thick slabs of peeling bark probably is suitable. Average diameter of maternity roost trees is 45 cm (18 in) (Table 6) and average diameter of roosts used by adult males is 33 cm (13 in) (Table 7). Height of the tree (snag) is greater than 3 m (10 ft), but height of the roosting tree is not as important as height relative to surrounding trees and the position of the snag relative to other trees, because relative height and position affect the amount of solar exposure. Primary roosts usually receive direct sunlight for more than half the day. Access to the roost site is unimpeded by vines or small branches. The tree is typically within canopy gaps in a forest, in a fenceline, or along a wooded edge. Primary roosts usually are not found in the middle of extensive open fields but often are within 15 m (50 ft) of a forest edge. Primary roosts usually are in trees that are in early-to-mid stages of decay.

Roosts during Spring

Most studies of roosting preferences by adult females have occurred during the summer maternity season, which is typically defined as 15 May to 15 August. However, Indiana bats first arrive at their summer locations as early as April or early May (Humphrey et al. 1977, Kurta and Rice 2002). During this mid-spring period, adult females occupy trees that are similar to those used in summer in terms of species, size, and structure (Britzke 2003, Butchkoski and Turner 2005, Britzke et al. 2006).

Sexual Differences in Habitat Use

Adult males of most species of bats probably enter torpor in summer more frequently than reproductive females, and hence, males probably can use a wider range of roosting situations than females (Barclay and Kurta in press). Some adult male Indiana bats form colonies in caves in summer (Hall 1962), but most are solitary and roost in trees. Adult males have been radiotracked to at least 239 trees of 26 species in eight states (Table 5). Males occasionally roost with reproductive females in the same tree, and males have been tracked to trees up to 95 cm (37 in) in diameter (Kurta and Rice 2002). However, males accept small trees more often than do females, and consequently, mean diameter of trees used by females and young (18 in or 45 cm; $n=359$) is 36 percent greater than the average for males (13 in or 33 cm; $n = 219$; Tables 6 and 7). Males also may be more tolerant of shaded sites.

Like female Indiana bats, adult males roost primarily under bark and less often in narrow crevices, but two males have been tracked to small cavities in trees (Gardner et al. 1991b, Gumbert 2001). Tree species used by males generally are similar to those chosen by females, although males have been found more frequently in pines (Table 5). The large number of conifers used by males, however, likely reflects the abundance of these trees in the forest surrounding certain caves in Kentucky, where the most intensive studies of male roosting have occurred (Kiser and Elliott 1996, Gumbert 2001).

Artificial Roosts

During summer, female and juvenile Indiana bats roost almost always in trees, as do adult males. Adult females, however, apparently used a crevice in a utility pole in Indiana (Ritzi et al. 2005), and adult males were found under metal brackets on utility poles in Arkansas (Harvey 2002). There also are a few instances of adult male and juvenile Indiana bats day-roosting under concrete bridges in Indiana (reviewed in Kiser et al. 2002). Although a few Indiana bats have

been captured in buildings during migration (before 15 May or after 15 August; Belwood, 2002), only four maternity colonies have been located in buildings. These include an abandoned church in Pennsylvania (Butchkoski and Hassinger, 2002), two houses in New York (A. Hicks, pers. comm., 2004; V. Brack, pers comm., 2005) and a barn in Iowa (Chenger 2003). Nevertheless, there are almost 400 roost trees for female Indiana bats indicated in Table 5, suggesting that use of buildings by maternity colonies is uncommon.

Similarly, bat houses are rarely occupied by Indiana bats. Reproductive females from the church in Pennsylvania also used a large free-standing bat house as an alternate roost, as well as a smaller bat house wrapped in aluminum sheeting (Butchkoski and Hassinger 2002, Butchkoski and Turner 2005). Before 2003, the only other published records of Indiana bats using bat houses were two solitary juvenile males using different bird-house-style bat boxes and a group of females in a rocket box after the reproductive period (Carter et al. 2001, Ritzi et al. 2005). However, Ritzi et al. (2005) recently found groups of reproductive females using two bird-house-style bat boxes for prolonged periods in Indiana. Use of these artificial structures coincided with destruction of two primary roost trees, and the authors speculated that portions of the colony were using the boxes as temporary replacements. The boxes had been in place for 11 years before being occupied and were two of 3,204 artificial structures of various styles that had been constructed.

Landscape Structure and Macrohabitat

Distance to Environmental Features

Distances from roosts to nearby environmental features have rarely been measured. Trees used by a colony in Illinois were closer to unpaved than paved roads and closer to intermittent streams than to perennial streams, although no comparison was made with randomly selected points (Gardner et al. 1991b). In Michigan, roost trees were closer to perennial streams than random locations, but there was no difference between roosts and random points in distance to roads of any type or to lakes/ponds (Kurta et al. 2002).

Insectivorous bats typically obtain 20 to 26 percent of their daily water from drinking (Kurta et al. 1989, 1990), and one might think that roost trees should be closer to water sources than random points. In upland areas lacking streams or lakes, Indiana bats, especially adult males, have been captured while flying over wildlife ponds and at water-filled road ruts (e.g., Wilhide et al. 1998), suggesting that the bats might be attracted to these artificial sources of water. However, water sources are ubiquitous in most areas where Indiana bat maternity roosts have been found. At one maternity site in Michigan, for example, average distance from a random point to a perennial stream is only 910 m (2,986 ft) and to a lake or pond, 541 m (1,775 ft) (Kurta et al. 2002). Such distances are energetically insignificant to a flying mammal (Barclay and Kurta in press), and distance to water likely does not impact selection of individual trees, at least in those areas of the continent where most maternity colonies of Indiana bats have been located. Although distance to water probably is not a factor in day-to-day roost selection, accessible sources of water might affect location of the home range of a colony on a broader landscape, i.e., colonies may locate in areas of more abundant, accessible sources of water (Carter et al. 2002).

Commuting Corridors

Many species of bats, including the Indiana bat, consistently follow tree-lined paths rather than cross large open areas (Gardner et al. 1991b, Verboom and Huitema 1997, Carter 2003, Chenger 2003, Murray and Kurta 2004, Winhold et al. 2005). Therefore, suitable patches of forest may not be available to Indiana bats unless the patches are connected by a wooded corridor, i.e., a component of suitable habitat may be the connectedness of different forest patches.

Unfortunately, biologists do not know how large an open area must be before Indiana bats hesitate or refuse to cross. There are observations of Indiana bats crossing interstate highways (Brack and Whitaker 2004) and open fields (Brack 1983). V. Brack (pers. comm., 2006) noted that he has observed Indiana bats following linear features not associated with tree cover, such as a treeless channelized ditch. Murray and Kurta (2004), however, showed that Indiana bats increased commuting distance by 55 percent to follow tree-lined paths, rather than flying over large agricultural fields, some of which were at least 1-km (0.6 mi) wide (Winhold et al. 2005).

Surrounding Habitats

At one time, the Indiana bat was considered a riparian specialist (Humphrey et al. 1977), but further study demonstrated that this categorization is not valid. Maternity roosts of some colonies have been found primarily in riparian zones (Humphrey et al. 1977), bottomland and floodplain habitats (Carter 2003), upland communities (Gardner et al. 1991b, Palm 2003), or in a mix of riparian and upland habitat (Callahan 1993). Indiana bats in Michigan (Kurta et al. 2002), in contrast, preferred roosting in wooded wetlands; although some roosts were in the floodplain of a major river, most were in low areas not associated with the river. Differences among studies probably reflect at least partly the varying location of intact woods in different agricultural landscapes (Murray and Kurta 2002, 2004).

Although the presence of female Indiana bats (i.e., maternity colonies) generally is not correlated with high forest cover, several studies suggest a correlation with the density of suitable roost trees. Miller et al. (2002) compared landscape and macrohabitat features surrounding sites where female Indiana bats were caught (i.e., maternity colonies) to sites where they were not caught in Missouri. While the study found that landscape features (e.g., forest cover) were too variable to accurately show differences between occupied and unoccupied sites, the occupied sites contained a higher density of large-diameter trees. Similarly, after analyzing a model for predicting habitat suitability, Farmer et al. (2002) concluded that the amount of land in forest, number of different habitats available, and area of water were not useful for predicting presence of Indiana bats. However, they reported that the utility of the model was based on a single component—density of suitable roost trees; and Indiana bats were more likely to occur in areas with a high density of potential roost trees (see also Clark et al. 1987).

Composition of the landscape surrounding a colony's home range was determined for a few maternity colonies. In Illinois, 67 percent of the land near one colony was agricultural, 33 percent was forested, and 0.1 percent consisted of farm ponds (Gardner et al. 1991b). In Michigan, landcover consisted of 55 percent agricultural land, 19 percent wetlands (including lowland hardwood forest), 17 percent other forests, 6 percent urban development, and 3 percent lakes/ponds/rivers (Kurta et al. 2002). Land within 4 km (2.5 mi) of primary roosts in Indiana contained an average of 37 percent deciduous forest cover, although forest cover varied from 10 to 80 percent (L. Pruitt, USFWS, pers. comm., 2005).

Using GIS, Carter et al. (2002) compared habitats in circles that were 2 km (1.2 mi) in diameter surrounding all roost trees known in Illinois with habitat surrounding randomly selected locations. Areas around roosts had fewer and smaller urban patches and more and larger patches of closed-canopy deciduous forest compared with random sites. Area and number of patches of coniferous forest did not differ between roosting and random locations, but roosting areas had more patches of water (e.g., ponds, lakes) than random sites. Finally, while roosts typically occurred in highly fragmented forests, roosting areas contained more patches of bottomland forest and agriculture than randomly chosen circles. Even though roosting areas contained more agriculture patches than randomly chosen circles, the overall area of agriculture was less for roosting areas. With regard to bottomland forests, the mean patch size of bottomland forest around known roost trees was 35.9 ha (88.7 ac) and the total area was 82.7 ha (204.4 ac), as compared to a mean patch size of bottomland forest around the randomly chosen circles of 1.5 ha (3.7 ac) and 2.7 ha (6.7 ac) for total area.

A Missouri study found that Indiana bats selected maternity roost sites based upon tree size, tree species, and surrounding canopy cover (Callahan 1993). In his study, the amount of forest within a 3-km (1.9 mi) radius of four maternity sites varied from 19 to 30 percent, while the amount of forest within a "minimum roost tree range" (i.e., the minimum-sized circle that would encompass all roost trees used by a colony) around the same four colonies ranged from 23 to 53 percent; the amount of agricultural land within the larger radius ranged from 58 to 81 percent, while the amount of agricultural land within the smaller radius ranged from 47 to 77 percent (Callahan 1993). Callahan suggested that the potential preference of Indiana bat maternity colonies for larger forested tracts would increase the chances that a suitable range of roost trees would be available for the colonies.

On a much larger scale, Gardner and Cook (2002) examined landcover in 132 counties in the United States for which there was evidence of reproduction by Indiana bats. Nonforested habitats, primarily agricultural land, made up 75.7 percent of the total land area in those counties. Deciduous forest covered 20.5 percent of the land, whereas coniferous forests and mixed coniferous/deciduous woodland occupied 3.4 percent.

Most Indiana bat maternity colonies have been found in agricultural areas with fragmented forests. Most females from the major hibernacula in Indiana, Kentucky, and Missouri migrate north for summer, into agricultural landscapes of the Midwest (Gardner and Cook 2002, Whitaker and Brack 2002). Similarly, recently discovered colonies in Vermont and New York also occur in agricultural regions and other areas with fragmented forests. Bats from hibernacula in New York were followed with aircraft as they left hibernation and migrated to agricultural areas of the Lake Champlain Valley and southern New York (Britzke 2003; A. Hicks, pers. comm., 2004, 2005). However, maternity colonies of Indiana bats have also been found in large forested blocks, even in predominantly agricultural states such as Indiana. For example, at least five maternity colonies are known on the Big Oaks National Wildlife Refuge, where 88 percent of the land is classified as forest or forested grassland (L. Pruitt, pers. comm., 2006). It is possible that areas from which many maternity colonies are known, such as northern Indiana, southern Michigan, or the Lake Champlain Valley, simply occupy the historical summer range of the species, and today the bats are using the best of whatever wooded areas are still available.

Although most focus to date has been on the extent of wooded areas that Indiana bats require, there are additional and possibly interrelated factors that may contribute to where Indiana bats typically reproduce on the continent. Climate likely plays an important role (Clark et al. 1987, Brack et al. 2002). As noted by Brack et al. (2002): "Areas of higher latitudes and elevations typically are cooler and wetter, and higher elevations experience greater seasonal variability, all of which can reduce the food supply, increase thermoregulatory demands, and reduce reproductive success of bats." Brack et al. (2002) suggested climate as a potential explanation for why forest cover is generally not predictive of the presence of Indiana bats, and why the species is more abundant in portions of its range where forest cover is lower, at a landscape scale. They noted: "The geographic association of good (i.e., warm) summer and good (i.e., cold) winter habitat is limiting for the Indiana bat (*Myotis sodalis*)."

They further explained that during summer, the Indiana bat is most common in an area of the Midwest, comprised of most of Indiana and Illinois, southern Iowa, southern Michigan, the northern half of Missouri, and western Ohio. This area accounts for more than 80 percent of known maternity colonies (USFWS 2004a). This portion of the species range is warmer in summer than more heavily forested parts of the species range to the east and northeast, where relatively higher latitudes and elevations typically are cooler and wetter, and temperatures at higher elevations are more variable, adding significantly to the cost of reproduction. Maternity colonies in this portion of the range are more likely to be found at lower elevations, where temperatures are more conducive to reproduction. For example, the recently discovered colonies in the Lake Champlain Valley occur in an area of fragmented forests relative to extensively forested and higher elevation areas nearby in the Adirondack Mountains. Harvey (2002) and Britzke et al. (2003) reported on the first documented maternity colony in western North Carolina on the Nantahala National Forest at an elevation of 1,158 m, the highest elevation reported for a maternity colony of Indiana bats (Britzke et al. 2003). The colony was originally located in 1999, and surveys at the site in 2000 failed to document the presence of the bats. Maternity colonies were located the same year in adjoining counties in eastern Tennessee in the Great Smoky Mountains National Park (Harvey 2002, Britzke et al. 2003). These colonies were found at elevations of 610 m and 670 m, and were subsequently relocated in both 2000 and 2001.

Other potential factors that likely affect where Indiana bats reproduce include distance from suitable hibernacula, competition for food with other species of bats, and competition with other bats or birds for roosting sites (Clark et al. 1987, Kurta and Foster 1995, Foster and Kurta 1999, Murray and Kurta 2002, Sparks 2003).

In summary, most maternity colonies of Indiana bats that are known exist in fragmented landscapes with low-to-moderate forest cover. However, it is not clear whether the distribution of known colonies reflects a preference for fragmented forests, a need for specific climates that happen to occur where forests have been fragmented by humans, degree of survey effort by biologists in different areas of the range, or some other factor. Maternity colonies of Indiana bats have been found in environments that vary considerably in amount of forest cover, and further study is needed to determine whether survival or productivity varies, positively or negatively, with the amount and type of forest available and the degree of fragmentation that is present.

Foraging Habitat

Observations of light-tagged animals and bats marked with reflective bands indicate that Indiana bats typically forage in closed to semi-open forested habitats and forest edges (Humphrey et al. 1977, LaVal et al. 1977, Brack 1983). Radiotracking studies of adult males, adult females, and juveniles consistently indicate that foraging occurs preferentially in wooded areas, although type of forest varies with individual studies; Indiana bats have been detected through telemetry using floodplain, riparian, lowland, and upland forest (Garner and Gardner 1992; Hobson and Holland 1995; Menzel et al. 2001; Butchkoski and Hassinger 2002; Cheng 2003; Sparks 2003; Murray and Kurta 2004; Sparks et al. 2005a, 2005b). Indiana bats hunt primarily around, not within, the canopy of trees, but they occasionally descend to subcanopy and shrub layers. In riparian areas, Indiana bats primarily forage around and near riparian and floodplain trees, as well as solitary trees and forest edges on the floodplain (Cope et al. 1974, Humphrey et al. 1977, Belwood 1979, Clark et al. 1987). Within floodplain forests where Indiana bats forage, canopy closures range from 30 to 100 percent (Gardner et al. 1991a).

Nevertheless, Indiana bats have been caught, observed, and radiotracked foraging in open habitats (Humphrey et al. 1977; Brack 1983; Clark et al. 1987; Hobson and Holland 1995; Gumbert 2001; Sparks et al. 2005a, 2005b). In Indiana, individuals foraged most in habitats with large foliage surfaces, including woodland edges and crowns of individual trees (Brack 1983). Many woodland bat species forage most along edges, an intermediate amount in openings, and least within forest interiors (Grindal 1996).

Analyses of habitats used by radiotracked adult females while foraging versus those habitats available for foraging have been performed in two states. In Illinois, floodplain forest was the most preferred habitat, followed by ponds, old fields, row crops, upland woods, and pastures (Gardner et al. 1991b, Garner and Gardner 1992). In Indiana, woodlands were used more often than areas of agriculture, low-density residential housing, and open water, and this latter group of habitats was used more than pastures, parkland, and heavily urbanized sites (Sparks 2003; Sparks et al. 2005a, 2005b). Old fields and agricultural areas seemed important in both studies, but bats likely were foraging most often along forest-field edges, rather than in the interior of fields, although errors inherent in determining the position of a rapidly moving animal through telemetry made it impossible to verify this (Sparks et al. 2005b). Nevertheless, visual observations suggest that foraging over open fields or bodies of water, more than 50 m (150 ft) from a forest edge, does occur, although less commonly than in forested sites or along edges (Brack 1983, Menzel et al. 2001).

In Virginia in autumn, Brack (2006) found that Indiana bats were active in nine habitats, and used open deciduous forests more than available, and developed lands, closed deciduous habitats, and mixed deciduous-evergreen habitats less than available. Agricultural lands, intermediate deciduous forests, old field, and water were used in proportion to availability. Wooded pastures (agricultural) and recently logged areas (open woodland) also provided foraging habitat. As the autumn progressed, these bats included less agricultural habitat and more deciduous forests (combined open, intermediate, and closed canopy) in their activity areas. Relative abundance of insect prey in open, exposed agricultural lands decreases with cooling temperatures and crop harvest.

Habitat Suitability Index Models

Two habitat suitability index (HSI) models are available for maternity sites of the Indiana bat in the Midwest, but neither has been sufficiently validated. The model of Rommé et al. (1995) uses nine variables, including two with subvariables. The model provides output to independently evaluate the quality of roosting and foraging habitat, and provides an evaluation of overall summer habitat quality as affected by two landscape-scale attributes.

