U.S. Fish and Wildlife Service

Indiana Bat (*Myotis sodalis*) Draft Recovery Plan: First Revision

April 2007

Department of the Interior
U.S. Fish and Wildlife Service
Great Lakes-Big Rivers Region - Region 3
Fort Snelling, Minnesota

Indiana Bat (*Myotis sodalis*) Draft Recovery Plan: First Revision

April 2007

Edited by

Lori Pruitt
U.S. Fish and Wildlife Service
Region 3
Bloomington, Indiana, Field Office

and

Leslie TeWinkel
U.S. Fish and Wildlife Service
Region 3
Regional Office – Fort Snelling, Minnesota

For

Region 3
U.S. Fish and Wildlife Service
Fort Snelling, Minnesota

Approved: ___XXXXXXXXXXXXXXXXXXXX_______
Regional Director, Region 3
U.S. Fish and Wildlife Service

Date: ______________________

Disclaimer

Recovery plans delineate reasonable actions which are believed to be required to recover and/or protect listed species. Plans are published by the U.S. Fish and Wildlife Service, sometimes prepared with the assistance of recovery teams, contractors, state agencies, and others. Objectives will be attained and any necessary funds made available subject to budgetary and other constraints affecting the parties involved, as well as the need to address other priorities. Recovery plans do not necessarily represent the views nor the official positions or approval of any individuals or agencies involved in the plan formulation, other than the U.S. Fish and Wildlife Service. They represent the official position of the U.S. Fish and Wildlife Service only after they have been signed by the Regional Director. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and completion of recovery tasks.

Literature Citation

U.S. Fish and Wildlife Service (USFWS). 2007. Indiana Bat (*Myotis sodalis*) Draft Recovery Plan: First Revision. U.S. Fish and Wildlife Service, Fort Snelling, MN. 258 pp.

Availability

Availability: Recovery plans can be downloaded from the Fish and Wildlife Service website: http://endangered.fws.gov

Cover photo: Indiana bat roosting under the bark of a hickory tree. Photo credit: ©Merlin D. Tuttle, Bat Conservation International, Inc. (www.batcon.org).

Acknowledgements

The U.S. Fish and Wildlife Service (USFWS) gratefully acknowledges the commitment of the Indiana Bat Recovery Team both to the development of the Draft Indiana Bat Recovery Plan: First Revision (Plan) and to the overall conservation of the species. The Recovery Team is composed of the following individuals: Rick Clawson, Team Leader, Missouri Department of Conservation; Virgil Brack, Jr., Center for North American Bat Research and Conservation, Indiana State University; Bob Currie, USFWS Asheville, North Carolina, Field Office; Gene Gardner, Missouri Department of Conservation; Michael Harvey, Tennessee Tech University; Scott Johnson, Indiana Department of Natural Resources; Al Kurta, Eastern Michigan University; John MacGregor, Kentucky Department of Fish and Wildlife; Craig Stihler, West Virginia Department of Natural Resources; Karen Tyrell, Team Consultant, BHE Environmental, Inc.; and Lori Pruitt, Recovery Team Coordinator, USFWS Bloomington, Indiana, Field Office.

The Plan resulted from the collective effort of many biologists dedicated to the species' conservation. The USFWS is grateful for the contributions of the following individuals who wrote portions of this document:
Rick Clawson, Missouri Department of Conservation
Bob Clevenstine, USFWS Rock Island, Illinois, Field Office
Paul Cryan, USGS Fort Collins Science Center
Bob Currie, USFWS Asheville, North Carolina, Field Office
Theresa Davidson, USFWS Columbia, Missouri, Field Office
Jessica Hogrefe, USFWS East Lansing, Michigan, Field Office
Andrew King, USFWS Bloomington, Indiana, Field Office
Al Kurta, Eastern Michigan University
Vicky Meretsky, Indiana University
Tom O'Shea, USGS Fort Collins Research Center
Georgia Parham, USFWS Region-3 Regional Office
Mary Parkin, USFWS Region-5 Regional Office
Lori Pruitt, USFWS Bloomington, Indiana, Field Office
Dan Sparks, USFWS Bloomington, Indiana, Field Office
Leslie TeWinkel, USFWS Region-3 Regional Office
Susi vonOettingen, USFWS New England Field Office

The draft Recovery Criteria were developed primarily during a meeting held at the USFWS Region-3 Regional Office in November 2005. The following individuals provided significant contributions at this meeting: Virgil Brack, Rick Clawson, Bob Currie, Al Hicks (New York State Department of Environmental Conservation), Al Kurta, Vicky Meretsky, TJ Miller (USFWS Region-3 Regional Office), Mary Parkin, Lori Pruitt, Stephanie Scheetz (formerly with USFWS Region-4 Regional Office), Annette Scherer (USFWS New Jersey Field Office), Jennifer Szymanski (USFWS Region-3 Regional Office), and Leslie TeWinkel. Additionally, Tom O'Shea, Vicky Meretsky, and Andrew King provided expert advice on issues related to the population biology of the species that assisted in further refining the Criteria.

Substantial internal review has occurred prior to the publication of the draft Plan. The following USFWS employees provided regional-level coordination, review, and expertise: Bob Currie, Ken Graham (Region-4 Regional Office), Andrew King, Lynn Lewis (Region-3 Regional Office), Marty Miller (Region-5 Regional Office), Mary Parkin, Lori Pruitt, Scott Pruitt (Bloomington, Indiana, Field Office), Stephanie Scheetz, Annette Scherer, Jennifer Szymanski, and Leslie TeWinkel. Kelly Herrmann, the USFWS's Region-3 Endangered Species Assistant, provided administrative and logistical assistance. The USFWS also recognizes the USFWS Field Office staffs throughout the range of the Indiana Bat who provided valuable reviews and insights. Thanks also go to Teresa Woods, USFWS Region-3 Regional Office, and Steve Morey, USFWS Region-1 Regional Office, for their work organizing and facilitating the Indiana Bat Risk Assessment Workshop in March 2005.

Finally, sincere thanks to Wendi Weber and TJ Miller from the USFWS Region-3 Regional Office for their assistance in shepherding the draft Plan through to publication.

Executive Summary

Current Species Status:
The Indiana bat is a temperate, insectivorous, migratory bat that hibernates colonially in caves and mines in the winter. In spring, reproductive females migrate and form maternity colonies where they bear and raise their young in wooded areas. Males and nonreproductive females typically do not roost in colonies and may stay close to their hibernaculum or migrate to summer habitat. Summer roosts are typically behind exfoliating bark of large, often dead, trees. Both males and females return to hibernacula in late summer or early fall to mate and enter hibernation.

The species was originally listed as in danger of extinction under the Endangered Species Preservation Act of 1966, and is currently listed as endangered under the Endangered Species Act of 1973, as amended. The current Recovery Priority of the Indiana Bat is 8, which means that the species has a moderate degree of threat and high recovery potential. As of October 2006, the Service had records of extant winter populations at approximately 281 hibernacula in 19 states and 269 maternity colonies in 16 states. The 2005 winter census estimate of the population was 457,000.

Biologically intrinsic needs of this species include limiting use of fat during hibernation, obligate colonial roosting, high energy demands of pregnant and nursing females, and timely parturition and rapid development and weaning of young. Factors that may exacerbate the bats vulnerability because of these constraints include energetic impacts of significant disruptions to roosting areas (both in hibernacula and maternity colonies), availability of hibernation habitat, and connectivity and conservation of roosting-foraging and migration corridors.

Habitat Requirements and Limiting Factors:
During winter, Indiana bats are restricted to suitable underground hibernacula. The vast 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. Suitable hibernacula in the central and southern United States often provide a wide range of vertical structure. These hibernacula tend to have large volumes and often have large rooms and vertical or extensive passages, often below the lowest entrance. Cave volume and complexity help buffer the cave environment against rapid and extreme changes in outside temperature, and vertical relief helps provide a range of temperatures and roost sites. Most Indiana bats hibernate in caves or mines where the ambient temperature remains below 10°C (50.0°F) but infrequently drops below freezing, and the temperature is relatively stable.

In summer, most reproductive females occupy roost sites under the exfoliating bark of dead trees that retain large, thick slabs of peeling bark. Primary roosts usually receive direct sunlight for more than half the day. Roost trees are typically within canopy gaps in a forest, in a fenceline, or along a wooded edge. Habitats in which maternity roosts occur include riparian zones, bottomland and floodplain habitats, wooded wetlands, and upland communities. Indiana bats typically forage in semi-open to closed (open understory) forested habitats, forest edges, and riparian areas.

Threats to the Indiana bat vary during its annual cycle. At the hibernacula, threats include modifications to caves, mines, and surrounding areas that change airflow and alter microclimate in the hibernacula. Human disturbance and vandalism pose significant threats during hibernation through direct mortality and by inducing arousal and consequent depletion of fat reserves. Natural catastrophes can also have a significant effect during winter because of the concentration of individuals in a relatively few sites. During summer months, possible threats relate to the loss and degradation of forested habitat. Migration pathways and swarming sites may also be affected by habitat loss and degradation. In addition to these threats, significant information gaps remain regarding the species' ecology that hinder sound decision-making on how best to manage and protect the species.