The model of Farmer et al. (2002) distilled the model of Rommé et al. (1995) down to only three variables, including number of habitat types that contributed more than 10 percent of the surrounding area, density of suitable roost trees, and percent of land in forest. Based on mist-netting data previously gathered in Missouri by Miller (1996), Farmer et al. (2002) concluded that only the density of suitable roost trees was potentially useful in predicting whether Indiana bats were present in a particular area. Farmer et al. (2002) were careful to point out that sound empirical support was lacking for various components of their model.

Carter (2005) recently used data collected in Illinois in a post-hoc test of both models. Although he believed his study area should be considered well above average (HSI of 0.8 to 0.9) in terms of quality of habitat, the model of Rommé et al. (1995) resulted in a value of only 0.42. The model of Farmer et al. (2002), in contrast, indicated an HSI of up to 0.8, suggesting that it might be more useful. Although such a post-hoc test is suggestive, the value of these HSI models will remain in doubt until they are validated through field studies that are designed and implemented specifically to test the predictions of the models at multiple sites. Carter (2005) noted that the HSI models assume a circular home range, although bats frequently use linear landscape elements (e.g., streams).

Critical Habitat

Critical habitat was designated for the species on 24 September 1976 (41 FR 41914). Eleven caves and two mines in six states were listed as critical habitat:

- Illinois - Blackball Mine (LaSalle Co.);
- Indiana - Big Wyandotte Cave (Crawford Co.), Ray's Cave (Greene Co.);
- Kentucky - Bat Cave (Carter Co.), Coach Cave (Edmonson Co.);
- Missouri - Cave 021 (Crawford Co.), Caves 009 and 017 (Franklin Co.), Pilot Knob Mine (Iron Co.), Bat Cave (Shannon Co.), Cave 029 (Washington Co.);
- Tennessee - White Oak Blowhole Cave (Blount Co.); and
- West Virginia - Hellhole Cave (Pendleton Co.).

Pursuant to section 7(a)(2) of the ESA, Federal agencies must take such action as necessary to insure that actions authorized, funded, or carried out by them do not result in the destruction or modification of these critical habitat areas.

Threats and Reasons for Listing

The Indiana bat was one of 78 species first listed as being in danger of extinction under the Endangered Species Preservation Act of 1966. The 1967 Federal document that listed the Indiana bat as "threatened with extinction" (32 FR 4001, March 11, 1967) did not address the five factor threats analysis later required by Section 4 of the 1973 ESA. The five listing factors are:

- A. The present or threatened destruction, modification, or curtailment of its habitat or range.
- B. Overutilization for commercial, recreational, scientific, or educational purposes.
- C. Disease or predation.
- D. The inadequacy of existing regulatory mechanisms.
- E. Other natural or man-made factors affecting its continued existence.

We address these factors in the summary below to organize threats to the Indiana bat in a manner consistent with current listing and recovery analyses under the ESA.

The Present or Threatened Destruction, Modification, or Curtailment of Its Habitat or Range

Destruction/Degradation of Hibernation Habitat

There are well-documented examples of modifications to Indiana bat hibernation caves that affected the thermal regime of the cave, and thus the ability of the cave to support hibernating Indiana bats. Examples are discussed below. Reasons for modifications include (but are not limited to) alterations to accommodate tourists, erection of physical barriers (e.g., doors, gates) to control cave access, and mining (particularly saltpeter). Frequently, the negative effects of cave modifications are compounded by physical disturbance of hibernating bats (discussed under threat B. Overutilization for commercial, recreational, scientific, or educational purposes). Because the Indiana bat congregates in large numbers in relatively few hibernacula, the species is inherently vulnerable to loss or degradation of hibernation habitat.

Wyandotte Cave in Indiana, a Priority 1 Indiana bat hibernaculum which currently harbors the largest known population of hibernating Indiana bats, has been subject to many physical alterations that have affected the ability of the cave to support hibernating Indiana bats. Based on staining, Tuttle and Kennedy (2002) suggested that Wyandotte Cave may have supported millions of hibernating Indiana bats. There is currently no technique for verifying the accuracy of estimates based on staining. However, historic accounts (based on visual observations) from the late 19th century and paleontological analysis also provide evidence that the cave supported a very large population (Munson and Keith 1984, Johnson et al. 2002). In the early 1950s, the private owners of the cave built a stone wall with steel-bar doors to control access to the cave. At the time the wall was built, the population of Indiana bats in the cave had already declined to approximately 15,000 bats (Richter et al 1993). By the winter of 1953-1954, the population of

Indiana bats in the cave declined to 1,000 (Mumford and Whitaker 1982). Richter et al. (1993) attributed the decline to an increase in the cave's temperature which resulted from restricted airflow caused by the stone wall. Between 1954 and 1974, the population in this cave remained low (550 to 3,200) relative to historic populations (Mumford and Whitaker 1982). The cave was purchased by the Indiana Department of Natural Resources in 1966, and in 1977 the stone wall was replaced with a steel-bar gate. The removal of the stone wall, at least partially, restored airflow in the cave (with a concomitant decrease in temperature). The population increased to almost 13,000 bats by 1991 (Johnson et al. 2002). (See the Overutilization for Commercial, Recreational, Scientific, or Educational Purposes: Disturbance of Hibernating Bats section for additional discussion on the recovery of the Indiana bat population of Wyandotte Cave).

Coach Cave in Edmonson County, Kentucky, provides another example of a large-scale decline in Indiana bat populations through hibernation habitat destruction associated with cave modifications that impeded airflow. Humphrey (1978) reported that in about 1962, the owners of the tourist resort on which this cave was located built an observation platform and building that covered the upper entrance to the cave. This construction caused the Indiana bat population in the cave to decline from 100,000 to 4,500. Humphrey (1978) noted that preconstruction roost temperatures in Coach Cave were 4 to 6°C, and that after construction temperatures increased to approximately 11°C, a temperature too high to provide favorable hibernation for Indiana bats. Humphrey further reported that modest increases in the number of Indiana bats in protected caves within nearby Mammoth Cave National Park suggested that some of the displaced bats moved to alternate hibernacula, but these increases fell far short of accounting for the number of bats displaced. Murphy (1987) reported that many of the bats, rather than search for an alternative entrance or alternative hibernaculum, instead clung to the walls of the new building where they reportedly were scraped off and "carted out by the thousands in wheelbarrow loads." She suggested these bats were unable to overcome their "homing instinct" to return to their traditional hibernaculum.

Additional examples of obstructed airflow resulting in increases in cave temperature in Indiana bat hibernacula have been documented in Missouri (Tuttle and Kennedy 2002), Kentucky (MacGregor 1993), and Indiana (Johnson et al. 2002). In addition to the negative effects that obstructions (e.g., doors, gates) can have on hibernating bats through changes in cave microclimate (particularly increases in cave temperatures), these structures can also physically restrict the access of bats to the cave, resulting in direct mortality. For example, Hovey (1882) reported accounts of a solid wood door that was built to control access to an internal passage in Wyandotte Cave. He wrote that "... when the proprietor fixed an oak door to this lower entrance ... the bats flew against it with such force as to kill themselves in large numbers."

Even apparently "bat friendly" gates (i.e., designed not to impede airflow) can impede the flight of bats and result in mortality. During summer 2001, a "bat friendly" angle-iron gate was installed at Pilot Knob Mine, a major Indiana bat hibernaculum in Iron County, Missouri. The gate was needed to control human access to the mine because the mine is unstable and unsafe for human entry. During counts at the entrance to the mine in October 2001, biologists observed Indiana bats striking the bars of the gate, some with sufficient force to kill the bats. In addition, some bats captured at the entrance had leg and head injuries, believed to be the result of strikes with the gate. Predators concentrated at the gate, taking advantage of disabled bats and bats

whose flight was impaired as they negotiated the gate. The position of the gate relative to the opening and the flight path of the bats was assumed to be the problem. A decision was made to dismantle portions of the gate to restore an unimpeded flight path for the bats (C. Shaiffer, USFWS, pers. comm., 2002). Well-designed and properly-positioned gates are considered the best way to control human access to hibernacula in most cases; however, this situation reinforces the need for pre- and post-gating monitoring to ensure that gates designed to protect bats do not have unintended impacts (Herder 2003). Martin et al. (2000) noted that horizontal angle iron gates (constructed since the mid-1980s) are presumed "to maximize protection from human entry, have nominal effects on airflow, and present limited obstruction to bat flight." However, effects on airflow (Martin et al. 2000) and behavioral response of bats to gates (Spanjer and Fenton 2005) merit careful consideration.

Modifications to hibernacula entrances do not always involve construction of a man-made object. Johnson et al. (2002) reported that sloughing mud, leaf litter, and other detritus into the sloping entrance to Batwing Cave, an Indiana bat hibernaculum in Crawford County, Indiana, had to be removed occasionally to maintain airflow. At some cave entrances accumulation of debris may be a natural phenomenon, but anthropogenic factors, such as increased siltation at cave entrances in agricultural areas, may exacerbate or accelerate the blockage (Brack et al. 2005b). One case of internal cave flooding occurred when tree slash and debris, produced by forest clearing to convert the land to pasture, were bulldozed into a sinkhole. The material blocked the cave's outlet for rainwater, causing a flood that killed an estimated 150 Indiana bats (J. MacGregor, pers. comm., 2005). Even modifications that do not impact a major cave entrance can impact the thermal environment in a cave. Blockage of even a small, inaccessible, entrance can cause changes to "chimney effect" airflow (Tuttle and Stevenson 1978) and result in dramatic changes in cave temperature. Such changes may be inadvertent and not apparent, until changes in temperature or the bat population in the cave are detected.

Quarry and mining operations can also result in physical alterations to hibernacula that may result in changes in the cave environment. Greenhall (1973) cited limestone quarrying as a factor in the destruction of hibernation sites for Indiana bats. Proposed quarries are recognized as a threat to the integrity of hibernacula, including Hellhole, the largest Indiana bat hibernaculum in West Virginia (B. Douglas, USFWS, pers. comm., 2004).

Dam construction can lead to destruction or degradation of hibernation habitat; caves and/or surrounding habitat can be inundated. Greenhall (1973) stated that the Meramec Basin Project, a proposal to dam the Meramec River in Missouri, would have resulted in the inundation of approximately 100 bat hibernation caves. In 1977, the U.S. Fish and Wildlife Service concluded that this project would jeopardize the continued existence of the Indiana bat. Fortunately, this dam, authorized in 1938 and deauthorized in 1981, was never constructed.

Collapse (subsidence) also threatens the integrity of some Indiana bat hibernacula, particularly those in mines. Ceiling collapse in caves is also possible, but is generally considered much less of a threat as caves are inherently more stable than mines. In February 1998, Indiana bats were discovered hibernating in Magazine Mine in Alexander County, Illinois, a silica mine that ceased operations in 1980. A survey was conducted in 1999, and over 12,000 Indiana bats were counted (Kath 2002). The entrance to the mine was susceptible to collapse. By 2000, there was a 70

percent reduction in size of the entrance and it was evident that eventually collapse would lead to the loss of the mine as a hibernaculum. A project to stabilize the entrance was completed in August of 2001. During winter 2004-2005, over 30,000 Indiana bats hibernated in the mine. The mine is still subject to minor collapses. Sixteen Indiana bats were found dead (or mortally injured) in 2005, apparently crushed when the ceiling where they roosted collapsed (T. Carter, Ball State University, pers. comm., 2005), but the threat of large scale collapse of the entrance has been abated. Pilot Knob Mine, an abandoned iron mine in Missouri, is another Indiana bat hibernaculum threatened with collapse. The mine is no longer safe to enter for surveys but is estimated to harbor approximately 50,000 Indiana bats. Unfortunately, the mine may become unsuitable as a hibernaculum due to collapse (LaVal and LaVal 1980, U.S. Fish and Wildlife Service 1983). Jamesville Quarry Cave in New York with a current population of approximately 4,000 hibernating Indiana bats is also threatened with collapse (A. Hicks, pers. comm., 2006).

Generally, threats to the integrity of hibernacula have decreased since the time that Indiana bats were listed as endangered. Increasing awareness of the importance of cave microclimates to hibernating bats and regulatory authorities under ESA have both helped to alleviate this threat. However, the threat of collapse in mines where Indiana bats hibernate, and the threat of inadvertent modifications to caves or natural catastrophes that can impact hibernacula remain.

Loss/Degradation of Summer Habitat, Migration Habitat, and Swarming Habitat

Humphrey et al. (1977) reported on the discovery, in Indiana in 1974, of the first known maternity colony of the Indiana bat. Prior to this discovery, it was not known that the Indiana bat's maternity colonies occur in trees. The authors noted that summer habitat is needed for the reproduction and survival of the Indiana bat and pointed out that the crucial events of gestation, postnatal development and post-weaning maturation takes place during this time. The authors also discussed that suitable summer habitat is destroyed by some human land uses and urged caution in managing those habitats. Humphrey et al. (1977) makes the observation that summer habitat does not appear to be limiting to the Indiana bat. Since that time, loss of forest cover and degradation of forested habitats have been cited as part of the decline of Indiana bats (U.S. Fish and Wildlife Service 1983, Gardner et al. 1990, Garner and Gardner 1992, Drobney and Clawson 1995, Whitaker and Brack 2002). In some areas, such as northern Indiana, up to 97 percent of the landscape has been cleared of trees, and the absence of woodlands on the landscape certainly equates to less habitat than in prehistoric and early historic periods. Potential threats to habitat used for migration and swarming are briefly discussed, although our understanding of these aspects of the life history of the Indiana bat is very limited.

As discussed in the Habitat Characteristics section, the Indiana bat is a tree bat that requires forested areas for foraging and roosting; however, at a landscape level Indiana bat maternity colonies occupy habitats ranging from completely forested to areas of highly fragmented forest. Within the core range in the Midwest, forest cover is much more fragmented, at the landscape scale, than at the eastern edge of the range (Brack et al. 2002). Forest cover also varies widely at the scale of individual maternity colonies; in Indiana, landcover within 2.5 miles of the primary maternity roosts of known maternity colonies ranged from 9 percent to over 80 percent forested (USFWS, unpublished data, 2005). Clearly, forest cover is not a completely reliable predictor of where Indiana bat maternity colonies will be found on the landscape (Farmer et al. 2002).

Although researchers have found it difficult to predict where maternity colonies may occur relative to forested habitat, we can reliably predict that once Indiana bats colonize maternity habitat, they will return to the same maternity areas annually. Philopatry of Indiana bat maternity colonies to their summer range is well documented. All major multi-year studies of maternity colonies within the core range in the Midwest have demonstrated that the adult females return to the same area every year to bear and raise their young. Studies confirming philopatry have been conducted in Indiana (Cope et al. 1974; Humphrey et al. 1977; Pruitt 1995; Whitaker and Gummer 2002; Brown and Brack 2003; Whitaker et al. 2004; J. Duchamp, Purdue University, pers. comm., 2005), Missouri (Callahan 1993, Timpone 2004), Illinois (Gardner et al. 1996), Michigan (Kurta et al. 1996, Kurta and Murray 2002), and Kentucky (B. Palmer-Ball, Jr., Kentucky State Nature Preserves Commission, pers. comm., 2005). Indiana bat maternity colonies were also observed to return to the same range in Vermont (S. vonOettingen, pers. comm., 2005), Pennsylvania (Butchkoski and Hassinger 2002, Butchkoski and Turner 2006), West Virginia (Apogee Environmental Consultants 2004; USFWS 2004a; B. Douglas, pers. comm., 2005), and Tennessee (Harvey 2002, Britzke et al. 2003). However, in one instance, (Harvey 2002, Britzke et al. 2003) a colony found in North Carolina (Nantahala National Forest) in 1999 could not be subsequently relocated in 2000.

Implications of philopatry are discussed by Kurta and Murray (2002). It is not known how long or how far female Indiana bats will search to find new habitat if their traditional maternity range is lost or degraded. If they are required to search for new habitat, it is assumed that this effort places additional stress on pregnant females at a time when fat reserves are low or depleted and they are already stressed from energy demands of migration and pregnancy. Such impacts have been documented in other bat species. Brigham and Fenton (1986) demonstrated that a colony of big brown bats (*Eptesicus fuscus*) excluded from their maternity roost in a building experienced a 56 percent decline in reproductive success. In a long-term study of an Indiana bat maternity colony in Indiana, Sparks et al. (2003) demonstrated that the natural loss of a single primary maternity roost led to the fragmentation of the colony (bats used more roosts and congregated less) the year following the roost loss. Although loss of a roost is a natural phenomenon that Indiana bats must deal with regularly, the loss of multiple roosts (potentially the entire home range) due to forest clearing likely stresses individual bats, as well as the social structure of the colony. Kurta (2005) discussed the loss of roosting habitat within the traditional range of Indiana bat maternity colonies and noted that impacts on reproductive success are a likely consequence of the loss of traditional roost sites. He suggested that reduced reproductive success may be related to stress, poor microclimate in new roosts, a reduced ability to thermoregulate through clustering, or reduced ability to communicate and thus locate quality foraging areas. He further suggested that the magnitude of these impacts would vary greatly depending on the scale of roost loss (i.e., how many roosts are lost and how much alternative habitat is left for the bats in the immediate vicinity of the traditional roost sites). Barclay et al. (2004) predicted that in species with higher adult survival compared to juvenile survival, such as bats, fitness is maximized by foregoing reproduction if conditions are not favorable (e.g., limited food resources) or if the female is in poor condition. By gathering data for 103 bat species they were able to verify that in many species of bats the proportion of female bats that are reproductive varies significantly from year to year. It is reasonable to conclude that Indiana bat reproductive rates would be affected by alterations which lowered the quality of their maternity habitat or forced females to search for new habitat.

Racey and Entwistle (2003) noted that traditionally managers have assumed that bats excluded from a roost would simply relocate with conspecifics in another roost. However, they cautioned that there is little evidence of this from molecular or banding studies of bats. The effect of landscape-level changes in summer habitat on overall Indiana bat populations is unclear.

Impacts of Forest Cover and Forest Management on Summer and Prehibernation Habitat

The most obvious impact of tree clearing on summering Indiana bats is felling of an occupied roost tree. We are aware of three accounts of occupied Indiana bat roost trees being felled. In all cases it was not known that the tree contained a bat roost when it was cut, and in all cases some of the bats in the tree were killed or injured. Cope et al. (1974) reported on the first known Indiana bat maternity roost tree, a dead elm in Wayne County, Indiana. The tree was located near a hedgerow that was being removed, and when the tree was destroyed during bulldozing bats were observed exiting. The original account stated that eight bats were "captured and identified as Indiana bats," and that about 50 bats flew from the tree. Although the original account did not specify how the eight bats were captured, J. Whitaker (Indiana State University, pers. comm., 2005) recounted that those bats were killed or disabled, retrieved by the landowner, and subsequently identified by a biologist. In another case, Belwood (2002) reported on the felling of a dead maple in a residential lawn in Ohio. One dead adult female and 33 nonvolant young were retrieved by the researcher. Three of the young bats were already dead when they were picked up, and two more died subsequently. The rest were apparently retrieved by adult bats that had survived. In a third case, 11 dead adult female Indiana bats were retrieved (by people) when their roost was felled in Knox County, Indiana (J. Whitaker, pers. comm., 2005).

While the direct killing of bats in an occupied roost during forest management activities is possible, retaining all snags (and possibly other potential roost trees) minimizes the potential that a roost tree, particularly a primary maternity roost, will be cut. This greatly reduces the potential for death or injury of large numbers of bats. Seasonal clearing restrictions (i.e., not cutting potential roost trees during the period when bats occupy summer range) eliminate the threat of killing bats in an occupied maternity roost. However, the effect of forest management on the quality of summer habitat, and the concomitant effect of that habitat alteration on bats, is more difficult to assess. Generally, forest management is considered compatible with maintenance of Indiana bat summer habitat, provided that key components of summer habitat are provided for in the management system. Retention of snags in managed forests and forest fragmentation are two important parameters that will be discussed.

Gardner et al. (1991a) noted that selective cutting of forests within their Illinois study area did not affect roosts or discourage bats from roosting in the harvested area. However, they cautioned that long-term effects of selective tree removal on the attrition rate of roosts were not known. MacGregor et al. (1999) studied male Indiana bat roost use during the autumn prehibernation swarming period in Kentucky. They found that bats did not roost in areas clearcut within the past 35 years, whereas forested habitat not actively managed during the past 40 years was used at about twice the expected level based on its availability. Two-age shelterwood cuts were used four to seven times as much as expected based on availability. They noted that the guidelines used for the shelterwood cuts called for retention of more live trees and more snags than previous

guidelines, and that retention of these trees was key to providing favorable roosting for male Indiana bats during the autumn prehibernation period, at least over the short-term.

Silviculture that involves short rotations and/or removal of dead and dying trees threatens the integrity of roosting habitat for Indiana bats. Retention of large snags and preservation of over-mature trees to provide for a sustained supply of large snags is essential to maintaining summer habitat for tree-roosting bats in general (Jung et al. 1999, Cryan et al. 2001), and Indiana bats specifically (Bat Conservation International 2001, Kurta et al. 2002, Miller et al. 2002, Schultes and Elliot 2002, Battle 2003). Loeb (2003) noted that on her study area in North Carolina large pine snags were important roosting habitat for Indiana bat maternity colonies (in contrast, use of pines as maternity roosts in the core maternity range in the Midwest is limited). She cautioned that ensuring a sustained supply of large pine snags is a particularly important consideration in managing for Indiana bats in the southeastern portion of the summer range because conifer snags are "more in flux" than hardwoods due to outbreaks of insects like the pine beetle.

Research has demonstrated that densities of tree-roosting bats are generally greater in old growth forests of temperate regions, where structural diversity provides more roosting options (Crampton and Barclay 1996, Brigham et al. 1997, Racey and Entwistle 2003) and important foraging areas for some species (Jung et al. 1999). Within the range of the Indiana bat, particularly within the core maternity range in the Midwest, old growth forest has been virtually eliminated, thus eliminating the opportunity to evaluate habitat value of old growth versus second growth forests. However, several Indiana bat researchers have suggested that forest management prescriptions designed to benefit Indiana bats should include managing a component of the forest to develop old growth characteristics (Clawson 1986, Callahan 1993, Krusac and Mighton 2002). Palm (2003) evaluated Indiana bat roost sites in Vermont's Champlain Valley and noted that occupied sites had greater snag basal area than potential roost sites and were comparable to snag basal area for old growth forests in the northeastern United States. She noted that Indiana bats roosting in large snags would benefit from the tendency for larger snags to persist longer in the environment. Krusac and Mighton (2002) suggested that hardwood rotation ages beyond 200 years in some areas may be needed to ensure a satisfactory distribution of large-diameter trees needed for tree-roosting bats.

Krusac and Mighton (2002) provided a summary of U.S. Forest Service management relative to Indiana bats, and provided insights into shortcomings of previous policies relative to providing sufficient numbers of large snags to support Indiana bat roosting requirements. Although some snags were retained, they noted that the density of snags was insufficient and there was no plan to leave live trees to provide for a sustained supply of snags. Furthermore, they noted that areas were set aside to develop old growth characteristics, which could potentially benefit Indiana bats, but that the designated sites tended to have low productivity that precluded development of large old trees. These policies changed after 1994 to provide for increased habitat suitability for Indiana bats. One continuing threat to snags, and thus Indiana bat roost trees, cited by Krusac and Mighton (2002) was cutting of trees for firewood. Cutting firewood on Forest Service lands required permits that specified that wood to be removed must be "dead and down," meaning that no standing trees were to be cut, whether dead or alive. Unfortunately, the policy was interpreted on many national forests to mean "dead or down," and standing dead trees were sometimes removed (Krusac and Mighton 2002). Others have also cited firewood cutting as a

threat to Indiana bat roost trees (U.S. Fish and Wildlife Service 1983, Evans et al. 1998). Based on research of roosting habits of male Indiana bats in Kentucky, Gumbert (2001) recommended that cutting of standing dead trees for firewood in the vicinity of hibernacula not be permitted.

The minimum size of a forest patch that will sustain Indiana bat maternity colonies has not been established. However, in highly fragmented landscapes the loss of connectivity among remaining forest patches may degrade the quality of the habitat for Indiana bats. Patterson et al. (2003) noted that the mobility of bats, associated with flight, allows them to exploit fragments of habitat. However, they cautioned that reliance on already diffuse resources (e.g., roost trees) leaves bats highly vulnerable, and that energetics may preclude the use of overly patchy habitats. Racey and Entwistle (2003) discussed the difficulties of categorizing space requirements in bats because they are highly mobile and show relatively patchy use of habitat (and use of linear landscape features), but that connectivity of habitats has some clear advantages (e.g., aid orientation, attract insects, provide shelter from wind and/or predators). Connectivity of habitats has been demonstrated to be important to Indiana bats. Murray and Kurta (2004) demonstrated the importance of wooded travel corridors for Indiana bats within their maternity habitat in Michigan; they noted that bats did not fly over open fields but traveled along wooded corridors, even though use of these corridors increased commuting distance by over 55 percent. Sparks et al. (2005a) also noted the importance of a wooded riparian travel corridor to Indiana bats in the maternity colony at their study site in Indiana. Carter et al. (2002) noted that in their southern Illinois study area Indiana bat roosts were in highly fragmented forests, but that both the number of patches and mean patch size of bottomland hardwood forest and closed-canopy deciduous forest were higher in the area surrounding roosts than around randomly selected points (i.e., Indiana bats were using the least fragmented forest blocks available to them in that landscape). Carter et al. (2002) found that mean patch size of bottomland forest for circles (2 km (1.2 mi) in diameter) surrounding roosts was 35.9 ha, compared to 1.5 ha around random locations. Mean patch size of closed-canopy deciduous forest was 7.9 ha around roosts compared to 3.4 ha around random locations. In both cases, the difference was statistically significant.

Impacts of Forest Conversion on Summer Habitat

As inferred from the discussion above, it is difficult to generalize how forest management, or lack of forest management, will affect Indiana bat summer habitat. Forest management, as well as natural disturbance to forest stands, has the potential to positively or negatively impact summer habitat quality for Indiana bats, depending on stand characteristics. However, even low quality forested habitat may, through management or natural succession, develop into higher quality habitat over time. In contrast, conversion of forested habitats to nonforested land uses represents a far greater threat to summer habitat for Indiana bats.

Throughout the range of the Indiana bat, there is less forest land now than there was prior to European settlement (Smith et al. 2003), particularly within the core of the species' range in the Midwest. Conversion to agriculture has been the largest single cause of forest loss. The conversion of floodplain and bottomland forests, recognized as high quality habitats for Indiana bats, has been a particular cause of concern (Humphrey 1978). While many researchers have suggested that forest loss may equate to less forested habitat available for the Indiana bat, we do not know if or how the amount of forest cover within the range of the species correlates with the size of the population. That is, we do not know if the extensive forest clearing which occurred

after European settlement resulted in a decrease in the population of the Indiana bat. Nor do we know if more recent reversion of some previously deforested lands back to forest in much of the Indiana bat's range has resulted in larger Indiana bat populations in those areas.

Dredging and channelization of riverine habitats to provide for agricultural drainage and flood control has also been cited as a specific threat to Indiana bat summer habitat (Humphrey et al. 1977, Humphrey 1992, Drobney and Clawson 1995). Channelization projects can impair bat habitat values directly, through the destruction of riparian vegetation which provides both roosting and foraging habitat for Indiana bats, and indirectly through impacts on water quality and insect production. However, at least some channelized streams that are allowed to revegetate develop "riparian" forests that support Indiana bats; these revegetated channelized streams are an important component of Indiana bat maternity habitat in the agricultural Midwest where forested habitat is limited. Projects to maintain these channelized streams frequently involve removal of second growth vegetation from the banks, which may result in the destruction of summer habitat for maternity colonies (U.S. Fish and Wildlife Service 2003). Trends toward increasingly intensive farming practices that result in the removal of hedgerows leave remaining forested parcels increasingly isolated and decrease the value of the area for Indiana bats. Agricultural chemicals also have negative effects on Indiana bats, which will be discussed under threat "E. Other natural or man-made factors affecting its continued existence."

A distinction should be drawn between conversion for agriculture and conversion for development. Agricultural conversion has been responsible for high rates of forest conversion within the range of the Indiana bat historically; however, some marginal farmlands have been abandoned and allowed to revert to forest. Since the time of listing as endangered, there has been a net increase in forest land within the range of the Indiana bat, particularly in the Northeast (Smith et al. 2003). Currently, the greatest single cause of conversion of forests within the range of the Indiana bat is urbanization and development (Wear and Greis 2002; U.S. Forest Service 2005, 2006). Indiana bats are known to use forest-agricultural interfaces for foraging. In contrast, Indiana bats appeared to avoid foraging in highly developed areas. At a study site in central Indiana, Indiana bats avoided foraging in a high-density residential area (Sparks et al. 2005a), although maternity roosts have been found in low-density residential areas (Belwood 2002). Development directly destroys habitat and fragments remaining habitat. Furthermore, any bats that remain following development are in closer proximity to people. Potentially, fear of rabies and general dislike of bats may lead to persecution of Indiana bat colonies located near human activity centers (Belwood 2002, Racey and Entwistle 2003).

Additional Considerations for Migratory Habitat and Surface Areas Surrounding Hibernacula

Migration and swarming are aspects of the life history of the Indiana bats that have not been extensively studied and are poorly understood. Generally, migration is considered a sensitive phase in the annual cycle for any animal that migrates. Fleming and Eby (2003) noted that "migratory populations require a progression of spatially distinct, often apparently unrelated, habitats to complete their annual cycles" and that migration is often identified as a trait that compounds the risk of extinction of endangered wildlife. Migratory stress may be a particular concern in bats compared to birds, because female bats migrate while pregnant and there is a sex bias in migration (i.e., females are much more likely to migrate than males). Both of these factors may magnify the impact of low quality or insufficient migratory habitat on the resulting

population. Further, some forms of mortality in bats (e.g., collisions with wind turbines, to be discussed under threat E) are more likely to occur during migration than at other times during the annual cycle. As discussed earlier in this document, little is known about the migratory habits and habitats of the Indiana bat. However, this is a sensitive point in the annual cycle of the species and degradation and loss of migratory habitat will exacerbate migratory stress.

The habitat surrounding hibernacula may be one of the most important habitats in the annual cycle of the Indiana bat. This habitat must support the foraging and roosting needs of large numbers of bats during the fall swarming period. After arriving at a given hibernaculum, many bats build up fat reserves (Hall 1962), making local foraging conditions a primary concern. Migratory bats may pass through areas surrounding hibernacula, apparently to facilitate breeding and other social functions (i.e., bats that utilize the area for swarming may not hibernate at the site) (Barbour and Davis 1969; Cope and Humphrey 1977). Modifications of the surface habitat around the hibernacula can impact the integrity, and in turn the microclimate, of the hibernacula. Areas surrounding hibernacula also provide important summer habitat for those male Indiana bats that do not migrate, which is thought to be a large proportion of the male population. Loss or degradation of habitat within this area has the potential to impact a large proportion of the total population. This is particularly true for hibernacula supporting large numbers of bats, or areas that support multiple hibernacula that together support large numbers of bats. For example, four caves located in eastern Crawford County and western Harrison County in southern Indiana, within approximately 10 miles of each other, harbored 128,000 Indiana bats during the 2005 hibernacula survey; this was 28 percent of the total rangewide population.

Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

Disturbance of Hibernating Bats

The original recovery plan for the species stated that human disturbance of hibernating Indiana bats was one of the primary threats to the species (USFWS 1983). The primary forms of human disturbance to hibernating bats result from cave commercialization (cave tours and other commercial uses of caves), recreational caving, vandalism, and research-related activities. There are well-documented examples of disturbance resulting in declines in populations of hibernating bats (Barbour and Davis 1969). Disturbance causes the bats to arouse and use fat reserves essential for successful hibernation. Thomas et al. (1990) demonstrated that arousal from hibernation is metabolically expensive for bats; little brown bats used as much fat during a typical arousal from hibernation as would be used during 67 days of torpor. Thomas (1995) measured baseline activity and the response of hibernating bats of two species of the genus *Myotis* to nontactile human disturbance in a hibernaculum and found that visits resulted in an increase in flight activity beginning within 30 minutes of the visit and that bat activity remained significantly above baseline levels for 2.5-8.5 hours after the disturbance.

Disturbance of hibernating Indiana bats seldom results in immediate mortality of bats within the hibernacula (Mohr 1972, Humphrey 1978), except in cases of vandalism when bats are purposely killed. Impacts may not be obvious, but there is general consensus that disturbance of hibernating bats affects survival, which may be expressed as decreased survival or lower rates of reproduction after the bats emerge from hibernation in the spring (Humphrey 1978). Not only is it difficult to evaluate the degree to which disturbance causes mortality, but it can also be

difficult to detect the arousal response to disturbance. Bats may not show any immediate response to disturbance, but a response may occur later, and therefore go undetected by the individual(s) that caused the disturbance (Mohr 1972, Thomas 1995). Impacts may not only be delayed but they can also prolonged (i.e., arousal may last far longer than the disturbance). Hicks and Novak (2002) remotely measured the response of Indiana bats to nontactile disturbance by researchers; monitoring included videocassette recordings, infrared thermometers to record bat cluster temperatures, and recordings of vocalizations. In the most severe response to disturbance they recorded, it took 11 hours after disturbance for bat activity to cease and 22.8 hours for temperature of the bat cluster to stabilize. In some cases, bats demonstrated no measurable response to disturbance.

Mammoth Cave in Kentucky, with a long and well-documented history of human use, provides an excellent example of impacts of human disturbance on hibernating Indiana bats. Based on staining, Tuttle (1997) estimated that the area referred to as the Historic Entrance of Mammoth Cave once harbored a very large number of hibernating bats (presumably many of them Indiana bats), perhaps millions. Toomey et al. (2002) reported results of historic and paleontological analyses that support the conclusion that a very large colony of hibernating Indiana bats used this area. Other lines of evidence (as previously discussed in the Population Distribution and Abundance: Historic Abundance section) also support this conclusion. Toomey et al. (2002) provided a detailed account of the history of human use of this cave, beginning with Native Americans between 2,000 and 4,000 years ago. The cave was subject to a massive saltpeter mining operation from 1812 to 1814 and became a tourist cave during the same time frame; the cave has been used continuously since that time for commercial purposes. This site no longer serves as a major Indiana bat hibernaculum, at least in part due to the direct disturbance of hibernating bats. Toomey et al. (2002) noted that physical alteration of the cave and resulting temperature changes were also integrally involved in the decline.

M. Tuttle (pers. comm., 2005) noted that the War of 1812 and the Civil War were major disturbance events in many bat hibernacula in the East because the caves were mined for nitrates to make gun powder. Caves that harbored large bat colonies were particularly sought out for this purpose. Evidence of past saltpeter mining is still present in many major Indiana bat hibernacula. As with other forms of commercial use, saltpeter mining resulted in direct disturbance of hibernating bats, as well as physical alterations to caves that degraded the thermal environment of the caves for hibernating bats.

Other examples of large declines of Indiana bat populations caused by commercial use of hibernacula were discussed by Murphy (1987 - Coach Cave in Kentucky), Humphrey (1978 - Bat Cave in Carter County, Kentucky) and Currie (2002 - Saltpetre Cave in Carter County, Kentucky). Few major hibernacula are still threatened by commercial use during the hibernation period. No currently occupied Priority 1 hibernacula are used for winter tours, although tours at Wyandotte Cave (a Priority 1 hibernacula in Indiana) have been discontinued only since 2003. Commercial tours are still conducted during the winter hibernation period in at least one currently occupied Priority 2 hibernacula.

Impacts of recreational caving on hibernating bats are more difficult to assess and to control compared with commercial uses because commercial caves are generally gated, or have some

effective means of controlling access. Many noncommercial Indiana bat hibernacula also have controlled access, but others do not and may be used for recreational caving during the hibernation season. When Mohr (1972) and others reported that it was the consensus of bat experts that disturbance of bats by cavers (as well as by scientists banding bats or conducting other research, which will be discussed below) was responsible for marked reductions in bat populations, steps were taken to reduce the level of disturbance. For example, the National Speleological Society appointed a Bat Conservation Task Force and alerted its membership to avoid important bat hibernacula during the hibernation period (Greenhall 1973). Increased awareness and voluntary cooperation of cavers who belonged to organized cave groups likely resulted in reduced levels of disturbance. However, it is more difficult to address visitors who are not associated with organized groups and are less likely to appreciate the sensitive nature of the cave environment and cave fauna. Disturbance of hibernating bats by cavers remains a threat in many hibernacula.

Direct killing of hibernating Indiana bats by vandals has been documented throughout the species' range (Greenhall 1973, Humphrey 1978, Murphy 1987). Hibernating bats have been shot, burned, clubbed, and trampled to death. In 1960, three boys killed an estimated 10,000 Indiana bats in Bat Cave (Carter County, Kentucky; Greenhall 1973), an incident that emphasized the vulnerability of Indiana bats to vandalism during winter when they are concentrated in hibernacula. MacGregor (1993) reported that over a period of 10 years in Kentucky, nine of the 78 known Indiana bat sites (11.5 percent) were impacted by the direct killing of bats or by campfires built inside hibernacula. Unfortunately, vandalism is an ongoing threat. During the winter of 2005, hundreds of gray bats were shot in a hibernaculum in Arkansas; Indiana bats were present but none were shot (B. Sasse, Arkansas Game and Fish Commission, pers. comm., 2005).