Recovery Strategy:
Given the population trends, biological constraints, habitat requirements, threats, and information needs, the recovery program for has four broad components: 1) rangewide population monitoring at hibernacula with improvements in census techniques, 2) conservation and management of habitat (hibernacula, swarming, and to a degree, summer), 3) further research into requirements of and threats to the species, and 4) public education and outreach. Like its predecessor, this recovery plan continues to have a focus on protection of hibernacula but also increases the focus on summer habitat and proposes use of four Recovery Units: Ozark-Central, Midwest, Appalachian Mountains, and Northeast. Delineation of these Recovery Units relied on a combination of preliminary evidence of population discreteness and genetic differentiation, differences in population trends, and broad-level differences in macrohabitats and land use. Recovery Units serve to protect both core and peripheral populations and ensure that the principles of representation, redundancy, and resiliency are incorporated.

Recovery Goals:
The ultimate goal of this Recovery Plan is to remove the species from the Federal list of Endangered and Threatened Wildlife. The intermediate goal is reclassification of Indiana bat to threatened status.

Recovery Objectives:
To reclassify the Indiana bat to threatened, the following objectives must be achieved: 1) permanent protection of 80 percent of Priority 1 hibernacula, 2) a minimum overall population number equal to the 2005 estimate (457,000), and 3) documentation of a positive population growth rate over five sequential survey periods. The Indiana bat will be considered for delisting when the Reclassification Criteria have been met, and the following additional criteria have been achieved: 1) permanent protection of 50 percent of Priority 2 hibernacula, 2) a minimum overall population number equal to the 2005 estimate, and 3) continued documentation of a positive population growth rate over an additional five sequential survey periods. If research on summer habitat requirements indicates the quality and quantity of maternity habitat is threatening recovery of the species, the Service will amend these objectives and the following criteria.

Recovery Criteria:
Reclassification:

1. Permanent protection of a minimum of 80 percent of Priority 1 hibernacula in each Recovery Unit, with a minimum of one Priority 1 hibernaculum protected in each unit.

2. A minimum overall population estimate equal to the 2005 population estimate of 457,000.
3. Documentation that shows important hibernacula within each Recovery Unit have a positive annual population growth rate over the next 10-year period (i.e., five survey periods).

Delisting:

1. Permanent protection of a minimum of 50 percent of Priority 2 hibernacula in each Recovery Unit.
2. A minimum overall population estimate equal to the 2005 population estimate of 457,000.
3. Documentation that shows a positive population growth rate within each Recovery Unit over an additional five sequential survey periods (i.e., 10 years).

Actions Needed:

1. Conserve and manage hibernacula and their winter populations.
2. Conserve and manage summer habitat to maximize survival and fecundity.
3. Plan and conduct research essential for recovery.
4. Develop and implement public information and outreach program.

Date of Recovery:

Contingent on funding and implementation of recovery actions, full recovery may occur by 2027.

Table of Contents

List of Tables

List of Figures

PART I. BACKGROUND

The Indiana bat (*Myotis sodalis*) is a temperate, insectivorous, migratory bat that hibernates in mines and caves in the winter and summers in wooded areas. The species was originally listed as being in danger of extinction under the Endangered Species Preservation Act of 1966 (32 FR 4001, March 11, 1967), and is currently listed as endangered under the Endangered Species Act (ESA) of 1973, as amended. Critical habitat for the Indiana bat was designated on September 24,1976; it consisted of 11 caves and two mines in six states (41 FR 41914, September 24, 1976). The original recovery plan for the species was published in 1983 (USFWS 1983). An agency draft of a revised plan was published in 1999 but was never finalized; comments received during the public comment period for that draft document are summarized in Appendix 1. The Recovery Priority of the Indiana Bat is 8, which means that the species has a moderate degree of threat and high recovery potential.

Species Description

The Indiana bat is a medium-sized bat in the genus *Myotis*. Its forearm length is 35-41 mm ($1^{3}/_{8}$-$1^{5}/_{8}$ in), and the head and body length ranges from 41-49 mm ($1^{5}/_{8}$-$1^{7}/_{8}$ in). This species closely resembles the little brown bat (*M. lucifugus*) and the northern long-eared bat (*M. septentrionalis*) (Barbour and Davis 1969). The northern long-eared bat is separated easily from the other two species by its long, pointed, symmetrical tragus (see figs. 15 and 34 in Barbour and Davis 1969). The Indiana bat usually has a distinctly keeled calcar (see definition in Appendix 6: Glossary), whereas the little brown bat does not (see Figure 42 in Barbour and Davis 1969). The hind feet of an Indiana bat tend to be small and delicate, with fewer, shorter hairs (the hairs do not extend beyond the claws) than its congeners (see Figure 14 in Barbour and Davis 1969). The ears and wing membranes have a dull appearance and flat coloration that does not contrast with the fur, and the fur lacks luster compared with that of little brown bats (Barbour and Davis 1969, Hall 1981). The nose of an Indiana bat is lighter in color than that of a little brown bat. The skull of an Indiana bat has a small sagittal crest, and the braincase tends to be smaller, lower, and narrower than that of the little brown bat (Barbour and Davis 1969, Hall 1981).

Taxonomy

The Indiana bat was first described as a species by Miller and Allen (1928), based on museum specimens collected in 1904 from Wyandotte Cave in Crawford County, Indiana. Before that time, specimens of the Indiana bat often were confused with those of other *Myotis*, especially the little brown bat. "That *Myotis sodalis* has been so long overlooked is due no doubt to the general resemblance the animal bears to *Myotis lucifugus*, with which species the specimens of it in museums have generally been confused; when its characters are recognized, however, there is no doubt as to its identity" (Miller and Allen 1928). The Indiana bat is monotypic, indicating there are no recognized subspecies. Alternative common names for the species are Indiana myotis, social bat, pink bat, and little sooty bat (Bailey 1933, Osgood 1938, Nason 1948, Mumford and Whitaker 1982).

Population Distribution and Abundance

Prehistoric Distribution and Abundance

Our understanding of the Indiana bat's prehistoric distribution and abundance is primarily limited to extrapolations from early historical accounts and the study of paleontological remains in caverns in the eastern United States because there does not appear to be a fossil record for *Myotis sodalis* (Thomson 1982). Researchers have identified several important prehistoric (and historic) Indiana bat hibernacula by analyzing bat bones, mummified bodies, guano deposits, stains and claw marks on cave ceilings and walls, and raccoon (*Procyon lotor*) scat containing *Myotis* bones and hair. For example, Tuttle (1997), using historical accounts and an analysis of staining (i.e., discolored areas of the wall or ceiling due to consistent and prolonged roosting by bats), concluded that Mammoth Cave, Kentucky, once housed one of the largest hibernating colonies of bats yet identified, with an estimated 9-13 million bats (primarily *M. sodalis* and *M. grisescens*). Even though Toomey et al. (2002) readily acknowledged difficulties in analyzing and limitations in interpreting cave roost stains, when taken together their historic and paleontological analysis in Mammoth Cave's Historic Entrance area supported the idea that Mammoth Cave once held a very large number of Indiana bats.

Similarly, Munson and Keith's (1984) previous historic research and paleontological analysis of prehistoric raccoon scat in Wyandotte Cave, Indiana, suggested that a very large hibernating population of *Myotis* roosted near the entrance of this extensive cave system throughout the last 1,500 years. Assuming their results were from a representative sample of the raccoon activity areas in Wyandotte Cave, they conservatively estimated that the cave contained 676,900 fecal segments, which collectively would contain remains of an estimated 1,713,000 individual bats (presumably *M. sodalis* was the predominant species present and preyed upon) (Munson and Keith 1984).

Other paleontological evidence indicating that prehistoric (or historic) Indiana bat numbers were once much higher has been documented in Bat Cave, Kentucky, in Mammoth Cave National Park, where an analysis of bone deposits revealed an estimated 300,000 Indiana bats had died during a single flood event at some previous point in time (Hall 1962). It is uncertain whether this catastrophic population loss occurred during prehistoric times or perhaps as recently as "The Great Flood of 1937," which devastated much of the Ohio River valley (Hall 1962).

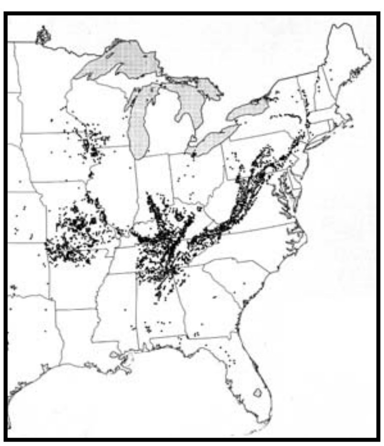
As a whole, existing paleontological evidence suggests that prehistoric abundance of Indiana bats may have exceeded most historic accounts and our current total population estimate by an order of magnitude. However, our degree of confidence in the accuracy of most prehistoric and historic population estimates remains relatively low because these estimates often depend on assumptions that cannot be readily tested, and confounding issues are common. For example, even conservative population estimates of Indiana bats based on stained areas on cave ceilings should typically be viewed with caution. Unfortunately, researchers currently have no means of empirically determining what percentage of the stained roosting areas found in caves today are attributable to the different *Myotis* species or over what period of time the stains were actually deposited (e.g., decades, centuries). Logically, in prehistoric or presettlement times, other *Myotis* species, such as the little brown bat and gray bat, may have been more abundant as well. However, because they typically do not aggregate on cave ceilings as tightly packed as do

Indiana bats, population estimates made from their stains may not only be falsely attributed to *M. sodalis*, but would be overestimated as well.