Progress has been made in reducing the number of caves in which disturbance threatens hibernating Indiana bats, but the threat has not been eliminated. Biologists throughout the range of the Indiana bat were asked to identify the primary threat at specific hibernacula (see Background section of Appendix 2 for details on the request). "Human disturbance" was identified as the primary threat at 39 percent of Priority 1, 2 and 3 hibernacula combined (Table 8, USFWS, unpublished data, 2006).

Table 8. Primary threats at Priority 1, 2, and 3 Indiana bat hibernacula.

Hibernacula by Priority (N=number of hibernacula)	Primary Threat							
	Human Disturbance % (N)	Collapse % (N)	Unsuitable Temperature % (N)	Encroaching Development % (N)	Flooding % (N)	Freezing % (N)	Predation % (N)	None Identified % (N)
Priority 1 (N=23)	35% (8)	9% (2)	13% (3)	9% (2)	9% (2)	0	0	26% (6)
Priority 2 (N=53)	38% (20)	4% (2)	8% (4)	4% (2)	0	0	0	47% (25)
Priority 3 (N=150)	41% (61)	5% (7)	<3% (5)	3% (4)	4% (6)	<1% (1)	<1% (1)	43% (65)
Priority 1, 2, 3 combined (N=226)	39% (89)	5% (11)	5% (12)	4% (8)	4% (8)	<1% (1)	<1% (1)	42% (96)

Biologists were subsequently asked if they considered human disturbance a threat (although not necessarily the primary threat). Biologists considered human disturbance a current threat in 45 percent of Priority 1, 2, and 3 hibernacula combined (35 percent of Priority 1, 43 percent of Priority 2, and 47 percent of Priority 3). The primary sources of human disturbance in these hibernacula were recreational cavers (66 percent), vandals (7 percent), commercial tours (1 percent), researchers (1 percent), and other sources (1 percent). The source was unknown (or no answer was provided) for 24 percent of the hibernacula.

Johnson et al. (2002) discussed strategies for reducing unauthorized visits to caves, including landowner outreach, cooperative agreements, interpretive signs, angle-iron gates, and alarm systems. Success of strategies varies, but properly designed and maintained gates are generally the most reliable management strategy (MacGregor 1993, Currie 2002). However, several authors have cautioned that bat populations do not necessarily increase after gating, and the response of populations to gating can be difficult to interpret because of interrelated factors (MacGregor 1993, Currie 2002, Johnson et al. 2002).

Regardless of the strategy, many Indiana bat populations have responded positively to control of disturbance during the hibernation period. Johnson et al. (2002) provided data on the number of unauthorized trips (i.e., trips not sanctioned for survey or research purposes) as measured by speloggers (light sensitive probes) placed in hibernacula in Indiana. They demonstrated that steps to reduce unauthorized visits to Ray's, Coon, and Grotto Caves, all hibernacula with long histories of unrestricted disturbance, were successful. They further documented increases in the Indiana bat populations in all of these hibernacula in response to the decreased winter disturbance. In contrast, no attempt was made to reduce visitation in Buckner Cave, a heavily visited hibernaculum, and the Indiana bat population declined from 500 in 1982 to one in 2001.

Wyandotte Cave in Indiana provides a dramatic example of the response of an Indiana bat population to reduction in disturbance. As previously discussed, numbers of Indiana bats in Wyandotte Cave increased when a stone wall, built in approximately 1954, was replaced by a steel bar gate in 1977 (Richter et al. 1993). Further increases in the population were observed in

response to the replacement of the steel bar gate with an angle-iron gate in 1991 (Johnson et al. 2002); the population increased from 13,000 in 1991 to over 28,000 in 2001 (Figure 13). These increases were attributed primarily to improved airflow and unimpeded access for bats, and occurred in spite of the fact that winter tours were held continuously throughout this period. The apparent recovery of the population at Wyandotte led several researchers to conclude that bats may have habituated to disturbance associated with tours (Johnson et al. 2002, Whitaker et al. 2003). However, the response of the bat population since the closure of the cave to tours during the winter of 2002-2003, the first time the cave was closed during winter in many decades, suggested that winter disturbance had been limiting recovery of the bat population in this cave (Figure 13). The population increased an average of 16 percent (2,025 bats) every two years between 1991 and 2003. A hibernacula survey was conducted in January 2003, just months after tours had been discontinued. A noteworthy observation during that survey was that 4,368 bats (14 percent of the total 31,217 bats) were hibernating in Bats Lodge, an area that had not been used during the previous 23 years. Brack and Dunlap (2003) concluded: "Presumably, the bats returned to an area with preferred temperatures but avoided in past years because of winter tours." Within two years of closure, the population in the cave increased to 54,913 bats (a 76 percent increase). The increase since the closure demonstrates that we should be cautious in interpreting trends in bat populations; even though the bat population in the cave was increasing (prior to closure), the disturbance associated with tours was apparently a limiting factor.

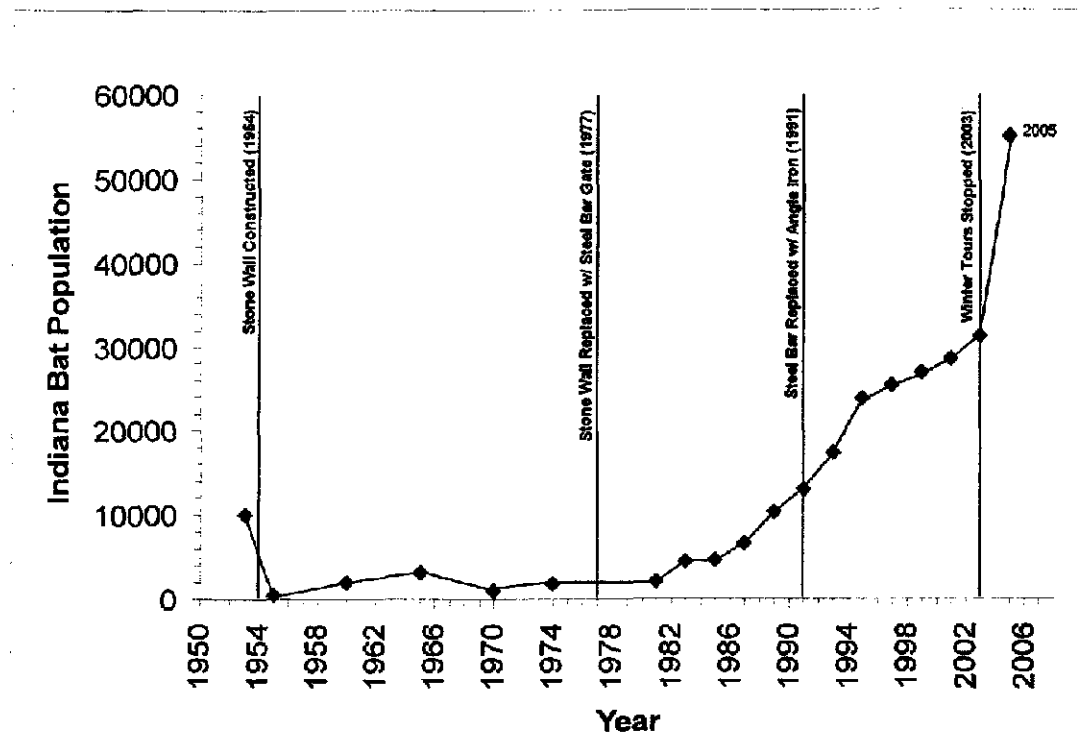


Figure 13. Changes in the population of hibernating Indiana bats in Wyandotte Cave, Crawford County, Indiana, relative to timing of structural changes to the cave and the cessation of winter tours.

Research, specifically research involving bat banding, was a factor in declines of populations of many cave bats. Peurach (2004) reported that requests for bat bands from the Bureau of Biological Survey (a bureau of the U.S. Department of Agriculture which previously distributed and tracked bat bands) reached an all-time high in 1962, when 250,000 bands were issued. By 1971, over 2,000,000 bat bands had been issued. Mohr (1952) reported that between 1932 and 1951 nearly 70,000 bats were banded in North America, and three-quarters of these were from caves. Griffin (1940a) reported: "The actual catching of bats is easy in caves. The bats are usually dormant and can be plucked from the walls by hand or with a net if out of reach." Banding projects were frequently long-term, lasting as long as 20 years, resulting in repeated disturbance of hibernating populations (Greenhall 1973). Indiana bats, with large numbers of hibernating bats in relatively few hibernacula, were a frequent target of large-scale banding projects (Hall 1962, Hassell 1963, Davis 1964, Myers 1964, Hassell and Harvey 1965, Humphrey 1978, LaVal and LaVal 1980). Some studies involved banding a large proportion of the total population; Griffin (1940b) visited four New England caves and estimated that 60 to 90 percent of the total population of Indiana bats in each cave was captured and banded. Collection of bats from hibernacula for sale to biological supply houses was cited as an additional threat to hibernating populations (Myers 1964). Myers (1964) observed that repeated trips to hibernating colonies of Indiana bats caused the bats to move to new roosting areas within a cave, or to other caves. LaVal and LaVal (1980) observed that bats demonstrated stronger philopatry to less disturbed caves, compared to caves where bats were frequently disturbed.

By the early 1970s, declines in hibernating populations of many species of bats, associated with banding disturbance, had been observed. In 1972, the U.S. Department of Interior, Bureau of Sports Fisheries and Wildlife placed a moratorium on the issuance of bat bands to new banders or for new projects. The restrictions were intended to "ease one of the major causes of disturbances to bat colonies in general and to the Indiana bat in particular" (Greenhall 1973). In addition to disturbance associated with arousal of hibernating bats, the restrictions also cited the potential for injuries associated with banding. At the Third Annual North American Symposium on Bat Research in 1972, bat biologists were asked not to carry on any studies that required bat banding (Greenhall 1973). We are unaware of any Indiana bat banding projects that involved the banding of hibernating bats since the mid 1970s (although some researchers have resumed banding Indiana bats in summer and swarming areas). Brack et al. (1983) reported that the Indiana bat recovery team decided that Priority 1 hibernacula should be censused only every other year beginning in 1982. Since the early 1980s, biennial hibernacula surveys constitute the major research-related disturbance of hibernating Indiana bats throughout most of the species range. Efforts are made to minimize the disturbance associated with these surveys (see Appendix 4: Indiana Bat Hibernacula Survey Guidelines). Any researcher entering an Indiana bat hibernaculum during the hibernation period is required to have authorization under Section 10 of the ESA (i.e., a permit or other form of authorization from the U.S. Fish and Wildlife Service). (See <http://www.fws.gov/forms/3-200-55.pdf> for a "Recovery Permit" application form).

Disturbance of Summering Bats

There are far fewer documented examples of disturbance of Indiana bats in summer due to "overutilization for commercial, recreational, scientific, or educational purposes," compared with impacts to hibernating bats. However, research-related disturbance of summering Indiana bats has been observed. Humphrey et al. (1977) reported a decrease in the population of Indiana bats at a maternity roost after they trapped emerging bats. Callahan (1993) documented the abandonment of three primary maternity roost trees of Indiana bats. Two were research related; the bats abandoned their roost trees after bats were captured with a handnet at the tree. The third tree was abandoned when underbrush was cleared from beneath the tree with a bulldozer. Gardner et al. (1991a) reported that climbing roost trees with ladders, placing thermocouples beneath bark, and conducting measurements of vegetation around roost trees caused varying degrees of disturbance. When possible, they avoided negative impacts by conducting activities near roosts when the bats were not present in the roost. They noted that removing bats directly from the roost usually caused the bats to flee, and they used less intrusive methods to capture bats when possible. Timpone (2004) reported that an Indiana bat roost tree was abandoned, and not used for the remainder of the maternity season, when two trees less than 100 meters from the roost were cut down.

Marking-related injuries have also been reported, particularly injuries related to bat banding (Baker et al. 2001), but some researchers have concluded that the risk of banding injuries and associated mortality of Indiana bats is slight (LaVal and LaVal 1980). Several researchers have also reported that impacts related to radiotagging of bats are minor. Neubaum et al. (2005) concluded that radiotagging had no apparent impacts on survival or condition of big brown bats. Kurta and Murray (2002) conducted a radiotelemetry study of Indiana bats in Michigan and concluded that the long-term effects of the radiotracking process were negligible. The importance of limiting the weight of the radiotransmitter relative to the weight of the bat has been stressed (Aldridge and Brigham 1988). We are aware of one instance in which a radiotagged Indiana bat died when the transmitter antenna became entangled in a barbed wire fence (D. Sparks, Indiana State University, pers. comm., 2005), but such events appear to be rare.

Mohr (1972) noted that handling of pregnant female bats may cause abortion. Myers (1964) reported that 53 of 71 female gray bats collected in Missouri aborted near-term fetuses when held in a collecting bag for approximately two hours. A female Indiana bat captured in a mist net in Kentucky aborted her fetus prior to release (Kessler et al. 1981). Hicks et al. (2005) are conducting a large-scale study on the efficacy and impacts of various marking techniques (metal and plastic bands, freeze brands, pit tags) on little brown bats; this study will provide additional insights into marking-related injuries. Generally, current procedures being used by researchers to capture, mark, and track Indiana bats during summer appear to result in minimal mortality, but continued caution and evaluation are warranted. (See Appendix 5: Indiana Bat Mist-Netting Guidelines). Any project involving the capture and handling of Indiana bats requires authorization under Section 10 of the ESA (i.e., a permit or other form of authorization from the U.S. Fish and Wildlife Service); therefore, the Service has the opportunity to review and comment on capture and marking procedures. (See <http://www.fws.gov/forms/3-200-55.pdf> for a "Recovery Permit" application form).

Disease or Predation

Disease and Parasites

The most studied disease of bats is rabies, which has been studied primarily because of human health implications. Rabies can be fatal to bats, although antibody evidence suggests that some bats may recover from the disease (Messenger et al. 2003). Pearson and Barr (1962) collected 93 hibernating bats from mines and caves in Illinois and none tested positive for rabies. They concluded that the possibility of finding rabid bats by random collections was remote. Generally the incidence of rabies in asymptomatic bats (i.e., bats exhibiting apparently normal behavior) is low (Messenger et al. 2003). In Indiana, none of 259 normally-behaving big brown bats tested positive for rabies, even though most of them were collected in areas where rabid big brown bats had been documented (Whitaker and Douglas in press). Whitaker and Douglas (in press) reported on the incidence of rabies in 8,262 bats, most found sick or dead, tested for rabies by the Indiana State Department of Health from 1966-2003. Of these, 445 (5.4%) tested positive for rabies. None of the 80 Indiana bats submitted tested positive for the disease. To our knowledge, rabies has never been reported in Indiana bats (Thomson 1982, Whitaker and Douglas in press), although relative to many other species few have been tested.

Generally, infectious disease is not cited as a major factor in the decline of bat populations, including the Indiana bat. However, Messenger et al. (2003) cautioned that mortality is a poorly understood aspect of the natural history of bats; the significance of various factors, including disease, on the overall mortality of a population of bats has rarely been documented. Further, species already threatened with degradation (including contamination) of their habitats may be particularly sensitive to disease outbreaks. The stress of migration can also contribute to the susceptibility of animals to disease, as has been suggested for rabies-related mortality in bats (Messenger et al. 2003). Because Indiana bats fly, are widely distributed, and are highly gregarious, they may be particularly vulnerable to disease occurrence and transmission.

Similarly, parasites are seldom cited as a factor contributing to declines in bat populations. Several authors have discussed the incidence of parasites in Indiana bats (Mumford and Whitaker 1982, Thomson 1982, Whitaker et al 2000, Ritzi et al. 2002), but none has suggested that parasites are implicated in the decline of the species. Ritzi et al. (2002) compiled a complete list of ectoparasites associated with the Indiana bat from the literature and their own work, and developed a key to ectoparasites of the Indiana bat. They noted that ectoparasites can affect the host's biology (e.g., hibernation, growth, roost switching in summer), but provided no evidence to suggest that ectoparasites pose a particular threat to the Indiana bat. Butchkoski and Hassinger (2002) observed hair loss in a maternity colony of Indiana bats roosting in an abandoned church in Pennsylvania. Similar atypical loss of hair occurred in little brown bats using the same roost, suggesting that the hair loss was somehow environmentally induced or perhaps caused by an unknown parasite. Although they did not observe mortality related to the hair loss, they discussed thermoregulatory implications.

Predation

Records of predation on bats at hibernacula are common. Analysis of prehistoric raccoon feces containing bones of Indiana bats from Wyandotte Cave (Munson and Keith 1984) and Mammoth Cave (Toomey et al. 2002) confirmed that Indiana bats were present and that hibernating bats

were preyed on by raccoons. Munson and Keith (1984) conservatively estimated that an average of 1,150 bats per year were consumed by raccoons over the past 1,500 years based on raccoon feces collected in Wyandotte Cave, noting that the true predation rate is possibly several times that figure. Evidence suggests that the majority of the bats were Indiana bats (Munson and Keith 1984). Bat bones are routinely observed in raccoon feces in mines used as Indiana bat hibernacula in New York and the feces are often found far from the hibernacula entrance, suggesting that the raccoons may be penetrating into hibernacula specifically to seek hibernating bats (A. Hicks, pers. comm., 2006). In Missouri hibernacula, Myers (1964) also observed that raccoon scats filled with bat bones were common and found far into caves, as well as high on cave walls wherever access by raccoons was possible. He further noted that dead bats within hibernacula he studied were quickly scavenged. On two occasions, groups of dead bats (banding mortalities) that were left in groups on the floor of caves in the evening were gone the next morning. Observations or evidence of predation by raccoons, mink (*Mustela vison*), snakes, owls, and feral and domestic cats in or at the entrance of hibernacula have been reported (Goodpaster and Hoffmeister 1950, Thomson 1982, Brack 1988, Butchkoski 2003). Evidence that hibernating Indiana bats were consumed by mice (*Peromyscus* sp.) has been observed on numerous occasions in Indiana caves, with one incident involving 13 dead Indiana bats (V. Brack, pers. comm., 2006). Cary et al. (1981) observed a black rat snake (*Elaphe obsoleta obsoleta*) preying on an Indiana bat outside a cave in Missouri, and Barr and Norton (1963) observed a black rat snake preying on a hibernating Indiana bat in a ceiling crevice of a cave in Kentucky. The incident occurred near the entrance, and they concluded that most hibernating bats are not highly susceptible to predation by snakes because most bats hibernate beyond the zone of light and at temperatures not conducive to snake activity. Most observations of predation on bats occur near the entrance of hibernacula (although note observations from Missouri and New York hibernacula above) and are not generally considered a major threat to hibernating populations. The exception is situations in which free flight of bats is impeded, usually by a gate or some other obstruction in the cave entrance. Predators have been observed to take advantage of situations in which bats are forced to slow down or land to negotiate an obstruction. Johnson et al. (2002) noted that a steel bar gate at Wyandotte Cave did not allow unrestricted flight and bats were forced to land and crawl through the gate. Predation by free-ranging cats was observed. At Pilot Knob Mine, predators concentrated at a newly constructed gate, taking advantage of bats forced to slow down or land as they negotiated the gate (C. Shaiffer, pers. comm., 2002).

Observations of predation on Indiana bats during the summer, when the bats are highly dispersed and difficult to observe, are less common than observations during hibernation. Sparks et al. (2003) documented Indiana bat maternity roosts in trees used by a red-bellied woodpecker (*Melanerpes carolinus*) and by a northern flicker (*Colaptes auratus*). In both cases, the woodpeckers were observed to probe under the piece of bark where the bats were roosting, resulting in vocalizations on the part of the bats, although no predation of bats by the woodpeckers was observed. On the same study area, they documented a raccoon denning in a hollow on an Indiana bat roost tree making repeated attempts to capture bats as they exited the roost, but never observed the raccoon taking a bat. Indiana bats roosting under bark are susceptible to predation, both within the roost and when they depart at dusk. Humphrey et al. (1977) observed an unsuccessful attack on a foraging Indiana bat by a screech owl (*Otus asio*) near the bat's roost. Predation pressure may exert influence on roost selection by bats (Kunz and

Lumsden 2003). There is no evidence that Indiana bats are particularly susceptible to predation within the roost, nor is there evidence that this has been a factor of the decline in this species. However, Sparks et al. (2003) noted that this form of mortality may be exacerbated when Indiana bats are forced to roost in highly fragmented habitats (i.e., small patches of forest) where roost sites are limited and mesocarnivores, such as raccoons, occur in higher densities (Dijak and Thompson 2000).

Competition

Interspecific competition among bats has not been well studied. Most ecological studies of bats have targeted only part of an assemblage, often a single species (Patterson et al. 2003). Researchers have observed that the overlap in roosting niches between Indiana bats and northern long-eared bats could lead to interspecific competition, particularly in habitats where roosts are not abundant (Foster and Kurta 1999), but Carter et al. (2001) reported no evidence of competition for roosts between these two species on their study area. Butchkoski and Hassinger (2002) noted no antagonistic behavior between Indiana bats and little brown bats that formed maternity roosts in the same abandoned church in Pennsylvania. Competition for roosts with other taxa has been noted. Kurta and Foster (1995) observed temporary takeover of an Indiana bat maternity roost by a pair of brown creepers (*Certhia americana*). Indiana bats temporarily abandoned a primary maternity roost tree that was being used by nesting pileated woodpeckers (*Dryocopus pileatus*) in Indiana. Indiana bats were observed "checking" this tree over a period of weeks, and resumed use of the roost when the woodpecker's young fledged in late July (D. Sparks, Indiana State University, pers. comm., 2005). T. Carter (pers. comm., 2004) observed that over a period of three years a colony of Indiana bats in an artificial roost structure in Illinois was gradually replaced by a colony of little brown bats; whether the little brown bats displaced the Indiana bats or the latter chose to return to natural roosts is not known. Clark (1984) speculated that little brown bats, which are much more common, may repress Indiana bats in northern Iowa.

Competition for prey is more commonly cited than competition for roosts but is also not well documented. Clark et al. (1987) cited numerous studies that supported the potential for competition between Indiana bats and other species for prey. Whitaker (2004) studied food habits among eight species of bats in a single community and showed that main foods were most similar for the Indiana bat, little brown bat, and northern long-eared bat. Lee (1993) noted that resource partitioning among Indiana bats, little brown bats, and northern long-eared bats is suggestive of interspecific competition among these species. Butchkoski and Turner (2005) documented partitioning of habitats used for foraging by little brown bats versus Indiana bats, and quantified that little brown bats spent far less time foraging compared to Indiana bats in the same area. Little brown bats at this study site used riparian areas for foraging while Indiana bats were using upland forest habitat. They concluded that the "larger foraging biomass at prime riparian sites may reduce the amount of foraging time required by little browns and suggests competition between Indiana bats and little browns for prime foraging locations." LaVal et al. (1977) similarly suggested that gray bats were competitively excluding Indiana bats from riparian foraging areas on their Missouri study area, and that Indiana bats were forced into more marginal foraging habitat away from streams.

The degree to which competition, for roosting and/or foraging habitat, is a limiting factor to the recovery of Indiana bat populations is not known. However, the impact of the competition on populations will be exacerbated by habitat fragmentation. Loss and degradation of habitat will force more individuals of sympatric bat species (as well as other taxa with similar habitat requirements) into smaller and potentially lower quality patches of habitat.

The Inadequacy of Existing Regulatory Mechanisms

Listing of the Indiana bat in 1967 under the Endangered Species Preservation Act brought attention to the dramatic declines in the species' populations and led to regulatory and voluntary measures to alleviate disturbance of hibernating bats (Greenhall 1973). Subsequent listing under the ESA in 1973 led to further protection of hibernacula. The Federal Cave Resources Protection Act of 1988 (18 U.S.C. 4301-4309; 102 Stat. 4546) was passed to "secure, protect, and preserve significant caves on Federal land" and to "foster increased cooperation and exchange of information between governmental authorities and those who utilize caves located on Federal lands for scientific, educational, or recreational purposes." This law provides additional protections for hibernacula located on Federal lands. At the time of listing, summer habitat requirements of the Indiana bat were virtually unknown, so listing had minimal impact on protection of summer habitat. Discovery of the first maternity colony under the bark of a dead tree in Indiana was made in 1971. Since the advent of radiotransmitters small enough to attach to bats in the late 1980s, summer habitat has been extensively studied and increasingly is the subject of consultation under the ESA.

State endangered species laws also afford protection to the Indiana bat; in most states protection is limited to prohibitions against direct take and does not extend to protection of habitat. The Indiana bat is state listed in 18 of 20 states where it currently occurs including Alabama, Arkansas, Connecticut, Illinois, Indiana, Iowa, Kentucky, Ohio, Oklahoma, Maryland, Michigan, Missouri, New Jersey, New York, Pennsylvania, Tennessee, Vermont, and Virginia. The species is also listed in four states where there are no current records (Florida, Georgia, Massachusetts, and South Carolina). State recognition of the need for protection of endangered species, including the Indiana bat, has increased dramatically. When listed under the ESA, the Indiana bat was only listed by two states (Martin 1973). Local laws, particularly ordinances that regulate development in karst areas, also help to protect areas surrounding caves and other karst features from inappropriate development, although local karst protection ordinances are not common within the species' range (Richardson 2003).

Generally, existing regulatory mechanisms are more effective at protecting Indiana bat hibernacula than summer habitat. Hibernacula are discrete and easily identified on the landscape, whereas summer habitat is more diffuse. Even in situations where we know a maternity colony is present, we seldom know the extent of the range of the colony. Further, the conservation value of protecting a hibernaculum is easier to demonstrate and quantify compared with the value of protecting summer habitat. Therefore, application of regulatory mechanisms at hibernacula is more easily justified. Similarly, factors that affect hibernacula directly (e.g., construction of barriers in cave openings) are easier to identify, and thus regulate, compared with activities in the surrounding landscape that less directly affect hibernacula (e.g., land-use practices that lead to siltation in cave entrances).

Ownership of Indiana bat habitat is probably the primary factor that limits effectiveness of existing regulatory mechanisms. Of 76 Priority 1 and 2 hibernacula, 15 (20 percent) are Federally owned, 18 (24 percent) are state owned, 42 (55 percent) are privately owned, and 1 (1 percent) has ownership recorded as "unknown" (USFWS, unpublished data, 2006). ESA protection extends to hibernacula that are privately owned, but recovery options are often limited on private lands. However, it should be noted that most private hibernacula owners are cooperative in efforts to protect Indiana bats.

We suspect that the majority of summer habitat occurs on private land, although this is difficult to document. The location of most Indiana bat maternity colonies is not known; the U.S. Fish and Wildlife Service estimates that the location of approximately 270 maternity colonies has been identified (Table 4), representing perhaps 6 to 9 percent of all colonies (see Current Summer Distribution: Maternity Colonies section for further discussion). We cannot assess ownership of summer habitat, as we did for hibernacula. However, in every state within the range of the Indiana bat, the majority of the forest land is privately owned (Smith et al. 2003), particularly in the core maternity range of the species in the Midwest (e.g., percentage of forest land privately owned is 84 percent in Illinois, 83 percent in Indiana, 88 percent in Iowa, 83 percent in Missouri, and 91 percent in Ohio). Krusac and Mighton (2002) and Kurta et al. (2002) noted that opportunities for managing for Indiana bat maternity habitat on public lands are limited and suggested that strategies for engaging private landowners in management are needed. Kurta et al. (2002) provided the example of ownership patterns within the range of one maternity colony they studied in Michigan. Roost trees for the colony were on property controlled by 11 different entities, and if foraging areas were also considered, the number of landowners involved with this one colony increased to over 35. Monitoring and management of maternity colonies on private lands can only be achieved through effective outreach to private landowners. Current regulatory mechanisms, or the manner in which those mechanisms have been implemented, have thus far not been effective in providing for this type of outreach on a broad scale.

Other Natural or Man-made Factors affecting Its Continued Existence

Natural Factors

Natural catastrophes in hibernacula have the potential to kill large numbers of Indiana bats. Based on a deposit of bones, a minimum of 300,000 Indiana bats were estimated to have been killed by a flood (probably a major flood in 1937) in Bat Cave, Edmonson County, Kentucky (Hall 1962). Other flooding events that killed large numbers of hibernating Indiana bats were reported by DeBlase et al. (1965) in Wind Cave, Breckinridge County, Kentucky (thousands of bats killed in 1964); T. Hemberger (Kentucky Department of Fish and Wildlife Resources, pers. comm., 2006) in Bat Cave, Carter County, Kentucky (3,000 bats killed in 1997); Johnson et al. (2002) in Batwing Cave, Crawford County, Indiana (several hundred bats killed in 1996); and Hicks and Novak (2002) in Haile's Cave, Albany County, New York (several hundred bats killed in 1996). Brack et al. (2005b) noted that there were 33 caves in Indiana known to have served as a hibernaculum for at least one Indiana bat during at least one winter and eight (24 percent) of these were known to have flooded, with known or inferred bat kills. Anthropogenic factors on the landscape (e.g., siltation in caves as result of agriculture in surrounding area) were implicated in at least some of these flooding events.

Indiana bats have also frozen to death in hibernacula (Humphrey 1978). In Bat Cave in Shannon County, Missouri, the population of hibernating Indiana bats fell from 30,450 in 1985 to 4,150 in 1987, and the remains of large numbers of dead bats were found on the floor beneath hibernating clusters. The bats had apparently frozen to death as the result of particularly cold temperatures recorded the previous winter (R. Clawson, pers. comm., 2006). A similar freezing event was reported (to R. Clawson) by a researcher who had worked in the cave in the late 1950s (R. Clawson, pers. comm., 2006). Richter et al. (1993) found more than 200 dead bats in Twin Domes Cave, Harrison County, Indiana in 1977 that had apparently died from exposure to subfreezing temperatures.

Structural differences among caves affect the temperature stability of the caves. Caves with large volume and structural diversity provide the most stable internal temperatures over the widest range of external temperatures, and thus provide the greatest protection from freezing (Tuttle and Kennedy 2002). Ironically, Indiana bats may be more likely to freeze to death in caves at the southern edge of their hibernation range (where ambient temperatures and thus internal cave temperatures are warmer), compared to more northern caves. In warmer regions, and depending on the configuration of the hibernaculum, Indiana bats may be forced to roost closer to the entrance (where the temperature tends to be lower in mid-winter) to find the low temperatures needed for hibernation. However, temperatures near the entrance are not only lower, but also more variable, and sustained cold temperatures outside the cave can subject bats to subfreezing temperatures. Historically, incidents of bats freezing in hibernacula have not been widespread (Humphrey 1978), and there has been no implication that mortality due to freezing has been a major cause of rangewide declines. However, freezing events can be devastating to local populations, as evidenced by the Bat Cave, Missouri, example discussed above. Further, mortality rates due to freezing may change if there are long-term climate changes, which will result in changes in hibernacula temperature. For more information on climate change in this plan, see Threats and Reasons for Listing: Other Natural or Man-made Factors affecting Its Continued Existence: Climate Change.

Discussions of temperature affecting bats typically center on hibernation, but temperature within maternity roosts is also an important consideration. Development of young bats is directly affected by temperatures inside the roost (Tuttle 1975, Racey 1982). Humphrey et al. (1977) reported that a cold summer delayed the recruitment of Indiana bats (i.e., time required until young could fly) by 2.5 weeks and the completion of migration by 3 weeks, exposing bats to freezing weather at the nursery and possibly affecting mortality, autumn mating, or fat storage for winter. Cool temperatures also reduce the food supply for Indiana bats (Humphrey et al. 1977, Belwood 1979). The extent to which temperatures inside maternity roosts impact productivity of Indiana bats is not known. However, cold spring temperatures could further stress pregnant females, already stressed by energy demands of hibernation and migration.

Anthropogenic Factors

Environmental Contaminants

Organochlorine Pesticides: Mohr (1953) was the first to raise concerns about the possible impact of insecticides on bat populations. Clark (1988) describes in some detail the four laboratory LD₅₀ (lethal dose to 50% of the tested animals) toxicological studies that were conducted with bats and organochlorines in the 1960s and early 1970s. The relevance of short-term laboratory LD₅₀ tests to long-term exposures in real world conditions has been a continual problem to those charged with managing wildlife (Clark 1988). One of the major reasons for this problem is that adverse reproductive effects can be significant in mammals when doses are sustained at levels three or four orders of magnitude lower than doses causing death in short-term studies (Rice et al. 2003). More appropriate toxicological research on wild mammals is needed (Hoffman 2003). The life history and unique physiological adaptations of bats make understanding these results even more difficult.

By the late 1970s and early 1980s, bat mortalities caused by organochlorine pesticides (dieldrin, heptachlor epoxide) were documented in several Missouri caves (Clark et al. 1978, 1980, 1983). It is not clear from these documented pesticide poisoning incidents how widespread this problem was. Did they represent only minor site specific problems or did they represent common occurrences throughout North America? The long-term effects these mortality incidents had on the bat populations that depend on Missouri for summer range and winter hibernation is still unknown. Furthermore, although the historic studies of bat/organochlorine poisonings documented lethality, there is still no understanding of the long-term health effects of sub-lethal doses of organochlorine pesticides to individual longevity and reproductive fitness.

More than 70 analytical data sets or subsets exist for analytical samples of bat carcasses, bat guano, and bat hair from caves throughout the range of the Indiana bat, including Missouri, Kentucky, New York, Indiana, Illinois, Ohio, Oklahoma, Tennessee, West Virginia, and Virginia (Martin 1992; Ryan et al. 1992; Hudgins 1993; McFarland 1998; New York State Department of Environmental Conservation et al. 2004; O'Shea and Clark 2002; BHE 2004, 2005; Adornato 2005; Sparks 2006; USFWS, Bloomington, Indiana Field Office, unpublished data, 1997-2006; USFWS, Cookeville, Tennessee Field Office, unpublished data, 1997-2001). From this incomplete literature review and data mining effort, it is clear that there are still potentially significant organochlorine contaminant problems in several Missouri caves. In 1997, McFarland (1998) took little brown bat samples from three Missouri caves late in the hibernation period as "reference samples" for several biomarker evaluations and chemical analyses. Even though the sample preparation methods likely biased the analytical chemistry results upward, McFarland's three reference caves (Great Scott, Scotia Hollow, and Onyx) had exceedingly high organochlorine residues with maximums approaching concentrations one would expect from the 1960s and 1970s. Furthermore, the ratio of parent compound DDT to its metabolites DDD and DDE implies that this is potentially a recent source (Aguillar 1984, Schmitt et al. 1999). There are some significant opportunities for further evaluation of the historical trends and current status of Indiana bat populations in Missouri in relation to the contaminant information that is available for bats in Missouri caves. If McFarland (1998) chemistries are an accurate reflection of current conditions, sublethal effects may be observable.

Other caves in Missouri have shown different results. Contaminant investigations of surrogate bats and guano from Fort Leonard Wood in Missouri and a reference site in the Mark Twain National Forest did not have elevated levels of organochlorine pesticide contamination (BHE 2004, 2005). On the eastern end of the Indiana bat's range, a comparison of historic guano samples and more recent guano samples (1991) from a cave in Scott County, Virginia indicated that residues of organochlorine pesticides have dropped from concentrations that were likely having adverse impacts to very low, nearly non-detectable concentrations (Ryan et al. 1992). Although this cave is more closely associated with gray bats and Virginia big-eared bats, it may be indicative of the pesticide levels to which Indiana bats in Virginia have been exposed. Of the cave-related samples that have been evaluated to date, it does not appear that bats at any caves other than Great Scott, Scotia Hollow and Onyx have organochlorine pesticide residues at concentrations that might pose an ongoing contaminant hazard (Martin 1992; Ryan et al. 1992; Hudgins 1993; McFarland 1998; New York State Department of Environmental Conservation et al. 2004; O'Shea and Clark 2002; BHE 2004, 2005; Adornato 2005; Sparks 2006; USFWS, Bloomington, Indiana Field Office, unpublished data, 1997-2006; USFWS, Cookeville, Tennessee Field Office, unpublished data, 1997-2001). In the future, comparisons need to be made between the caves for which there are analytical chemistry data and the range-wide importance of these caves to Indiana bat. Additionally, an effort should be made to identify which priority Indiana bat caves have no or limited chemistry data in order to fill these data gaps. Of the samples collected from field locations within the range of Indiana bat summer habitats none had remarkable organochlorine concentrations.

Other site specific organochlorine contaminant problems may be adversely impacting Indiana bats. For example, Stansley et al. (2001) documented recent bat mortalities in localized areas where chlordane had historically been used.