Historic Winter Distribution

Historically, the Indiana bat had a winter range restricted to areas of cavernous limestone in the karst regions of the east-central United States (Miller and Allen 1928, Hall 1962, Thomson 1982, Figure 1). Prior to and during much of the European settlement of the eastern United States, winter populations of Indiana bats likely occurred in karst regions of what would eventually become Alabama, Arkansas, Georgia, Illinois, Indiana, Iowa, Kentucky, Maryland, Massachusetts, Missouri, New Jersey, New York, North Carolina, Oklahoma, Pennsylvania, Tennessee, Vermont, Virginia, and West Virginia. Based on early accounts and other indirect evidence (Silliman et al. 1851, Blatchley 1897, Tuttle 1997, Tuttle 1999), some researchers have suggested that vast numbers, presumably the majority, of Indiana bats historically converged at a relatively small number of large complex cave systems to hibernate (e.g., Wyandotte Cave in Indiana; Bat, Coach, and Mammoth caves in Kentucky; Great Scott Cave in Missouri; and Rocky Hollow Cave in Virginia) and used other caves to a lesser extent (Olson 1996, Tuttle 1997, Tuttle 1999, Toomey et al. 2002, Whitaker et al. 2003).

When Miller and Allen first described *Myotis sodalis* in 1928, they had examined museum specimens originating from ten states including Alabama, Arkansas, Illinois, Indiana, Kentucky, Michigan, North Carolina, Pennsylvania, Tennessee, and Vermont (Miller and Allen 1928). Based on these records, they described the species' distribution as the "eastern United States from the central Mississippi Valley and northern Alabama to the western part of New England" (Figure 2). Because the majority of the specimens they had studied were collected from wintering localities, Miller and Allen (1928) noted that the species' summer distribution likely covered a more considerable area, which decades later proved to be true. By 1960, winter populations of Indiana bats had been reported from approximately 74 different hibernacula in 18 states (USFWS, unpublished data, 2006; Figure 3; Appendix 2).



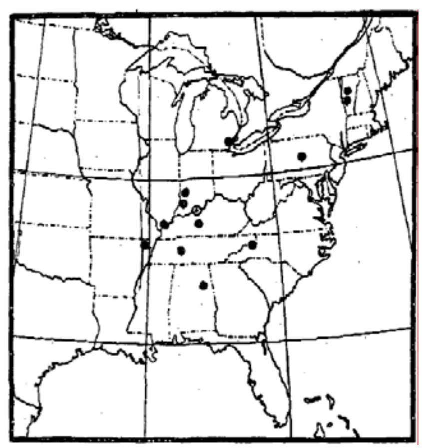


Figure 1. Cavern areas of the eastern United States (from Davies 1970) (on left).

Figure 2. Known distribution of *Myotis sodalis* in 1928 (from Miller and Allen 1928) (on right).

Historic Summer Distribution

The historic summer distribution and range for this species is poorly documented. The first maternity colony was not discovered until the summer of 1971 in east-central Indiana (Cope et al. 1974). Nonetheless, based on our current knowledge of Indiana bat seasonal migration patterns and limits, and locations of historic and potential hibernacula, it is reasonable to assume that the species' historic summer distribution was more or less similar to its current summer distribution (Figure 3).

The historic summer range almost certainly included areas where the bats have now been locally extirpated due to extensive loss and fragmentation of summer habitat (e.g., forests, woodlands, wetlands). This loss of habitat resulted from land-use changes that began with pioneer settlements, and continue to the present in some areas from ongoing development, agriculture, and coal and mineral extraction. Habitat within the historic summer range evidently was capable of sustaining millions of Indiana bats during the presettlement and early settlement period, which may no longer be feasible today. Gardner and Cook (2002) provided an historical summary of the literature on the Indiana bat, especially that pertaining to summer distribution of reproductive individuals.

Historic Abundance

With the arrival of European settlers in the central portion of the Indiana bat's range in the late 1700s and early 1800s, land conditions and natural resource usage began to change dramatically (Parker and Ruffner 2004) and undoubtedly affected the species local and presumably regional abundance. For example, abundance of hibernating bat populations almost certainly declined after settlers discovered large deposits of nitrates or saltpeter, essential for making gunpowder, and began year-round mining operations within some of the major hibernacula. Saltpeter mining operations at Mammoth Cave, Kentucky, Wyandotte Cave, Indiana, and other Indiana bat hibernacula peaked during the War of 1812 and generally ended shortly after the war. Most historic accounts regarding winter bat populations in caves during this period are anecdotal and only offer an idea of the species' relative abundance. By the 1820s, tourism had become lucrative at several major hibernacula and increased rapidly over the next 100 years. In October 1850, biologist Benjamin Silliman, Jr. of Yale University visited Mammoth Cave, made detailed observations, and reported that "bats are numerous in the avenues within a mile or two of the mouth of the cave. We found countless groups of them on the ceilings" (Silliman et al. 1851, Tuttle 1997). Amazingly, Mammoth Cave, alone, still held "millions" of bats in 1850 (it has been assumed many were Indiana bats) after being subjected to severe winter disturbance from saltpeter mining, tourism, and adverse impacts associated with cave entrance alterations and restricted airflow (Tuttle 1997).

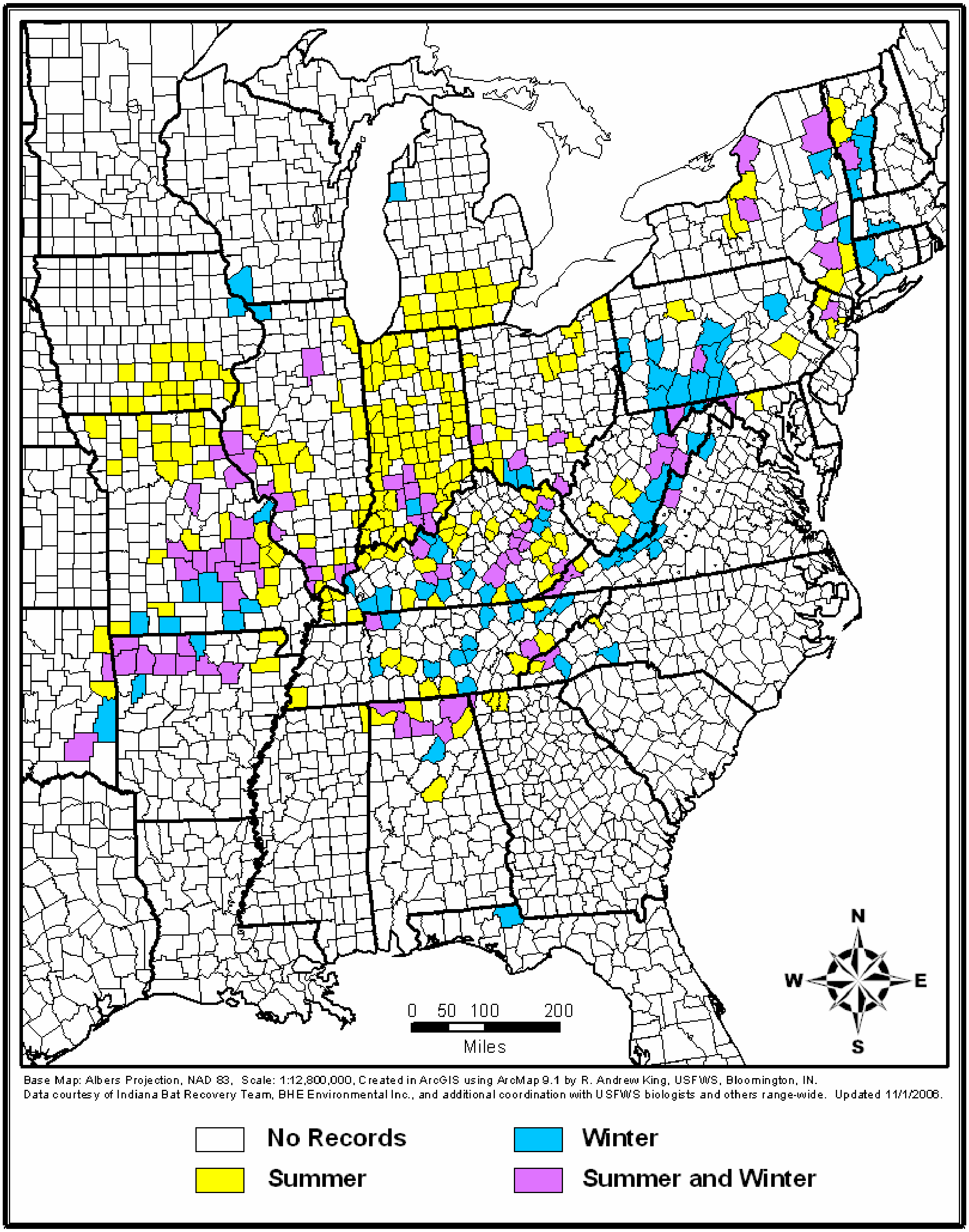


Figure 3. Distribution of counties with known summer and winter records of the Indiana bat.

Categorization of Hibernacula[1]

In the original Recovery Plan (USFWS 1983), Indiana bat hibernacula were assigned priority numbers based on the number of Indiana bats they contained. For example, originally a Priority 1 (P1) hibernaculum was a site that had contained 30,000 or more Indiana bats since 1960. During a meeting of Recovery Team members and U.S. Fish and Wildlife Service (Service) biologists in November 2005, a decision was made to revise the existing hibernacula priority definitions. With the end goal of achieving a wider and more even distribution of essential hibernation sites across the species' range, the P1 population criterion was lowered from 30,000 bats to 10,000 and the "since 1960" part of all the hibernacula definitions was omitted. These changes effectively increased the number of P1 hibernacula from 11 sites in four states to 23 sites in seven states. Likewise, the population criteria were also changed for Priority 2, 3, and 4 hibernacula. On a case-by-case basis, the Service may consider elevating a particularly important (i.e., "essential") Priority 2 (P2) hibernaculum (e.g., one that holds a key geographic location/distribution within the range or very high regional importance) to P1 status, even though it may not meet the P1 population criteria at that time. As of October 2006, no P2 hibernacula had been elevated to P1 status in this manner.

The revised hibernacula priority numbers and other new subcategories are defined below, and are used throughout the rest of this document.

Priority 1 (P1): Essential to recovery and long-term conservation of *M. sodalis*. Priority 1 hibernacula typically have (1) a current and/or historically observed winter population ≥ 10,000 Indiana bats and (2) currently have suitable and stable microclimates (e.g., they are not considered "ecological traps" as defined below). Priority 1 hibernacula are further divided into one of two subcategories, "A" or "B," depending on their recent population sizes. Priority 1A (P1A) hibernacula are those that have held 5,000 or more Indiana bats during one or more winter surveys conducted during the past 10 years. In contrast, Priority 1B (P1B) hibernacula are those that have sheltered ≥ 10,000 Indiana bats at some point in their past, but have consistently contained fewer than 5,000 bats over the past 10 years.

Priority 2 (P2): Contributes to recovery and long-term conservation of *M. sodalis*. Priority 2 hibernacula have a current or observed historic population of 1,000 or greater but fewer than 10,000 and an appropriate microclimate.

Priority 3 (P3): Contribute less to recovery and long-term conservation of *M. sodalis*. Priority 3 hibernacula have current or observed historic populations of 50-1,000 bats.

Priority 4 (P4): Least important to recovery and long-term conservation of *M. sodalis*. Priority 4 hibernacula typically have current or observed historic populations of fewer than 50 bats.

High Potential (HP): A special designation given to P2, P3, or P4 hibernacula that are deemed capable of supporting 10,000 or more Indiana bats in the future if (1) an appropriate microclimate is restored (or created in the case of some mines) and/or (2) the site is protected

[1] Hibernacula priorities are primarily assigned on the basis of winter population sizes; they do not correspond to Implementation Schedule task priorities.

from disturbance. These sites typically have no recorded direct observations of significant numbers of *M. sodalis* (i.e., at least none that can be readily confirmed; they differ from a P1B site in this respect). Instead most “high-potential” hibernacula have one or more forms of indirect evidence indicating previous use by large numbers of *Myotis* and/or *M. sodalis* (e.g., anecdotal historic accounts and/or paleontological evidence such as bones, mummified remains, ceiling staining, etc.). As of October 2006, two caves had been designated as having HP: Mammoth Cave in Kentucky and Rocky Hollow Cave in Virginia.

Ecological Trap (ET): A hibernaculum having a history of repeated flooding or severe freezing events that have resulted in the mortality of most hibernating *M. sodalis*. Hibernacula with other environmental conditions that pose a severe and/or imminent threat to the majority of hibernating bats may also be designated as “ecological traps” by the Service (e.g., threat of catastrophic collapse). As of October 2006, three caves had been preliminarily designated as ETs: Bat Cave (Shannon Co.) in Missouri (freezing), Haile’s Cave in New York (flooding), and Clyfty Cave in Indiana (flooding). These preliminary designations were made based on the recommendations of Indiana bat experts familiar with these caves, and on the history of Indiana bat mortality in these caves. The designations will be reevaluated when procedures for evaluation and designation of hibernacula as ETs are developed (see Recovery Action 1.1.2).

Current Winter Distribution

As of November 2006, the Service has winter records of extant winter populations (i.e., positive winter occurrence since 1995) of the Indiana bat at approximately 281 different hibernacula located in 19 states (USFWS, unpublished data, 2006; Table 1; Figures 3 and 4; Appendix 2). Likewise, based on the 2005 winter surveys, there were a total of 23 Priority 1 hibernacula in seven states: Illinois (n=1), Indiana (n=7), Kentucky (n=5), Missouri (n=6), New York (n=2), Tennessee (n =1), and West Virginia (n=1) (Table 1, Table 2, Figure 4). A total of 53 Priority 2 hibernacula are known from the aforementioned states, as well as Arkansas, Ohio, Pennsylvania, and Virginia (Table 1, Figure 4). A total of 150 Priority 3 hibernacula have been reported in 16 states (Table 1, Figure 4). A total of 213 Priority 4 hibernacula have been reported in 23 states (Table 1, Figure 4). Some records from the periphery of the range likely represent occasional wanderers or accidentals rather than viable winter populations (USFWS 1983). For example, only a single winter record of a single Indiana bat has been recorded in the states of Florida and Wisconsin despite multiple winter bat surveys having been conducted over several decades (USFWS, unpublished data, 2006).

Even though hibernating Indiana bats were dispersed across 16 states in 2005, over 90 percent of the estimated rangewide population hibernated in just five states, including: Indiana (45.2%), Missouri (14.2%), Kentucky (13.6%), Illinois (9.7%), and New York (9.1%) (USFWS, unpublished data, 2006). In 2005, 81.9 percent (374,653 bats) of the rangewide winter population hibernated in P1 hibernacula (n=23), while P2 (n=53), P3 (n=150), and P4 (n=213) sheltered 14.4%, 3.3% and 0.4% of the total population, respectively (USFWS, unpublished data, 2006). The ten most populous hibernacula in 2005 collectively held 71.6 percent of the rangewide total with Wyandotte Cave in southern Indiana leading the list with 54,913 bats (12.0% of total) (USFWS, unpublished data, 2006; Table 2).

In the 1960s and 1970s the vast majority of the known rangewide population, by a ratio of 3:1, hibernated in the southern portion of the species' winter range (i.e., Kentucky and Missouri; Clawson 2002). However, by 2001 and through 2005 the majority (60%) of remaining Indiana bats occupied hibernacula in the (more or less) northern portion of the winter range (Table 3). Few specific drivers of this apparent population shift have been rigorously explored or identified, but inappropriate hibernacula temperatures (see Tuttle and Kennedy 2002) and regional climate change are either known or generally suspected in having had a role. We currently have an incomplete understanding of the links between *M. sodalis*' hibernation energetics, its biogeographical distribution, and climate change. However, the predictive modeling approach recently used by Humphries et al. (2002) for *M. lucifugus* could provide some insight into *M. sodalis*' potential winter distribution if global climate change occurs.

In at least three known cases, the species has expanded its current winter range beyond its historic winter limits as a result of occupying man-made hibernacula (e.g., mines, tunnels, a dam) in relatively recent times. Some occupied man-made structures are relatively far removed from natural cave areas (e.g., Black Ball Mine in northern Illinois, Lewisburg Limestone Mine in west central Ohio, Tippy Dam near the eastern border of Lake Michigan in Michigan). Of the 33 mines with extant winter populations (i.e., one or more positive records since 1995), some have served as hibernacula for Indiana bats for nearly a century or more (e.g., Pilot Knob Mine in Missouri; Clawson 2002). Others, where mining activities have been abandoned more recently, have only supported significant winter populations within the past decade, such as the Magazine Mine in southern Illinois (Kath 2002). These findings suggest that Indiana bats are capable of expanding their winter distribution by colonizing suitable hibernacula as they become available within and for some distance beyond their traditional winter range. In 2005, approximately 30 percent (136,410 bats) of the rangewide population of Indiana bats hibernated in man-made hibernacula (24 mines, one dam, and one tunnel) and the other 70 percent (320,964 bats) hibernated in natural caves (USFWS, unpublished data, 2006). In addition, it appears in some instances that Indiana bats may redistribute themselves over relatively short periods of time (e.g., several years) as evidenced by swift population declines in some hibernacula that coincided with rapid population increases at others nearby (e.g., Twin Domes and Wyandotte caves in Indiana; USFWS, unpublished data, 2006). Such rapid increases cannot be attributed to reproduction alone, and are due at least in part to immigration.