Polychlorinated Biphenyls: PCBs, as a complex mixture, have been in the environment longer than any other known persistent organic pollutant. PCBs came into use in industrial applications in 1929 but were not detected in environmental samples until 1966 (Jensen 1972). They are one of the most ubiquitous industrial chemical mixtures contaminating our landscape. They often get moved from upland disposal sites via erosion or groundwater contamination to our waterways and riparian zones resulting in a concentrating zone within a flood plain. Based on the toxic nature of PCBs they may be contributing to adverse impacts on Indiana bats in localized areas throughout the bat's range. Despite the lack of PCB research on bats, PCBs have been studied in numerous other mammals and associated with a wide range of adverse effects including growth, neurobehavioral, hormonal, reproductive, embryotoxic, immunotoxic, and lethal effects (Chapman 2005). PCBs have been implicated in the disruption of the endocrine systems of fish, birds and mammals (Colburn et al. 1996). PCBs have been shown to suppress serum triiodothyronine (T₃) and thyroxine (T₄) in laboratory rats (Byrne et al. 1987) and decrease expression of male secondary sex characteristics and fertility in creek chubs (Sparks et al. 2005c). There are many published reviews of PCB effects on wildlife (e.g., Bosveld and Van den Berg 1994, Leonards et al. 1995, Eisler and Belise 1996, Hoffman et al. 1996, Henshel 1998). Many adverse effects associated with PCBs appear to be mediated through the same mode of action as 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and are therefore attributed to the dioxin-like congeners of PCB called coplanar PCBs (Chapman 2005). For this reason, research

on the adverse effects of dioxin on wildlife contributes much to our understanding of potential adverse impacts associated with coplanar PCBs. Most PCB congeners do not appear to have dioxin-like properties yet may also be responsible for toxic effects through different modes of action (Fischer et al. 1998).

The most meaningful toxicological work for the Indiana bat is likely that performed for mammals. With regard to PCB impacts, the mink is one of the best studied and most sensitive mammals (Platonow and Karstad 1973, Aulerich and Ringer 1977, Aulerich et al. 1985, Hornshaw et al. 1983, Ringer 1983, Foley et al. 1991, Bursian et al. 2003, Brunström et al. 2001, Beckett et al. 2005). Certain congeners of PCBs (hexachlorobiphenyls), as low as 0.1 mg/kg fresh weight in the diet, have caused 50 percent mortality in three months, and completely inhibited reproduction in survivors (Aulerich et al. 1985). Placental transfer of PCBs occurs in mink and gives rise to embryotoxicity (Ringer 1983) and deformities in newborn kits (Kubiak and Best 1991, Heaton et al. 1995).

In the limited studies of PCBs impacts to bats (Clark and Prouty 1976, Clark and Lamont 1976, Clark 1978, Clark and Krynsky 1978) there is also evidence of reproductive failures in bats. For instance, Clark and Lamont (1976) documented enhanced placental transfer of PCBs in bats prior to Ringer (1983) documenting it in mink. In Clark's original field work, a higher incidence of still births were seen in yearling bats and were a cause of concern, prompting Clark to conduct laboratory feeding studies of pregnant bats. These were excellent pioneering studies but unfortunately they are not directly applicable to our current information needs. In Clark's earliest studies (Clark et al. 1975, Clark and Lamont 1976, Clark and Krynsky 1978), the PCBs detected appeared to be Aroclor 1260 so Clark's laboratory dosing studies were done with Aroclor 1260. Aroclor 1260 exhibits less toxicity to mammals than Aroclors 1242, 1248, or 1254 (Tillitt et al. 1992) and is only rarely the source of PCB contamination found within the range of the Indiana bat. In addition, PCBs appear to have their greatest adverse impacts when exposures occur during early embryonic development (Henshel 1998). Unfortunately, it was not possible for Clark to dose wild-captured, pregnant bats with PCBs until they were midway through gestation. Adverse impacts were uniformly seen in the younger bats, whether "dosed" with PCBs or not. Clark attributed these observed reproductive impacts to the natural phenomenon of poor energetics in the yearlings' first pregnancies.

PCB transfer from the female to its young through nursing is the most important exposure route in prevalent bats. Juvenile bats typically contain the highest concentrations of PCBs in studied populations (Clark and Prouty 1976). Adult male bats may continue to bioaccumulate PCBs throughout their life and will generally have higher concentrations than adult females (Clark et al. 1975). It is uncertain what effect this may have on the reproductive fitness of older males. In the bats studied, female bats typically contain their highest concentrations as juveniles and yearlings up until they give birth and begin lactating. Because the maternal transfer of PCBs to the fetus, and to pups through lactation is remarkably high, there is a significant depuration in maternal body burden of PCBs (Clark et al. 1975). As females grow older, PCB concentrations may increase again with age; however, much of the PCB body burden will continue to be transferred to offspring (Clark and Krynsky 1978). Therefore, yearling females are at the greatest risk of having stillborn pups because, in general, they are the most contaminated animals (Clark and Prouty 1976).

Another important factor that contributes to the likelihood that PCBs can potentially cause adverse impacts to bats is that they have long lives for a small mammal. The short-term PCB laboratory toxicity studies in other mammals may underestimate the effects on the Indiana bat considering the unique physiological differences between bats and rodents. The long-lived nature of bats and low fecundity may predispose them to heightened risk. Chapman (2005) discussed why typical toxicity studies (and risk assessments based on these) do not adequately address long-term exposures to contaminants. Brunström et al. (2001) showed a dramatic decrease in mink reproductive success between the first and second years of study. This calls into question the safety of currently accepted "no observed adverse effect levels" (NOAELs) for protecting wildlife populations such as Indiana bats which have one pup per year. Similarly, Restum et al. (1998) documented lower mink reproductive success after a second breeding season than for a single breeding season, and lower for the second generation of female mink exposed (combined natal and post-natal exposure) than for the initial female generation exposed only as adults. These findings are consistent with an increase in the reproductive toxicity of dioxin (TCDD) associated with exposure to multiple generations of rats compared to exposure to a single generation (Murray et al. 1979).

Linzey (1988) reported that reproductive success of second generation PCB-treated white-footed mice (*Peromyscus leucopus*) was reduced in comparison with performance of the parental generation reported by Linzey (1987). Linzey (1988) stated "that effects of chronic exposure to PCBs are cumulative through generations, probably due to length of exposure as well as to exposure during critical periods of growth and development." McCoy et al. (1995) also reported the PCB body burden in oldfield mice (*Peromyscus polionotus*) approximately doubled between generations at a constant exposure concentration, and was associated with increasingly adverse effects. Applying their study to field exposures, McCoy et al. (1995) stated "for wild populations that remain in the same area for many generations, cumulative effects may have serious consequences." In the case of Indiana bats, such effects could be particularly meaningful, resulting in declines in maternity colony numbers and range reductions through extirpation from what appears to be otherwise suitable habitat.

Thousands of miles of rivers and streams throughout the range of the Indiana bat have fish consumption advisories due to PCB contamination. Although there is no direct causal link between fish consumption advisories and impacts to bats, the consumption advisories can serve to identify habitats where exposure to these chemicals may occur.

Exposure to PCBs can take place in maternity habitat where it contaminates relatively few bats or exposure can take place at swarming sites near hibernacula where potentially many more bats would be exposed. Presently, for areas that have been sampled, Indiana bats using Ray's Cave, Indiana, near the heavily PCB contaminated Richland Creek are not accumulating concentrations of concern (D. Sparks, USFWS, pers. comm., 2005). Recent guano samples from Coon and Grotto Caves (Monroe County, Indiana) indicate that a nearby PCB-contaminated Superfund site is not currently posing a risk to Indiana bats. Conversely, both guano and Indiana bat carcasses from Wyandotte Cave (Crawford County, Indiana) have PCB concentrations that are 10-fold higher than guano and Indiana bat carcasses from Ray's, Coon, and Grotto Caves. At this time no known sources of PCBs are within the potential swarming foraging range of Wyandotte Cave;

more investigation is warranted (D. Sparks, USFWS, pers. comm., 2005). PCB residue concentrations in nine bats that were found sick or dead and taken to the Indiana Department of Health Rabies Laboratory ranged from non-detect to over 4 parts per million (ppm) wet weight (D. Sparks, USFWS, pers. comm., 2005), a level at which sublethal adverse effects have been seen in other classes of animals (DeWitt et al. 2006, Henshel et al. 2006).

Work in summer habitat along Pleasant Run Creek, Indiana, resulted in collection of surrogate species and guano for chemical analysis. One of the adult male little brown bats contained 46.8 ppm fresh wet weight PCBs (USFWS, Bloomington, Indiana Field Office, unpublished data, 2003), likely the highest PCBs level yet reported in a bat carcass. A juvenile found dead on August 6, 2004, contained 18.8 ppm PCBs, fresh wet weight, possibly a lethal concentration.

Guano samples collected from bats foraging near Pleasant Run Creek, Indiana, contained significant concentrations of PCBs (1.47 to 1.61 ppm, wet weight). To get a rough idea of exposure through diet one can assume PCBs are absorbed from food at a rate similar to energy assimilation (this is a reasonable assumption based on the fact that PCBs are lipid-soluble and lipids are most easily digested and that Buckner (1964) documented energy assimilation efficiencies of 78 to 93 percent in four species of shrews, small mammals of a similar metabolism to bats), then the concentration of PCBs in the diets of these bats ranged from approximately 5 to 16 ppm, wet weight. These dietary estimates exceed dietary adverse effect levels for other mammals (Chapman 2005).

Organophosphate and Carbamate Insecticides: With the restrictions on the use of organochlorine pesticides in the 1970s, organophosphates (OPs) and carbamate (CA) insecticides have become the most widely used pesticides in the world (Smith 1987). OPs and CAs act primarily by inhibiting acetylcholinesterase (AChE), an enzyme essential for nerve function within the peripheral and central nervous system (O'Brien 1967). Clinical signs of toxicity include a diverse array of abnormal behaviors such as tremors and eventual paralysis. Death occurs due to respiratory failure (Grue et al. 1997). Birds appear to be much more sensitive to acute exposure to OPs and CAs than mammals (Hill 1995) and most of what is known about these pesticides comes from the hundreds of confirmed wildlife mortality incidents throughout the world (Grue et al. 1983) and from laboratory studies using single dose, acute toxicity studies. Only two such acute toxicity studies have been done with OPs and bats (Clark 1986, Clark and Rattner 1987). Because acute laboratory toxicity tests have dealt with high doses and looked at death as the measurable endpoint, their value for comparison to field conditions and chronic exposures is reduced. Grue et al. (1997) provided a good review of what was known about the sublethal adverse effects OPs and CAs have on thermoregulation, food consumption, and reproduction. Because of the unique physiology of bats in relation to reproduction, high energy demands and sophisticated thermoregulatory abilities, much more research needs to be done with these pesticides and their effects on bats.

To date, understanding how OP and CA pesticides are used and how these practices might intersect with the natural history and habitat use of Indiana bats throughout its range is limited. As an example, the following reviews the facts about one common OP pesticide, chlorpyrifos. Within the range of Indiana bats, the National Agricultural Statistics Service (NASS) database indicates that in 2000 approximately 3.5 million pounds of chlorpyrifos was applied to an

estimated 4 million acres of planted corn. In 2002, the NASS database indicated that approximately 1.5 million pounds were used on approximately 1.7 million acres of planted corn. These are crude estimates developed from active ingredient application rates for the states that actually reported data in those years. Many known maternity colonies are located in corn-producing areas. It is unknown whether or not this is cause for concern, yet, recent improvements in analytical chemistry techniques for monitoring the persistent organochlorine pesticides and PCBs have found low levels of chlorpyrifos in almost every recently analyzed Indiana bat carcass and guano sample (Sparks 2006). BHE (2004, 2005) also detected low levels of chlorpyrifos in several surrogate bat samples from Fort Leonard Wood and from nearby controls. This confirms that exposure to OP pesticides is routinely occurring in at least parts of the Indiana bat's range.

In addition, several bats from Indiana that died under suspicious circumstances (i.e., cause of death unknown) were tested for contaminants. The following OP pesticides were detected in 3 of 9 submitted samples: diazinon, methyl parathion, and chlorpyrifos (Sparks 2006). In guano samples recently evaluated from several Indiana caves (Coon, Grotto and Wyandotte Caves), the OP pesticide dichlorvos was detected (Sparks 2006). Dichlorvos is an OP insecticide registered for multiple indoor and outdoor uses (U.S. Environmental Protection Agency undated). Target pests include flying or resting adult mosquitoes, flies, gnats, chiggers, ticks, cockroaches and other nuisance insect pests (U.S. Environmental Protection Agency undated). Maul and Farris (2005) documented significant levels of cholinesterase (ChE) inhibition in 8.7 percent of northern cardinals (*Cardinalis cardinalis*) sampled from agricultural field edges in northeast Arkansas. If sublethal reductions occur in the ChE enzymes of Indiana bats as a result of these documented OP exposures, some attributes that may be affected include foraging and navigational abilities. Impairment of foraging ability could affect meeting energy requirements. Navigational impairment could risk trauma if bats collide with hard objects (i.e., trees). More research needs to be done on the sublethal effects of this widely used class of pesticides on bats (O'Shea and Clark 2002).

Pyrethroid Insecticides: In general, pyrethroid insecticides are absorbed slowly in mammalian gastro-intestinal tracts, and what is absorbed is metabolized quickly (Miyamoto 1976). Mice were documented to be more susceptible to pyrethroid toxicity than were rats, and female rats more susceptible than males but only at very high doses relative to environmental exposures (Miyamoto 1976). A few studies showed that if administered intravenously, then pyrethroids are very toxic, further indicating that absorption is a key factor. Pyrethroids are less toxic when exposures are dermal or via inhalation (Miyamoto 1976). However, pretreatment of the animals with an organophosphorus compound actually enhances toxicity to some pyrethroids (Miyamoto 1976).

Quisand et al. (1982) dosed lactating cows with the pyrethroid fluvalinate orally and documented the following metabolic processes over eight days. Approximately 53 percent was excreted in urine, 42 percent excreted in feces, 0.9 percent was found in milk. Other tissues contained traces of the metabolic products, but more than 70 percent left as parent compound (Quisand et al. 1982).

Shore et al. (1991) investigated the toxicity and tissue distribution of polychlorinated phenol (PCP) and permethrin (a pyrethroid) used as a wood preservative at bat roosting locations. While PCP was found to be very toxic and accumulative, permethrin alone caused no toxic effects and was not detectable in tissues.

McFarland (1998) pointed out slight differences in toxicity between formulations of permethrin which is evidence that absorption is the most important factor regarding pyrethroid toxicity. This is in agreement with Miyamoto (1976). As for the residues that McFarland (1998) documented in some overwintering bats, these do not appear to be significant. In nine bats (of mixed species, including Indiana bats) from Indiana that were analyzed for contaminants, no pyrethroid residues could be found (USFWS, Bloomington, Indiana Field Office, unpublished data, 2002). The greatest risk to bats from pyrethroids is indirect; the significant reduction or loss of the insect prey base near a maternity colony could have an adverse impact on survival.

Inorganic Contaminants: Lead is the most ubiquitous toxic metal and is detectable in practically all phases of the inert environment and in all biological systems (Goyer 1996). It has been associated with a wide range of toxic effects from neurological, hematological, renal, and reproductive (Goyer 1996). Clark (1979) documented lead concentrations in big and little brown bats from Laurel, Maryland, exceeding levels found in small mammals with renal abnormalities associated with lead contamination. Levels of environmental lead contamination have declined significantly since the introduction of lead-free gasoline products (Goyer 1996). The residual contamination from lead mining in southwestern Missouri could be sufficient to cause adverse effects to Indiana bats on the western limits of its range. None of the hair, carcass, and guano samples that have been reviewed at the Bloomington, Indiana, Field Office approach the lead concentrations documented by Clark (1979) (Martin 1992; Ryan et al. 1992; Hudgins 1993; McFarland 1998; New York State Department of Environmental Conservation et al. 2004; O'Shea and Clark 2002; BHE 2004, 2005; Adornato 2005; Sparks 2006; USFWS, Bloomington, Indiana Field Office, unpublished data, 1997-2006; USFWS, Cookeville, Tennessee Field Office, unpublished data, 1997-2001).

Mercury exhibits toxicological properties in all of its forms (elemental, inorganic, and organic); however, its organic form, methyl mercury, is the most important in terms of toxicity from environmental exposures (Goyer 1996). To date, no mercury toxicity studies have been done with bats. Hair levels of mercury have been found to be a reliable measure of exposure to alkyl or methyl mercury (Goyer 1996). In mice, residues of 2 to 5 ppm in hair have been associated with loss of motor coordination and decreased swimming ability (Suzuki 1979). In cats, 7.6 ppm in hair coincided with adverse effects (Eaton et al. 1980). The lack of long-term studies, the difficulty in relating rodent studies to bats, and the complex issues surrounding the speciation and metabolism of mercury make it impossible to interpret the limited existing mercury data available for bats (USFWS, Cookeville, Tennessee, Field Office, unpublished data, 1997-2001; USFWS, Bloomington, Indiana, unpublished data, 1997-2001). Of the data available, fewer than 20 percent of the samples contain mercury (reported as total) above the detection limits and when detected, concentrations have ranged in the 2 to 4 ppm range (with less than ideal detection limits at approximately 1 ppm).

Direct Losses at Oil Spills / Production Well Pits: In 1992 and 1993, oil pits in the oil production well fields of southwestern Indiana were surveyed for dead animals. Hundreds of dead birds and bats were found in oil pits in counties with Indiana bat summer habitat (USFWS, Bloomington, Indiana, Field Office, unpublished data, 1993-1994). Identification of oiled bat carcasses was done by the Ashland, Oregon, Forensics Laboratory, but most bats were only identified to *Myotis spp.* Many of the larger operations maintain netting over oilpits, which can also result in bat mortalities. Although this is not likely to be a widespread problem for Indiana bats, it is possible that some individuals are occasionally taken in this manner.

Oil and Hazardous Substance Spills: Spills of petroleum and crude oil can have significant short-term impacts to occupied summer habitats and likely result in take of some individual Indiana bats. These infrequent events will always pose a threat to local populations of Indiana bats utilizing affected summer habitats.

The potential threat of a pipeline rupture or major transportation accident causing a spill into Indiana bat hibernacula has not been determined. A petroleum product spill into a waterway or sinkhole leading into a hibernacula could cause significant mortalities in these sorts of confined spaces due to asphyxiation, irrespective as to whether or not bats would come into direct contact with the spill.

Other Contaminant Threats: Documentation of adverse impacts to bats from pesticides and other potential toxics is difficult. R. Gerhold (Southeastern Cooperative Wildlife Disease Study, pers. comm., 2005) provided 19 case histories on bat mortality incidents that have occurred in the past 5 years. Three of these cases were confirmed to have rabies, three were confirmed to be trauma-related, and 12 cases had undetermined causes. A few of the undetermined cases seem to have toxicological implications. For example, a case in Florida involved the spraying of diquat® to control an algal bloom on a small artificial pond. In the three days following this event, eight Mexican free-tailed bats were found dead under a bat house near the pond.