Emigration and immigration of bats between regional hibernacula are known to occur, but a detailed characterization or quantification of these movements has yet to be made. Initial observations of local and regional winter population dynamics suggest Indiana bat winter populations likely follow some form of a metapopulation model (Hanski 1998, Cronin 2003). While records of short and long-distance movements of banded bats between caves have long been known (Hall 1962), only recently has genetic analysis been used to determine the relative degree of gene flow occurring among and between winter populations.

Table 1. Distribution and priority numbers of Indiana bat hibernacula by state.

State	No. of Hibernacula by Priority Number[1] (No. with positive occurrence since 1995)					Total No. of Hibernacula with Any Previous Winter Record	Total No. of Hibernacula with "Extant" Winter Populations (≥1 bat since 1995)
	P1	P2	P3	P4	ET		
Alabama	-	-	2 (1)	8 (4)	-	10	5
Arkansas	-	4 (3)	12 (9)	18 (2)	-	34	14
Connecticut	-	-	1 (0)	1 (1)	-	2	1
Florida	-	-	-	1 (0)	-	1	0
Georgia	-	-	-	2 (0)	-	2	0
Illinois	1 (1)	6 (6)	7 (6)	8 (3)	-	22	16
Indiana	7 (7)	1 (1)	16 (16)	12 (9)	1 (1)	37	34
Iowa	-	-	-	2 (0)	-	2	0
Kentucky	5 (5)	15 (15)	39 (34)	50 (20)	-	109	74
Maryland	-	-	-	4 (3)	-	4	3
Massachusetts	-	-	1 (0)	-	-	1	0
Michigan	-	-	-	1 (1)	-	1	1
Missouri	6 (6)	10 (7)	24 (18)	26 (8)	1 (1)	67	40
New Jersey	-	-	2 (2)	1 (0)	-	3	2
New York	2 (2)	4 (4)	3 (3)	5 (2)	1 (1)	15	12
North Carolina	-	-	-	3 (1)	-	3	1
Ohio	-	1 (1)	1 (1)	5 (0)	-	7	2
Oklahoma	-	-	-	3 (2)	-	3	2
Pennsylvania	-	2 (1)	5 (3)	18 (7)	-	25	11
Tennessee	1 (1)	6 (3)	16 (13)	11 (4)	-	34	21
Vermont	-	-	5 (3)	1 (0)	-	6	3
Virginia	-	3 (3)	5 (5)	8 (4)	-	16	12
West Virginia	1 (1)	1 (1)	11 (11)	24 (14)	-	37	27
Wisconsin	-	-	-	1 (0)	-	1	0
Total	**23**	**53**	**150**	**213**	**3**	**442**	**281**

[1] P1: ≥10,000 bats. P2: 1,000-9,999 bats. P3: 50-999 bats. P4: 1-49 bats. ET: Ecological Trap.

Table 2. Winter population estimates through time for P1A (n=16) and P1B (n=7) Indiana bat hibernacula. All P1 hibernacula (n=23) have at some point in the recorded past had ≥10,000 hibernating Indiana bats and currently provide suitable winter habitat. P1A hibernacula have maintained a minimum of 5,000 Indiana bats during the last 10 years, whereas P1B hibernacula have not met this criterion in the last 10+ years.

State	County	Hibernaculum Name	Priority	Max. Pop. Estimate Since 1960	Max. Pop. Estimate Since 1980	Max. Pop. Estimate Since 1995	Current/ 2005 Pop. Estimate
IL	Alexander	Magazine Mine	P1A	33,500	33,500	33,500	33,500
IN	Crawford	Batwing Cave	P1A	50,000	29,960	10,125	6,850
IN	Crawford	Wyandotte Cave	P1A	54,913	54,913	54,913	54,913
IN	Greene	Ray's Cave	P1A	62,464	62,464	62,464	54,325
IN	Harrison	Jug Hole Cave	P1A	29,430	29,430	29,430	29,430
IN	Harrison	Twin Domes Cave	P1A	100,000	98,250	78,875	36,800
IN	Monroe	Coon Cave	P1A	10,675	10,675	10,675	9,270
IN	Monroe	Grotto Cave	P1A	10,338	10,338	10,338	9,875
KY	Carter	Bat Cave	P1A	100,000	51,500	31,400	29,500
KY	Edmonson	Dixon Cave	P1A	16,550	16,550	7,200	3,100
MO	Iron	Pilot Knob Mine	P1A	139,000	94,775	50,550	50,550
MO	Washington	Great Scott Cave	P1A	85,700	85,700	14,850	6,450
NY	Ulster	Walter Wm. Pres. Mine	P1A	11,394	11,394	11,394	11,394
NY	Ulster	Williams Hotel Mine	P1A	15,438	15,438	15,438	15,438
TN	Blount	White Oak Blowhole Cave	P1A	12,500	12,500	7,861	7,861
WV	Pendleton	Hellhole Cave	P1A	11,890	11,890	11,890	11,890
KY	Edmonson	Coach Cave	P1B	100,000	600	101	0
KY	Edmonson	Long Cave	P1B	7,600	7,527	1,153	1,153
KY	Letcher	Line Fork Cave	P1B	10,000	8,379	1,863	1,844
MO	Crawford	Onyx Cave	P1B	12,850	8,994	380	180
MO	Franklin	Copper Hollow Sink Cave	P1B	21,000	9,295	250	250
MO	Pulaski	Brooks Cave	P1B	19,461	11,850	750	70
MO	Pulaski	Ryden Cave	P1B	10,539	5,800	40	10

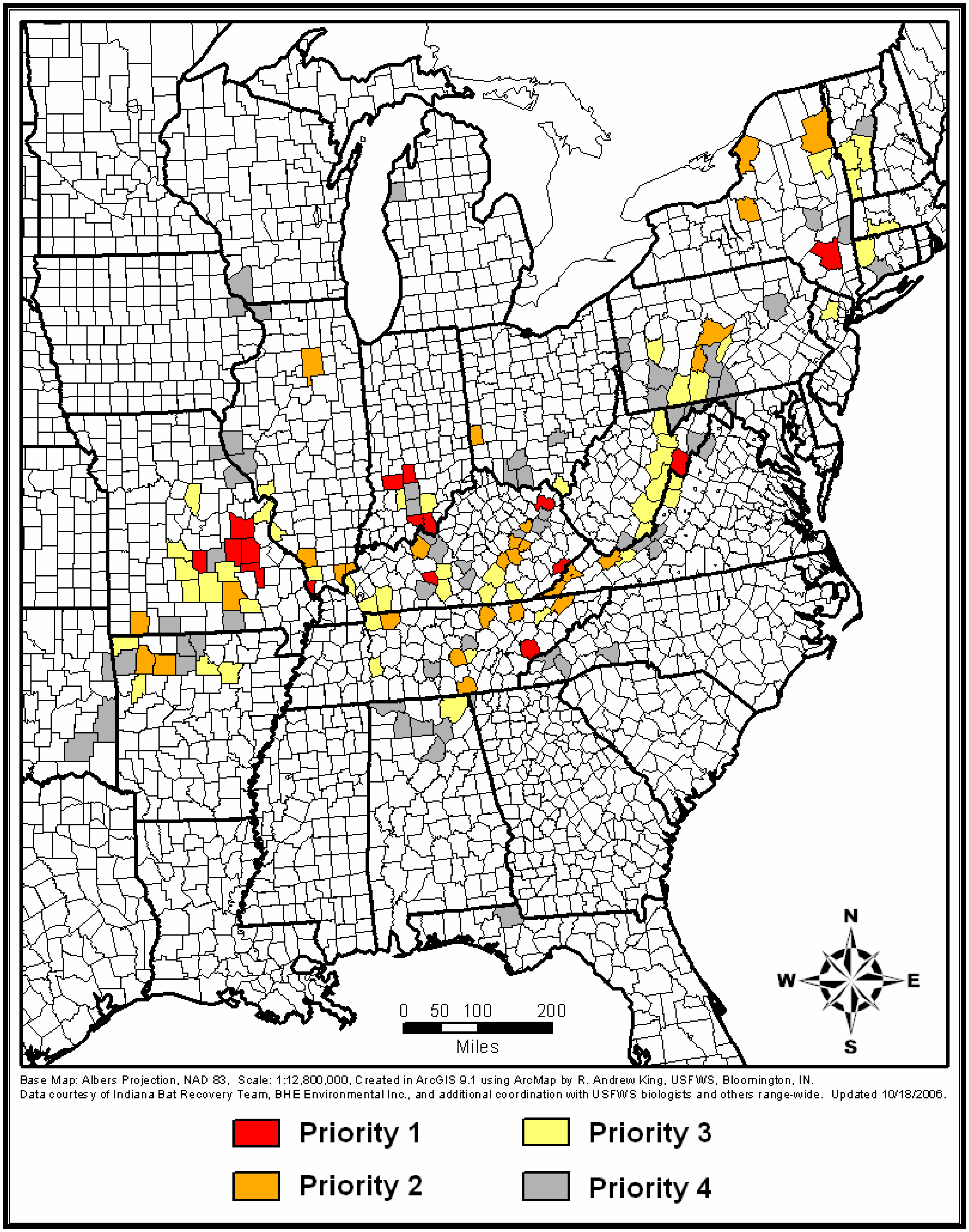


Figure 4. Distribution of counties with known Indiana bat hibernacula records and their current priority numbers. Note: For counties with multiple hibernacula with different priority numbers, only the color of the highest priority hibernacula is shown.

Table 3. Size and distribution of hibernating populations of the Indiana bat by region and state, based upon estimates nearest to the year indicated.[1]

Region	State	1965	1980	1990	2001	2003	2005
Southern Region	Alabama	350	350	350	250	317	296
	Arkansas	15,000	15,000	4,500	2,476	2,124	2,067
	Illinois (southern)	14,700	14,700	14,500	19,491	32,330	42,539
	Kentucky	248,100	102,200	78,700	50,047	47,876	62,380
	Missouri	399,000	342,000	150,100	72,983	66,805	65,104
	Oklahoma	0	0	0	0	5	5
	Tennessee	20,100	20,100	16,400	10,172	8,900	9,971
	Virginia	3,100	2,500	1,900	833	1,090	735
	Subtotal	700,350	496,850	266,450	156,252	159,447	183,097
	% of Rangewide Total	79.3%	73.2%	56.3%	41.0%	40.0%	40.0%
Northern Region	Illinois (Blackball Mine)	100	100	400	1562	1648	1804
	Indiana	160,300	155,200	163,500	173,076	183,332	206,610
	Michigan	0	0	0	20	20	20
	New Jersey	0	0	0	107	644	652
	New York	20,200	21,100	26,800	29,746	32,924	41,702
	Ohio	150	3,600	9,500	9,788	9,436	9,769
	Pennsylvania	700	700	400	702	853	746
	Vermont	0	0	0	159	175	297
	West Virginia	1,500	1,200	6,500	9,744	9,741	12,677
	Subtotal	182,950	181,900	207,100	224,904	238,773	274,277
	% of Rangewide Total	20.7%	26.8%	43.7%	59.0%	60.0%	60.0%
	Grand Total	883,300	678,750	473,550	381,156	398,220	457,374

[1]Not all surveys occurred exactly as portrayed in the table. Population estimates for a particular period were based on the survey nearest to the year indicated, either prior to or subsequent to that year, so that all caves are represented in each period.

Current Winter Population Groups

Vonhof and McCracken's statistical analysis of genetic samples (mtDNA extracted from wing membrane punches) (M. Vonhof, Western Michigan University, pers. comm., 2006) collected from hibernating Indiana bats from widely dispersed hibernacula suggested that genetic variance among samples was best explained by dividing sampled hibernacula (n=13) into four separately defined population groups, as follows:

- Midwest, included sampled populations in AR, MO, IN, KY, OH, Cumberland Gap Saltpeter Cave in southwestern VA, and Jamesville Quarry Cave in Onondaga Co., NY,
- Appalachia, included White Oak Blowhole Cave in east TN, and Hellhole Cave in WV,
- Northeast 1 (NE1), included Barton Hill Mine and Glen Park Caves in northern NY (Essex and Jefferson counties, respectively), and
- Northeast 2 (NE2), included Walter Williams Preserve Mine in Ulster Co., NY.

Vonhof and McCracken's other findings and conclusions included:

- Most winter populations had a high haplotype and nucleotide diversity,
- Low genetic diversity in 3 of the 4 winter populations sampled in NY,

- Some level of male- and/or female-mediated gene flow was occurring among 3 of the 4 defined groups (Midwest, Appalachia, and NE2), but apparently there was no gene flow for either sex between the NE1 group and the other groups.
- The low levels of genetic diversity in NE1 and NE2 (i.e., a severe genetic "bottleneck"), are indicative of relatively recent colonization of the Northeast within historical times (e.g., estimated at 153 years before present for NE1) by a small number of individuals.

Interestingly, these recent findings also agree with Hall's (1962) taxonomic studies of over 1,000 museum specimens collected from throughout the Indiana bat's range. Hall noticed that Vermont specimens tended to have more distinct banding of the fur, longer hairs on the feet, and that their skulls had significantly narrower nasal breadth than those in other parts of the range. He stated that "if the establishment of populational ranges has acted as an isolating mechanism, it has not produced any noticeable variation, except in the case of the northeast population." Hall concluded that "the establishment of populational ranges restricts gene flow within the species" and that "this apparently has not been in effect long enough to allow race differentiation to occur."

Current Summer Distribution

Maternity Colonies

The first Indiana bat maternity colony was not discovered until 1971 (in east-central Indiana, Cope et al. 1974). As of October 2006, we have records of 269 maternity colonies in 16 states that are considered to be locally extant (Table 4). Of the 269 colonies, 54 percent (n=146) have been found (mostly during mist-netting surveys) within the past 10 years (i.e., since 1997; Table 4, Figure 5, Appendix 2). Because maternity colonies are widely dispersed during the summer and difficult to locate, all the combined summer survey efforts have found only a fraction of the maternity colonies presumed to exist based on the rangewide population estimates derived from winter hibernacula surveys. For example, based on the 2005 rangewide population estimate of 457,374 bats, and assuming a 50:50 sex ratio, and an average maternity colony size of 50 to 80 adult females (Whitaker and Brack 2002), then the 269 maternity colonies in Table 4 may only represent 6 to 9 percent of the 2,859 to 4,574 maternity colonies we would assume exist. Regardless of reasonable disagreements regarding the average colony size, the geographic locations of the majority of Indiana bat maternity colonies remain unknown.

Most capture records of reproductively active female and juvenile Indiana bats (i.e., evidence of a nearby maternity colony) have occurred in glaciated portions of the upper Midwest including southern Iowa, northern Missouri, much of Illinois, most of Indiana, southern Michigan, and western Ohio, and in Kentucky; however, a growing number of maternity records have been documented in New York, New Jersey, and Vermont in recent years as a result of spring emergence studies and mist netting efforts (Gardner and Cook 2002; USFWS, unpublished data, 2006; Table 4; Figure 5; Appendix 2). The more rugged, unglaciated portions of the Midwest (Ozarks/southern Missouri, parts of southern Illinois, and south-central Indiana), Kentucky, and most of the eastern and southern portions of the species' range appear to have fewer maternity colonies per unit area of forest than does the upper Midwest. Additional summer survey efforts and spring emergence studies will be needed in some areas, particularly along the periphery of the range, before final conclusions may be reached regarding the extent of the species' summer range. Likewise, a comprehensive analysis of existing positive and negative summer survey data is warranted.

Although Indiana bat maternity colonies occur throughout much of the mideastern United States (e.g., West Virginia, Virginia, Pennsylvania, New York), they appear to be relatively less abundant than in the Midwest or more central portion of the range. This apparent regional difference in summer distribution and relative abundance, especially of maternity colonies, may be influenced in large part by geographic distribution of important hibernacula and by regional differences in climate and elevation. During the summer, higher latitudes and elevations typically are cooler and wetter, and temperatures at higher elevations are more variable, adding significantly to the cost of reproduction (Brack et al. 2002). In short, our understanding of how and to what extent distribution of hibernacula and local and regional climate and elevation differences influence the distribution and abundance of maternity colonies is still evolving.

Adult Males

Male Indiana bats are found throughout the range of the species, but in summer are most common in areas near hibernacula (Hall 1962, Gardner and Cook 2002, Figure 5, Appendix 2). Please refer to the Life History and Summer Habitat sections for additional information.

Current Abundance

By compiling individual population estimates from bat surveys conducted within 214 hibernacula during the winters of 2003-2004 and 2004-2005, the Service has estimated that the Indiana bat's 2005 rangewide population was approximately 457,000 bats (USFWS, unpublished data, 2006; Table 3).

In 2005, 82 percent of the rangewide population hibernated within 22 of the 23 Priority 1 hibernacula (Table 2). Thirteen of the current Priority 1 hibernacula (n=23) have been surveyed every 2 years from 1983 to 2005. Due to hazardous conditions within Pilot Knob Mine in Missouri, this P1 hibernaculum cannot be safely entered to conduct a standard winter survey. Fall trapping rates at the entrance to this mine, however, have shown that large numbers of bats continue to use it (Clawson 2002). Although it is not feasible to confirm, bat surveyors are aware of some hibernacula that have physically inaccessible areas ranging in size from small cracks and crevices to large rooms where Indiana bats are known or believed to roost. In these situations, our population estimates may be viewed as being conservative (i.e., underestimations).