Often bats necropsied at the U.S. Geological Survey Wildlife Health Laboratory in Madison are found to be emaciated (G. McLaughlin, U. S. Geological Survey Wildlife Health Laboratory, pers. comm., 2005). Cause of death could be related to adverse weather conditions that affect food availability such as a drought or an unexpected cold snap. Alternatively, a sublethal dose of an organophosphate or carbamate could perhaps reduce a bat's foraging capability for a few hours or days.

Climate Change

Potential impacts of climate change on temperatures within Indiana bat hibernacula were reviewed by V. Meretsky (pers. comm., 2006). Climate change may be implicated in the disparity of population trends in southern versus northern hibernating populations of Indiana bats (Clawson 2002), but Meretsky noted that confounding factors are clearly involved. Humphries et al. (2002) used climate change models to predict a northern expansion of the hibernation range of the little brown bat; such modeling would likely result in predictions of range shifts for Indiana bats as well. Potential impacts of climate change on hibernacula can be compounded by mismatched phenology in food chains (e.g., changes in insect availability relative to peak energy demands of bats) (V. Meretsky, pers. comm., 2006). Changes in maternity roost temperatures

may also result from climate change, and such changes may have negative or positive effects on development of Indiana bats, depending on the location of the maternity colony. The effect of climate change on Indiana bat populations is a topic deserving additional consideration.

Collisions with Man-made Objects

Collisions of bats with man-made objects have not been fully evaluated, but concern for bat mortality related to such collisions is growing, specifically with reference to collisions with turbines at wind-energy plants. Johnson (2005) reviewed bat mortality due to collisions with turbines at wind-energy developments in the United States. Eleven species of North American bats have been recorded among the mortalities; species within the genus *Lasiurus* form a large proportion of the bats killed. No documented mortality of Indiana bats at wind farms has occurred to date. However, there is growing concern regarding the potential for bat kills given the rapid proliferation of wind farming and the large-scale mortality that has occurred at some facilities. Limited knowledge of the migratory behavior of bats limits our ability to understand and evaluate why bats are susceptible to striking wind turbines (Larkin 2006). Wind-energy developments, particularly near hibernacula or along potential migration routes where large numbers of Indiana bats could be impacted, should be evaluated as a potential threat.

Bat collision mortalities have also been associated with communication towers and other man-made structures (Johnson 2005). For example, Martin et al. (2005) reported that since 1997 remains from more than 126 bats that collided with military aircraft have been processed. This figure probably largely underestimates total strikes as most of these incidents do not result in serious, if any, damage to the aircraft, and therefore are not consistently reported. Like collisions with wind turbines and communication towers, strikes with aircraft occur most often during the fall migration. Russell et al. (2002) verified that an Indiana bat was killed by collision with a vehicle on a Pennsylvania road. There is no implication to date that Indiana bats are particularly susceptible to such collisions, but they may represent a threat to local populations under certain conditions.

Conservation Efforts

Conservation measures provided to the Indiana bat through its status as a listed species include cooperative grants to states, inter- and intra-agency consultations, prohibitions, permits, and land acquisition. Other measures have also been implemented that relate indirectly to its Federal status; these include protection of hibernation and maternity sites, research and monitoring, and outreach.

Cooperative Grants to States

Section 6 of the ESA establishes a program that enables the Service to develop cooperative management agreements with the states for Federally listed species and to provide grants for the conservation of these species. Many states within the range of Indiana bats have used Section 6 funds to protect and conserve the species. These conservation activities have included the development and implementation of landowner agreements to protect significant caves, construction of cave gates or fences at hibernacula, monitoring hibernacula, and conducting or

supporting research directed at gaining a better understanding of the Indiana bat's life history and conservation needs.

Several state agencies have made considerable investments in bat conservation; some have staff dedicated primarily to endangered bats (B. Currie, USFWS, pers. comm., 2006). For example, the Missouri Department of Conservation has developed a plan to conserve the endangered bats of Missouri. This plan provides specific management recommendations for Indiana bats.

Inter- and Intra-agency Consultations

Section 7(a) (1) of the ESA requires all Federal agencies "to utilize their authorities in furtherance of the purposes of this ESA by carrying out programs for the conservation of..." Federally listed endangered and threatened species. All Federal agencies within the range of the Indiana bat, in consultation with the Service, have a responsibility to develop and carry out programs for the conservation of this species.

Section 7(a) (2) of the ESA and its implementing regulations (50 CFR 402) require Federal agencies to evaluate their actions with respect to any species that is proposed or listed as endangered or threatened and to ensure that the activities they authorize, fund, or carry out are not likely to jeopardize the continued existence of such species, including the Indiana bat. If a Federal agency's action is likely to adversely affect Indiana bats, the responsible Federal agency must initiate formal consultation with the Service. Upon completion of formal consultation the Service issues a biological opinion on impacts of the proposed action to the listed species.

Through informal and formal consultations with the Service, many National Forests within the range of the species have developed standards and guidelines in their Forest Land and Resource Management Plans that protect hibernacula and conserve nonhibernation habitat (i.e., maternity habitat, swarming and staging habitat, male summer habitat) (Clawson 2000, USFWS 2004b). For example, the Mark Twain National Forest draft Forest Plan Revision contains 42 standards and guidelines that will protect, maintain or enhance Indiana bat habitat and/or protect individuals and/or hibernating populations. (National Forest Plans are available from the U.S. Forest Service: <http://www.fs.fed.us>). Biological opinions for actions taken on National Forests and by other Federal agencies also have detailed terms and conditions to minimize incidental take associated with the proposed action. Terms and conditions include such actions as retaining snags and large live shagbark and shellbark hickories and white oaks, seasonal cutting restrictions, measures to avoid smoke impacts from prescribed burning, retention of all known roosts until they naturally fall to the ground, installation of bat boxes, continued surveying and monitoring of bat populations, and other measures (T. Davidson, USFWS, pers. comm., 2005).

Army Regulation 200-3 requires Army installations to prepare Endangered Species Management Plans (ESMPs) for all facilities that contain Federally listed species. The purpose of an ESMP is to provide a comprehensive plan for maintaining and enhancing populations and habitats of federally listed and candidate species while maintaining mission readiness consistent with Army and Federal environmental regulations. According to the 2005 survey of threatened and endangered species on Army lands, the Indiana bat occurs on 12 Army installations (Rubinoff et al. 2006).

Prohibitions

Section 9 of the ESA and its implementing regulations (50 CFR 17.21) set forth a series of general prohibitions and exceptions that apply to all endangered wildlife. These prohibitions, in part, make it illegal for any person subject to the jurisdiction of the United States to take (by definition take includes harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, collect, or attempt any such conduct); import or export; ship in interstate or foreign commerce in the course of commercial activity; or sell or offer for sale in interstate or foreign commerce any listed species. It is also illegal to possess, sell, deliver, carry, transport, or ship any such wildlife that has been taken illegally. Agents of the Service and state conservation agencies are exempt from some of these prohibitions. Authorization for others to conduct these activities must be obtained through a permit issued under the authority of Section 10 of the ESA.

Permits

Section 10 of the ESA and its implementing regulations (50 CFR 17.22 and 17.23) provide for the issuance of permits to carry out otherwise prohibited activities involving endangered wildlife under certain circumstances. For endangered species, such permits are available for scientific purposes or to enhance the propagation or survival of the species (section 10(a)(1)(A)), and for incidental take in connection with otherwise lawful activities (section 10(a)(1)(B)).

Approximately 60 section 10(a)(1)(A) permits for Indiana bats have been issued in Region 3 of the Service since 1996. Permits have been issued in Regions 4 and 5 of the Service also. Most of these permits have been issued so that summer mist-netting surveys and hibernacula population counts can be accomplished. The information gathered from these efforts has resulted in the documentation and protection of several maternity colonies and hibernacula through subsequent section 7(a)(2) consultations. These surveys have also given us critical information on the life history and habits of the Indiana bat.

Land Acquisition

Indiana bat summer and hibernation habitat has been acquired using Service monies, other Federal dollars, and funds from private entities such as The Nature Conservancy. Mount Aeolus Cave (Dorset Cave) and Brandon Silver Mine in Vermont, Maine Graphite Mine, Walter Williams Preserve, and Barton Hill Mine in New York are some examples of hibernacula acquired or protected solely or in conjunction with The Nature Conservancy.

Protection of Hibernation Sites

Protection of Indiana bat hibernacula has been recognized as a high priority in the species' critical habitat designation (USFWS 1976) and Federal recovery planning documents (USFWS 1983). Consequently, the Service and its state and private cooperators have concentrated their recovery efforts on providing appropriate protection to these sites. Approximately half of the Priority 1 and many of the Priority 2 hibernacula have been protected with gates (USFWS, unpublished data, 2006). At some sites, fences have been used when the nature of the entrance or other factors precluded use of gates. Some of the early gating efforts were counterproductive and caused more harm than good (Tuttle 1977). Recognizing these early failures, the Service, in conjunction with an extensive network of public and private partners, has developed a recommended gate design that protects hibernating bat populations while having minimal negative impact on the bats or their roost sites. A brief summary of the evolution of bat gate

design is provided in Currie (2000). The current design standard is constructed of angle-iron steel (Tuttle and Taylor 1998).

The conservation of caves and mines used as Indiana bat hibernacula is well documented (Burghardt 2000; Posluszny and Butchkoski 2000; Currie 2002; Johnson et al. 2002; J. Widlak, USFWS, pers. comm., 2005). A properly designed gate can eliminate human disturbance, allow unimpeded flight of bats, and can maintain or restore suitable microclimate within hibernacula (Currie 2002, Johnson et al. 2002). Stabilizing the entrance to caves and mines may also provide suitable hibernation habitat for Indiana bats. The use of fencing, signing, closure of trails into or very near to cave entrances, conservation easements, designation of forested areas as old growth management areas, and the installation of remote alarm systems to alert cave owners of trespass are other types of conservation efforts that have been used to deter human disturbance in hibernacula (Johnson et al. 2002; J. Eberly, U.S. Forest Service, pers. comm., 2005; A. Hicks, pers. comm., 2005; J. Hogrefe, USFWS, pers. comm., 2005; S. vonOettingen, pers. comm., 2005).

Whatever method is used to protect a cave or mine, monitoring must be used to determine effectiveness. Of the caves or mines protected, some have shown increases or stability in Indiana bat populations (Currie 2002; R. Clawson, pers. comm., 2005; A. Zimmerman, USFWS, pers. comm., 2005). In Illinois, a population of Indiana bats has been growing rapidly since 1996, the year when Magazine Mine was protected (Kath 2000, 2002). Other caves and mines that have been gated have shown decreases in population (Currie 2002; R. Clawson, pers. comm., 2005), indicating that factors other than disturbance are causing the decline (Tuttle and Kennedy 2002).

The Nature Conservancy has taken a proactive role in the conservation of Indiana bats through the acquisition of important hibernacula, development of conservation agreements with landowners, construction of gates at entrances to cooperatively protected caves, and working with private, Federal, and state land managers to ensure proper management of significant bat roosts (H. Garland, The Nature Conservancy, pers. comm., 2006).

Location and Protection of Maternity Colonies

While species experts agree that most major Indiana bat hibernacula have been discovered, the location of relatively few maternity colonies is known. Assuming an average maternity colony size of 80 adult female bats (see Life History/Ecology: Colony Formation section) and assuming that half of all hibernating bats are female, the current population of approximately 457,000 bats would represent approximately 2,860 maternity colonies, although there is no way to currently assess the accuracy of this estimate. The location of 269 maternity colonies has been documented (Table 4; colonies are presumed extant, but see limitations of data noted in the table), which represents a relatively small proportion of all colonies. This is not surprising, given the difficulty and expense of locating Indiana bat maternity colonies. It is probable that we will never be able to document the location of most maternity colonies. Nonetheless, tremendous progress has been made in locating maternity colonies. Of the 269 colonies, 54 percent (n=146) have been found within the past 10 years (1997 or later) (USFWS, unpublished data, 2006). Progress has also been made in the protection of maternity colonies. Forty five of the known colonies were located primarily on Federal land and these colonies are afforded protection

through Section 7(a)(2) of the ESA, as described above. Nine of these colonies were located on National Wildlife Refuges; habitat for colonies located on refuges is protected and managed for the long-term conservation of the species. Fifteen colonies were located on Department of Defense (DOD) facilities. In addition to consulting under ESA, many DOD installations have taken additional measures to protect Indiana bat colonies. For example, Camp Atterbury in Indiana supports at least five maternity colonies of Indiana bats and has established Indiana Bat Management Zones and other management measures to help insure the long-term conservation of Indiana bats on the facility. Extensive monitoring and research has been conducted at Camp Atterbury and has contributed to our understanding of the summer ecology of the species. Fourteen colonies were located on National Forests and the protection of habitat for Indiana bats is specifically addressed in the Forest Land and Resource Management Plans for those forests, such as the example provided for Mark Twain National Forest (see Conservation Efforts: Inter- and Intra-agency Consultations).

Progress is also being made on the protection of Indiana bat maternity colonies on private land. For example, 13 maternity colonies were located in conjunction with survey work conducted for proposed highway construction (I-69) in Indiana; all of these colonies were located primarily on private land. The Federal Highway Administration and the Indiana Department of Transportation propose to work with willing landowners to secure conservation easements that will protect roosting and foraging habitat, and minimize the impact of proposed highway construction on these colonies. One Habitat Conservation Plan (HCP) has been completed for the Indiana bat (American Consulting, Inc. 2002). This plan protects a maternity colony of Indiana bats located on lands immediately adjacent to the Indianapolis International Airport. An Interagency Task Force completed an HCP that includes a variety of measures that will avoid or lessen the impact of commercial and airport development and road construction and provide for future conservation of the bat and its habitat near the airport. The plan includes provisions for protection of existing bat habitat, planting and protection of hardwood trees to provide for additional bat habitat, monitoring the Indiana bat population in the project area for 15 years, and public education and outreach.

Research and Monitoring

The Service established a formal monitoring program for the Priority 1 Indiana bat hibernation sites in 1980. Most Priority 1 sites have been surveyed biennially by the same individuals since that time. Many states have followed the Service's lead in this monitoring effort and have had the same researchers monitor their Priority 2 and 3 sites over this same time period. This monitoring effort has enabled the Service to track the status of the species over time. Efforts to further refine and standardize protocols are ongoing (see Population Trends in Hibernacula: Background section). Additionally, although much remains to be done, a number of researchers have investigated the role of summer habitat in the conservation of the Indiana bat. For additional information on this research, refer to the Summer Habitat section.

The role of temperature and humidity and other aspects of roost site microclimate in the maintenance and restoration of hibernation sites have been investigated (see Hibernation Habitat: Hibernacula Microclimate section). This research has enabled us to improve our hibernation site protection efforts by reconfiguring altered entrances and internal cave and mine passages and restoring microclimatic conditions that are optimal for Indiana bat hibernation. Restoration

efforts have been successfully undertaken at Coach Cave in Kentucky, and Wyandotte Cave in Indiana, and are underway at Saltpeter Cave in Kentucky (B. Currie, pers. comm., 2006).

Research on bat echolocation and the use of ultrasonic bat detectors has seen many advances in the past several years. Livengood (2003) and Britzke et al. (2002) have examined the value of using the echolocation detectors for monitoring Indiana bats. They have found that Indiana bat calls are sometimes difficult to distinguish from other *Myotis* species. However, the model proposed by Britzke et al. (2002) offers promise in accurately identifying Indiana bat calls.

The genetic structure of the Indiana bat has received a preliminary analysis (see Population Distribution and Abundance: Current Winter Population Groups). The results of this research will provide a better understanding of the species' genetic composition and may enable us to put in perspective the role that peripheral populations play in the long-term conservation needs of the species.

Much of the recent research on the Indiana bat was summarized in a series of papers presented at a 2001 symposium entitled "The Indiana Bat: Biology and Management of an Endangered Species" held in Lexington, Kentucky (Kurta and Kennedy 2002). The proceedings from this symposium contain 27 papers covering different aspects of Indiana bat biology, including its status and distribution, winter and summer habitat management, foraging and roosting behavior, and the effects of environmental contaminants.

One of the goals of the recently established Indiana State University Center for North American Bat Research and Conservation is to coordinate research efforts on the Indiana bat (<http://www.indstate.edu/ecology/centers/bat.htm>).

Education and Outreach

Education has been an integral part of the recovery effort for the Indiana bat. Service efforts to change public perceptions concerning the conservation and protection of the Indiana bat and other endangered and declining bats were initiated with a bat conservation presentation developed for the Service by Bat Conservation International in the early 1980s. Bat Conservation International also developed a three-panel bat education exhibit for the Service. This exhibit was on display for several years at Mammoth Cave National Park, Cumberland Gap National Historic Site, and other locations. The Arkansas Game and Fish Commission working with the Service produced *Bats of the United States* (Harvey et al. 1999). This full-color educational booklet continues to be a popular educational tool that is used by the Service and other private and public educators throughout the country. The Service, working with the American Cave Conservation Association and several Federal agencies developed and produced a series of cave management workshops targeted at Federal, state, and private cave managers responsible for caves supporting Indiana bats or other cave-dependent species of Federal concern.

The Service, Bat Conservation International, and others have cooperated with the Office of Surface Mining to host forums for Federal, state, and private owners and managers of abandoned mines about the significance of abandoned mines to bats and their role in long-term bat protection and conservation. These forums focused on bat conservation and mining (Vories and

Throgmorton 2000), bat gate design (Vories and Throgmorton 2002), and the Indiana bat and coal mining (Vories and Harrington 2005). These forums have been instrumental in bringing bat biologists and mining experts together to better understand bat biology and the effects of mining on bats. The proceedings of all of these forums were published by Office of Surface Mining and are available to the public (see citations above).

The Service, in cooperation with U.S. Forest Service, Bat Conservation International, American Cave Conservation Association, National Speleological Society, other Federal Agencies, and state and private organizations held a series of bat gate construction workshops that have been beneficial in increasing the use of properly designed gates at caves and mines supporting Indiana bats.

The efforts of Bat Conservation International, American Cave Conservation Association, National Speleological Society, The Nature Conservancy, and other nonprofit organizations to educate the public about Indiana bats and bat conservation in general have been instrumental in changing public perceptions about bats. Federal and state biologists and private-sector individuals also provide education and outreach programs to school children on a regular basis (T. Davidson, pers. comm., 2005). These activities provide a positive conservation message about bats and their conservation and will increase public support for the protection of the Indiana bat and other endangered bats in the United States.