In most winters, a few new hibernacula are discovered somewhere across the range, but most of these contain far fewer than 1,000 Indiana bats (i.e., P3) and many contain <50 bats (i.e., P4; USFWS, unpublished data, 2006). Discovery of previously unknown hibernacula with >1,000 Indiana bats is uncommon, but occasionally does occur. Of hibernacula first documented during the past 10 years, only three have held more than 5,000 Indiana bats when initially discovered: Magazine Mine in Illinois, Lewisburg Limestone Mine in Ohio, and Williams Hotel Mine in New York. Over the past 25 years, no hibernaculum has contained more than 10,000 Indiana bats when initially discovered (USFWS, unpublished data, 2006).

Table 4. States and counties with recorded Indiana bat maternity colonies.[1,2,3] These colonies are considered likely to be locally extant (within limits of data noted in footnote 3).

State	No. of Recorded Maternity Colonies	Counties with Recorded Maternity Colonies (if multiple colonies, then # is shown)
Arkansas	1	Clay
Illinois	28	Adams (2), Alexander, Bond, Cass, Ford, Henderson, Jackson (3), Jersey, Macoupin, Monroe (4), Pike (2), Pulaski, Randolf, Saline, Schuyler, Scott, St. Clair, Union, Vermilion, and Washington (2)
Indiana	83	Bartholomew (3), Clinton (2), Crawford, Davies (2), Dearborn, Gibson (2), Greene (3), Hendricks (2), Henry, Howard, Huntington, Jackson (3), Jasper, Jay, Jefferson (2), Jennings (2), Johnson (3), Knox, Koskiusko, LaPorte (2), Marion, Martin, Monroe (2), Montgomery (3), Morgan (4), Newton, Parke (2), Perry (2), Pike (2), Posey, Pulaski (2), Putnam (2), Randolph (3), Ripley (2), Rush, Shelby (2), Spencer, St. Joseph, Steuben, Tippecanoe (4), Vermillion, Vigo, Wabash (2), Warren (2), Warrick (2), Wayne, and Wells
Iowa	27	Appanoose (2), Davis, Decatur (2), Des Moines (2), Iowa, Jasper, Keokuk, Lucas (2), Madison (2), Marion (7), Monroe, Ringgold, Van Buren, Wapello, and Washington (2)
Kentucky	32	Ballard, Ballard/Carlisle, Bath (3), Breckinridge, Bullitt (4), Daviess, Edmonson (3), Floyd, Harlan (3), Henderson (2), Hickman (2), Jefferson (3), Logan, McCracken (2), Pulaski, Rowan, Spencer, and Union
Maryland	2	Carroll (2)
Michigan	11	Calhoun, Cass, Eaton, Hillsdale, Jackson, Lenawee (2), Livingston, St. Joseph (2), and Van Buren
Missouri	20	Chariton, Gasconade, Iron, Jefferson, Knox (2), Lewis, Linn, Macon, Madison, Marion, Mercer, Monroe, Nodaway, Pulaski, Scotland, St. Francois, St. Genevieve, Sullivan, and Wayne
New Jersey	7	Morris (5), Somerset, and Sussex
New York	31	Cayuga, Dutchess (5), Essex, Jefferson (9), Onondaga (4), Orange (8), and Oswego (3)
Ohio	11	Ashtabula, Butler, Clermont, Cuyahoga, Greene, Hocking, Lawrence, Paulding, Pickaway, Summit, and Wayne
Pennsylvania	2	Berks and Blair
Tennessee	3	Blount (2) and Monroe
Vermont	7	Addison (6) and Chittenden
Virginia	1	Lee
West Virginia	3	Boone (2) and Tucker
Total	**269**	

[1] Unpublished data obtained in response to a data request sent to Service Field Offices in February 2006.

[2] Most maternity colony records were based upon the capture of reproductively active females and/or juveniles between 15 May and 15 August.

[3] This table includes records of maternity colonies considered to be locally extant (even though records may not have been verified in recent years). Although some additional records exist, we did not include them if subsequent surveys failed to detect their presence (i.e., the colony may have disbanded, relocated, was extirpated, or was present but not found). Records were also not included if suitable habitat no longer exists at a previously occupied site.

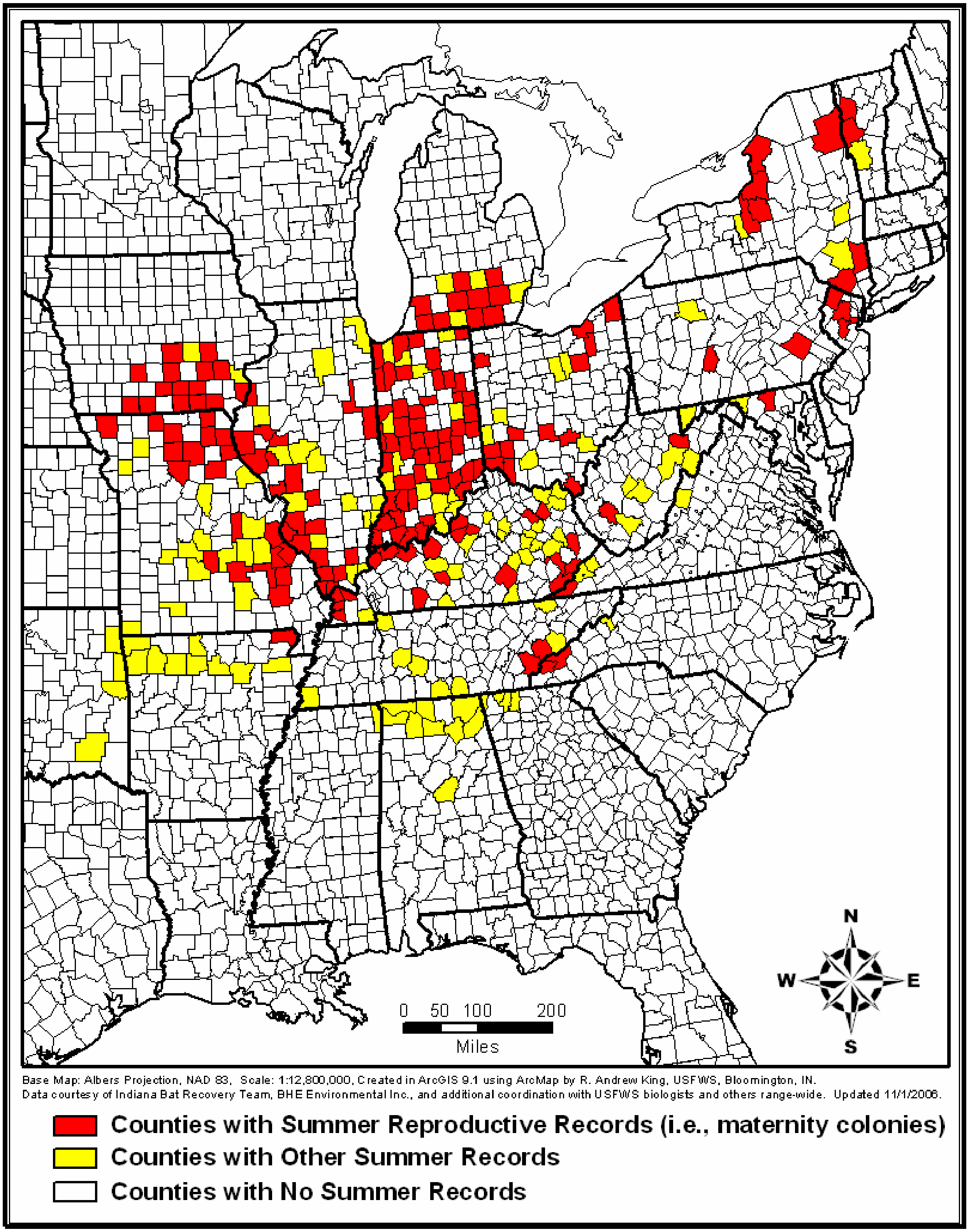


Figure 5. Distribution of counties with known summer reproductive records of Indiana bats (i.e., presence of reproductively active females and/or juveniles between 15 May and 15 August). Lack of records may reflect a lack of surveys, and does not necessarily mean the species is not present.

Population Trends in Hibernacula

Background

During the 1950s, biologists began conducting winter bat surveys at irregular intervals and recording population estimates for about a dozen Indiana bat hibernacula (Hall 1962; USFWS, unpublished data, 2006; Appendix 3). Since that time, hundreds of additional populations of hibernating Indiana bats have been discovered, and our knowledge of the winter distribution and status of the species has greatly expanded. Many hibernating populations have decreased in size since rangewide monitoring began (Figure 6), especially in Kentucky and Missouri (Table 3). By the time the plight of the Indiana bat was officially recognized in 1967, remaining populations represented a small portion of historical numbers. These hibernating populations were often confined to smaller caves, which likely had less thermal stability, fewer and less optimal roosting options, and had a higher risk of predation than traditional hibernacula. By 1985, more than 85 percent of the known, rangewide population hibernated in just eight caves and one mine.