Biological Constraints and Needs

The purpose of this section is to identify the biological limiting factors that must be honored when designing Indiana bat management programs or evaluating project effects on the bat. This should inform not only recovery recommendations but also the development of Habitat Conservation Plans, Section 7 consultations, Safe Harbor Agreements, and any other ESA activities that may affect this species. Biological factors are described below in terms of how limiting they are to the entire population and to specific demographic segments of the population (i.e., adult females, juveniles, and adult males).

All Indiana Bats

For this flying mammal with a long lifespan and low fecundity, the fundamental limiting factors to population viability are number of years over which individual bats are able to produce offspring, annual productivity, and survival of young to reproductive age. The species' life history strategy is to produce one young each year with high survival rates for both young and adults (Humphrey and Cope 1977). To survive through all stages of their annual cycle, energy regulation is critical. Not only do Indiana bats need efficient access to good foraging areas to maximize energy inputs, they also need appropriate year-round conditions for effective thermoregulation and energy conservation to control outputs. Thus, availability of hibernacula and forest roosting sites that facilitate energy conservation are needed throughout the range of the species to maintain current distribution and population viability.

Environmental factors such as structural integrity of the hibernaculum and suitable temperatures, air flow, and humidity levels, as well as lack of disturbance, are needed to prevent excessive

arousal (resulting in energy loss), which may limit bat survival over the winter and during spring emergence. Following emergence, when fat reserves and food supplies are low, migration provides an additional stress and, consequently, mortality may be higher immediately following emergence (Tuttle and Stevenson 1977).

Indiana bat migration has not been extensively studied and is poorly understood; further, little information is available to determine habitat use and needs for Indiana bats during migration. Generally speaking, however, Fleming and Eby (2003) noted that migratory populations require spatially distinct habitats to complete their annual cycles and that migration is often identified as a trait that compounds the risk of extinction of endangered wildlife.

Indiana bats prey on emerged aquatic and terrestrial flying insects. Consequently, despite a lack of data regarding the extent to which availability of foraging habitat may be limiting, some amount of foraging habitat that supports the Indiana bat's prey base--including forested areas, streams/ponds (which also provide drinking water), and riparian corridors--is essential to the survival of these bats.

Commuting habitat that connects summer foraging and roosting areas is also necessary to maximize foraging success and conserve energy. As a rule, Indiana bats do not cross large open areas and will follow tree lines or fencerows to reach foraging areas despite increased energy expenditures and commuting distances (Murray and Kurta 2004, Winhold et al. 2005), although exceptions to this have been noted. Variable distances to foraging areas may be attributed to rangewide differences in habitat type, interspecific competition, and landscape terrain. Fall swarming also requires the presence of suitable roost trees, foraging areas, and water in the vicinity of each occupied hibernaculum. Adequate habitat connectivity is needed to allow for movement of bats among these various elements.

To facilitate both the social interactions needed for maintaining productivity and the energetics needed for high survivorship, the Indiana bat relies on two major strategies: clustering and site fidelity. These strategies are discussed below.

Clustering

The Indiana bat is an obligate colonial roosting bat. Clustering during hibernation and through the formation of summer maternity colonies is essential for both survival and completion of the bat's annual reproductive cycle. There are multiple physiological and social advantages to colonial roosting; possibly the most important benefit for Indiana bats is thermoregulation (see discussions in both the Life History/Ecology: Maternity Colony Formation and the Hibernation Habitat: Hibernacula Microclimate sections).

Cluster density may also be limiting for hibernating bats. Indiana bats roost in dense clusters in hibernacula, potentially for thermal benefits or the conservation of water (see Hibernation Habitat: Hibernacula Microclimate section). Although the link between cluster size and overwinter survival has not been quantified, there are several benefits to being a member of a large hibernating population, including the social and energetic advantages of roosting in dense clusters, and having many individuals available during fall swarming to ensure reproductive success. These advantages may buffer individual populations from extirpation.

Site Fidelity

It is generally accepted that most Indiana bats return to the same hibernaculum each year (LaVal and LaVal 1980). These bats also tend to hibernate in the same cave or mine at which they swarm, although there are exceptions to this pattern. Colonization of new hibernacula has been documented (Hall 1962, Hicks and Novak 2002, Kath 2002), indicating that Indiana bats have some capacity to exploit unoccupied habitats and expand their winter distribution. Nonetheless, availability of hibernation habitat is limited. Site fidelity and limited availability indicate the vital importance of conserving extant hibernacula and associated swarming habitat and restoring previously occupied hibernacula and/or swarming habitat.

Indiana bats also show fidelity to summer roosting and foraging areas (see Life History/Ecology: Site Fidelity section). Benefits of site familiarity include reduction in time spent searching for new sites, more profitable exploitation of local food resources, and greater awareness of resident predators. Whenever roosts and foraging sources are eliminated, bats are forced to seek new habitat and expand their foraging range, potentially reducing foraging success and exposing bats to increased predation and competition. Availability of traditional roosting and foraging areas, at least at the landscape level, are important to survival and productivity. In addition, the distance and wooded connectivity between roosts and foraging areas may be limiting for Indiana bats at some sites (Murray and Kurta 2004, Sparks et al. 2005b).

Adult Females

Given the life history strategy of the Indiana bat, female survivorship is central to continued population viability. Further, because Indiana bats produce only one pup per year, they may be limited in their ability to rebound after population losses.

Although efficient energy regulation is a biological need for all Indiana bats, this need is amplified for reproductive females as they must maximize inputs and conserve outputs not only with regard to their own survival but to successfully bear young. Timing of reproduction is likely weather-dependent (Racey and Entwistle 2003), and local and regional climate and elevation differences influence the distribution and abundance of maternity colonies, although our understanding of this is still evolving.

When female Indiana bats emerge from hibernation and migrate to their summer maternity areas, fat stores are depleted and the bats must increase their food intake to support pregnancy and lactation. Failing to meet their energy needs may result in malnutrition, delayed birth, decreased milk production, or delayed maturation of pups. Rapid weaning allows females to accumulate fat more efficiently for migration and hibernation, decreasing the likelihood of mortality during fall migration and hibernation.

Roost sites are more limiting for adult females than for males. Summer maternity sites must have a sufficient supply of suitable roost trees and adequate connectivity between roosting sites and foraging areas and water sources, although specific minimum requirements are not known. Roost sites include clusters of primary and alternate roost trees (Kurta et al. 1996). Reproductive female bats may disperse from the primary maternity roost and use alternate roosts after young are capable of flight, although they remain in the established maternity area until migration.

Maintenance of established roosting habitat aids in colony cohesion, stress control, energy regulation, and thermoregulatory efficiency.

Although the presence and density of primary roost trees is essential for maternity colonies, individual roosts are ephemeral. Maternity colonies are evolutionarily adapted to the loss of individual maternity trees. Nonetheless, such losses can exact a demographic cost, especially in the context of alterations at the landscape level that affect the roost site, roost trees, and foraging habitat.

Because energy demands of bats increase during pregnancy, commuting distances to foraging areas must be such that bats do not expend excessive energy. Connectivity between roosting and foraging areas is also important, as female Indiana bats appear to avoid crossing open expanses of land during maternity activity (although exceptions have been noted).

Clustering

In order to meet their energy, thermoregulation, and social needs, adult females are colonial year-round. Shortly after arriving in the fall swarming area and mating, female Indiana bats are ready to hibernate in dense roosting clusters of various sizes. In the summer, adult females from different hibernacula converge to form maternity colonies (see Life History/Ecology: Maternity Colony Formation section for a discussion of potential benefits of forming maternity colonies).

Maternity colonies have been characterized as “fission-fusion” societies (Kurta 2005, Barclay and Kurta in press). This type of society has a fluctuating composition, with most members residing in one tree while others depart to either form small subgroups or roost individually before returning to the main group; however, all members of a colony maintain social interactions. The key benefit of the fusion reaction for bats may be thermoregulation. In temperate areas, reproductive female bats are often poor thermoregulators, and colonial roosting may help provide the thermal conditions needed for the survival and reproductive fitness of adult females (i.e., promotes efficient heat transfer within thermally neutral roosting environments). The reasons for fission reactions are not clear, and are likely related to multiple factors (Barclay and Kurta in press).

Adults in maternity colonies use multiple roosts, and when a primary roost tree falls, bats may disperse among alternate roost trees. It is not known how long it takes for the colony to attain the same level of roosting cohesiveness that it experienced prior to the loss of a primary roost. However, until the bats are reunited, individuals may experience increased stress resulting from the energy demands of searching for another primary roost and the thermoregulatory costs of roosting in less optimal alternate trees and/or having to roost singly.

Despite the persistence and biological importance of the numerous small colonies (summer and winter) across the species' range, individual maternity colonies may have a minimum size threshold below which they are no longer viable, even if some females prolong their use of the site until the colony fully disappears. The relationship between viable population size and colonial behavior is recognized as an important aspect of Indiana bat biology that needs to be more fully understood.

Site Fidelity

In addition to hibernaculum fidelity, most evidence indicates that reproductive females exhibit a high degree of fidelity to maternity colony sites and foraging ranges (see Life History/Ecology: Site Fidelity section). Females from multiple hibernacula tend to return to the same general area--and even to the same primary roost tree as long as it is available--to establish maternity colonies from year to year. The Indiana bat's site fidelity may facilitate the ability of members of a maternity colony to regroup in the spring.

While there is ample information regarding the Indiana bat's site fidelity to maternity habitat, information about the bat's response to maternity habitat loss is limited. This information gap allows for competing assumptions. Some scientists suggest that this behavioral trait renders the Indiana bat particularly vulnerable to loss of maternity colony habitat; others surmise that individuals in a maternity colony can readily move to other sites with minimal impacts to the colony. Additional research is needed to determine the bat's response to maternity habitat loss.

Juveniles

The fat accumulation necessary for juvenile survival and eventual recruitment into the breeding population is contingent upon an adequate prey base. Early parturition and rapid growth appear to be important in providing juveniles the time needed to complete growth and acquire adequate fat reserves prior to hibernation. If their maturity is delayed, juveniles will have less time to forage and build up the fat reserves necessary for fall migration and hibernation, placing them at an increased risk of mortality.

Until the ability to fly is achieved, young Indiana bats must obtain nutrients from their mothers. If these nutrients are lacking, dependent young become susceptible to malnutrition (which may delay volancy and maturation) and starvation. In cases of malnutrition, the risk of increased mortality rates may continue through fall migration and hibernation.

Juvenile survival also depends on a suitable thermal environment, which is likely achieved through clustering with other bats in the shelter of maternity roosts. Availability of the roosting habitat needed by adult females is, therefore, also needed by prevolant and newly volant juveniles; loss or degradation of roost sites can also subsequently be manifested as reduced juvenile fitness and survivorship during migration or hibernation. To contribute to population viability, juvenile Indiana bats must survive to mate during the fall swarming season and complete their annual cycle over the winter and through spring emergence and migration. Maternity habitat must, therefore, support juvenile growth and survivorship.

Adult Males

Adult males have few specific biological needs or constraints beyond those outlined above for all Indiana bats. In general, they require suitable fall roosting and foraging areas near their hibernaculum, suitable conditions within the hibernaculum for overwinter survival, and adequate roosting and foraging habitat when they emerge from the hibernaculum in the spring. The fall swarming period, which involves males congregating around potential hibernacula and mating with returning females, is a critical period for mating and intensive foraging by males to build the fat stores needed to survive hibernation.

In contrast to the obligate colonial behavior of reproductive females, adult males often roost alone. In general, summer behavior among adult males (and non-reproductive adult females) is variable. Some adult males roost and forage near hibernaculum entrances while others are found either in proximity to reproductive females and juveniles in their summer habitat or widely distributed over various types of habitat across the species' range.

Summary

The life history strategy of the Indiana bat influences its vulnerability and resiliency, leading to several considerations that should be addressed during recovery implementation and project evaluations, including:

- Energetic impacts of significant disruptions to roosting areas, whether hibernacula or summer colonies
- Availability of hibernation habitat
- Connectivity and conservation of roosting/foraging areas and migration corridors

Although each of these considerations can be factored into recovery proposals and project evaluations based on currently available information, more insight into habitat fragmentation effects and migration habitat requirements is needed. In addition, further assessment is called for regarding the extent to which habitat is limiting in the landscape around known extant maternity colonies, whether bats adjust to changes in habitat at or around maternity colonies, and, if so, whether there is an associated energetic cost to this adjustment.




NORDEX N100/2500

Noise measurements

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	NORDEX N100/2500 Noise levels	Doc. No.: F008_228_A03_EN Revision: 02 Date: 2009 Jan 01
Department responsible Central Engineering/TAP	Replaces F008_228_A03_EN_R01	Classification IP – Nordex internal
Created Haevernick/CE TAP	Checked Wilke/CE TAP	Released Resing-Wörmel/CE-TAP, Kirchner/CE PJE
Status FI – Final		

Document will be published electronically – Original with signatures at "Department responsible".

Noise Emission Nordex N100/2500

Preliminary levels
according to IEC 61400-11: 2002 [1]

Hub height: 100 m

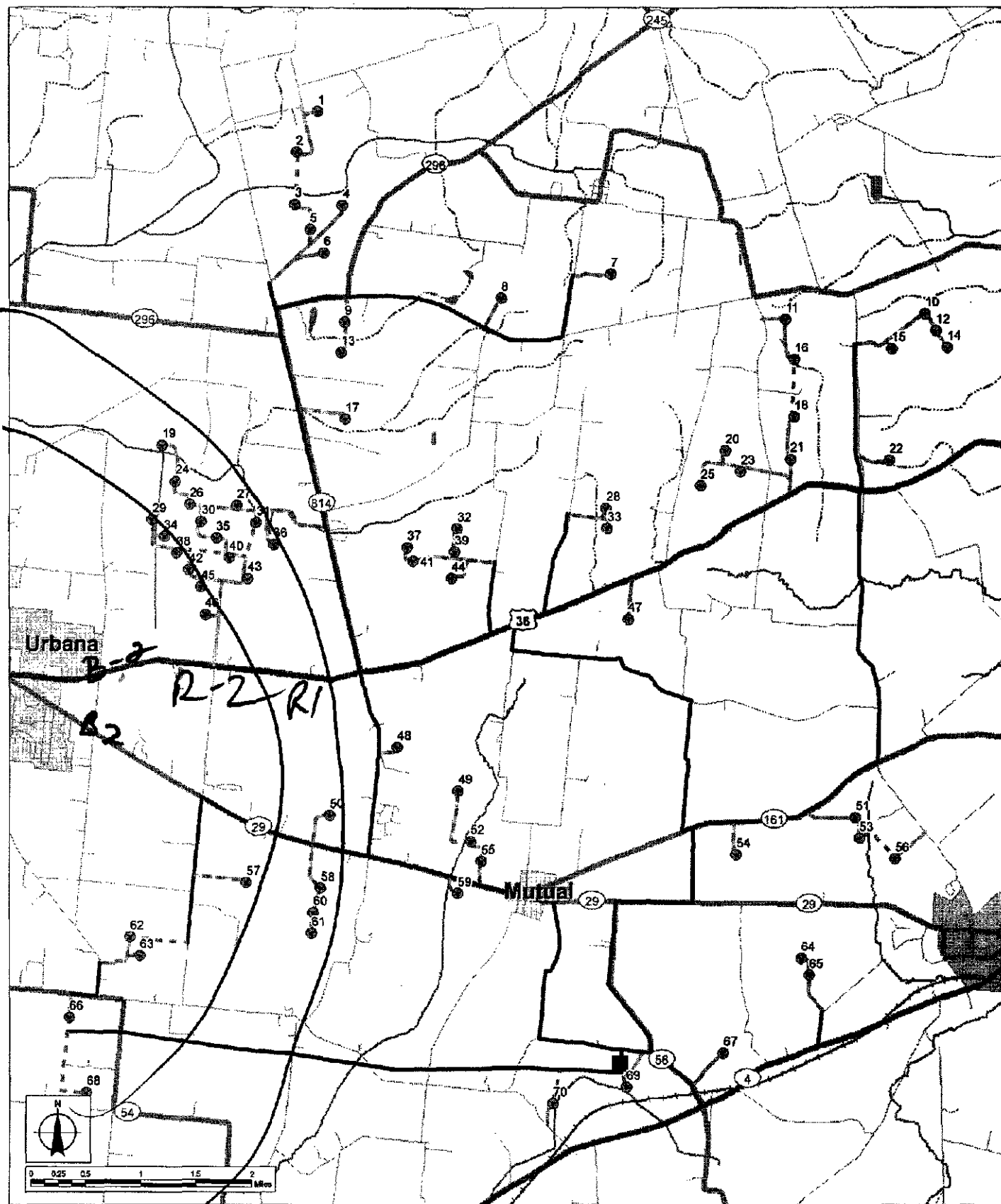
Standardised wind speed (at 10 m height)	Apparent sound power level
V_s [m/s]	L_{WA} [dB(A)]
3	98.5
4	100.5
5	103.0
6	106.5
7	107.5
8	107.5
9	107.5
10	107.5
11	107.5
12	107.5

The calculation of the standardised wind speed at 10 m height according to IEC 61400-11:2002 [1] is based on a terrain roughness length $z_0 = 0.05$ m. The actual wind speed at 10 m height can be different to the standardised wind speed depending on the actual terrain roughness length.

The noise can be tonal in the vicinity of wind turbines. The specified sound power levels include potential tonal penalties K_{TN} according to „Technische Richtlinien für Windenergieanlagen“ [2], without taking account any tonality $K_{TN} \leq 2$ dB.

Measurements are to be carried out by a measuring institute accredited for noise emission measurements at wind turbines according to ISO/IEC 17025 [3] at the reference position as defined in IEC 61400-11 [1]. The data analysis must be carried out according to the preferred method 1 of IEC 61400-11 [1]. The tonal penalties in the vicinity of wind turbines K_{TN} based on these measurements are to be determined according to „Technische Richtlinien für Windenergieanlagen“ [2].

- [1] IEC 61400-11 ed. 2: Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Techniques; 2002-12
- [2] Technische Richtlinie für Windenergieanlagen – Teil 1: Bestimmung der Schallemissionswerte, Revision 18; FGW 2008-02
- [3] ISO/IEC 17025: General requirements for the competence of testing and calibration laboratories; 2005-08



Buckeye Wind Project
Champaign County, Ohio

Figure 2- Proposed Project Layout

- Substation
- Turbines
- - - Buried Interconnect
- Overhead Interconnect
- Access Roads

March 2009

Scale: 1 inch = 0.5 mile
Data: ESRI, USGS, NOAA, etc.

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Exhibit
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