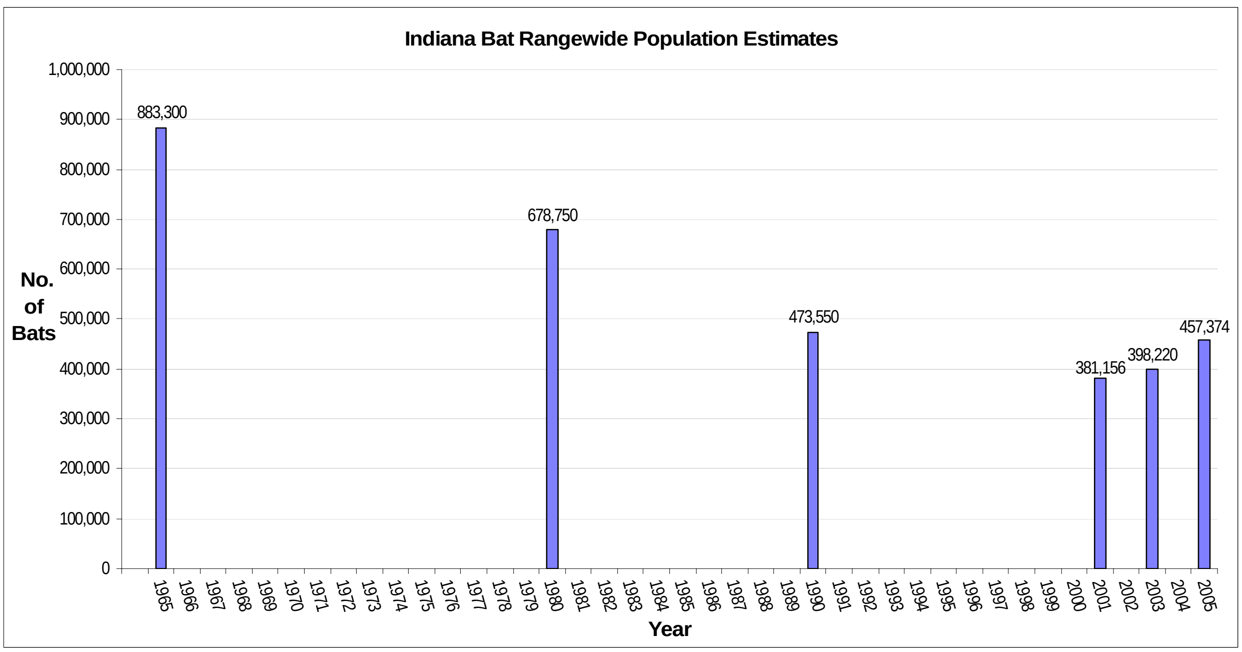


Figure 6. Indiana bat rangewide population estimates (Data sources: 1965-1990, Clawson 2002; 2001-2005, USFWS, unpublished data, 2006). Rangewide estimates calculated from all known hibernacula were not attempted or data was not available for most years prior to 2001.

During the 1960s and most of the 1970s, winter surveys of the largest Indiana bat populations known at that time were relatively few and far between, and many medium-sized and large winter populations had not yet been discovered. Since the release of the original Recovery Plan in 1983, with few exceptions, a standardized survey approach has been used to make biennial estimates of all known winter bat populations within the most populous hibernacula (i.e., P1s and P2s).

Because the 1983 guidelines for "Census Taking" (Appendix VI in USFWS 1983) failed to request bat surveyors to quantify, estimate, or report the amount of error associated with their respective population estimates, cave-by-cave estimates of accuracy or bias are generally unavailable for use in assessing our overall confidence in rangewide population estimates made to date. Furthermore, multiple assumptions must be made before any reasonable rangewide population estimate can be generated; particularly for the earlier survey periods when many hibernacula had not yet been discovered (see discussion below, Appendix 3). Collectively, these assumptions likely represent the single largest source of error when one attempts to calculate a rangewide estimate from the existing data set. Therefore, the Service has had no valid means of assigning a confidence level to previous rangewide population estimates or for statistically analyzing apparent rangewide population trends.

To better address this situation and other data deficiencies, the Service has been collaborating with Dr. Vicky Meretsky, a biometrician and associate professor at Indiana University. In January 2006, the five primary Indiana bat survey teams (representing IL, IN, KY, MO, and NY) were led by Dr. Meretsky through a winter survey exercise (sponsored by the Service) at the Magazine Mine in Illinois (King 2006). The results of this exercise will help the Service identify and quantify different sources of variability associated with population estimates being made by different surveyors using similar and different survey techniques (e.g., *in situ* visual estimates of bat cluster sizes/densities vs. *ex situ* counts/estimates of bats within clusters captured in digital photographs). The forthcoming results of the Magazine Mine exercise (V. Meretsky, Indiana University, pers. comm., 2006) will ideally be used to calculate a confidence interval for the 2005 rangewide population estimate and future estimates and to assist in the development of an improved winter survey protocol.

Rangewide Population Estimates

Nearly all of the existing rangewide population estimates for the Indiana bat were generated by simply adding together all available estimates from traditional winter surveys of all known hibernacula during a specified period in time. However, if one takes a close look at the actual proportion of the currently known hibernacula that were known and/or actually surveyed during previous decades, it is apparent that rangewide estimates calculated for any given year prior to about 1980 should be regarded as approximate (Appendix 3). The uncertainty associated with these early rangewide estimates is relatively high (compared to recent estimates) because of large, irregular gaps of time between winter surveys, small number of surveys conducted in any given year, and asynchrony and non-standardization among the surveys that were conducted (Appendix 3, Figure 6).

After standardized surveys of all known P1 hibernacula were initiated in the 1980s, the quality of the rangewide estimates quickly improved. Clawson (2002) made a reasonable and conservative effort to reduce the amount of error associated with calculating rangewide estimates (especially for decades with scant data) by forward- and/or backfilling in the missing data cells with the same estimates for each individual hibernaculum that had been recorded during its most recent survey. In a similar manner, when a "new" P1 or P2 hibernaculum was discovered, Clawson used its first post-discovery population estimate to backfill the blanks in the data set for each of the previous time periods being calculated (see Clawson 2002 for rationale for backward projection of estimates for newly discovered populations). Again, while such data manipulations were necessary and undoubtedly improved the accuracy of rangewide population estimates, the current estimates calculated for years prior to 1980 should be considered as approximate. As an example, more than half of the bats that were included in the calculation of the rangewide estimate for the year "1965" in Figure 6 where attributed to hibernacula that had not yet been discovered at that point in time, but those bats were assumed to have been present in those hibernacula prior to discovery of the hibernacula.

Apparent Long-term Trend

Over the long term, from 1965 to 2001, there has been an overall decline in Indiana bat numbers, which has been discussed at length and is attributed to many causes (Figure 6, USFWS 1983, Kurta and Kennedy 2002, see Threats and Reasons for Listing section). Estimated numbers consistently declined through this period. Even with the discovery of many new, large hibernacula, the rangewide population estimate dropped approximately 57 percent from 1965 to 2001.

Since the advent of systematic attempts to estimate population numbers, some specific drivers (e.g., changes in cave air flow/temperatures, human disturbance levels) have been clearly linked to positive and negative trends in some of the most important hibernacula (see Tuttle and Kennedy 2002), but the underlying causes of population changes at other hibernacula remain unknown or incompletely known. In spite of the uncertainties surrounding various aspects of the winter population data, the Service's confidence in apparent positive and negative population trends observed within individual hibernacula and collectively in the long-term, rangewide decline remains relatively high for the following reasons: 1) continuity and consistency–with very few exceptions, the same small group of highly qualified biologists have been surveying the same caves/mines using consistent survey techniques since standardized surveys began in the 1980s; 2) surveyors have demonstrated high levels of attentiveness, thoroughness, and scientific integrity while completing the winter surveys through the years; and 3) other lines of evidence clearly point to large population changes in numerous hibernacula. For example, consistently observed gradual population declines in numerous regional hibernacula and obvious population crashes (e.g., >50% declines and complete absence of Indiana bats in some cases) in other traditionally important hibernacula in the same region of the bat's range (e.g., Missouri, Kentucky) are compelling evidence of a true decline, regardless of whether statistical significance can be applied to the numbers.

Apparent Short-term Trend

Rangewide estimates of species numbers over the three most recent biennial survey periods do not show the same declining trend seen in estimates spanning 1965-2000 (Figure 6). There was approximately a 15-percent increase from the 2003 estimate of 398,000 bats to the 2005 rounded estimate of 457,000 bats (USFWS, unpublished data, 2006; Table 3; Figure 6). Unfortunately, our interpretation of this apparent increase is confounded at this point because we have yet to develop and implement a standardized approach of measuring and reducing sources of variability and observer error as described above. In spite of some changes in methodology over time and a general lack of data regarding the statistical accuracy and variability of hibernacula estimates, the Service believes that the apparent upward trend in recent years is real because the same highly qualified biologists have been consistently conducting the winter surveys at all of the largest hibernacula over the past 20 years. This high level of surveyor consistency coupled with obvious, large increases at some high-priority hibernacula in Indiana, Illinois, Kentucky and New York in recent years (see Table 3), provides us with some confidence that the long-term decline may have halted. We anticipate that planned improvements in hibernacula survey methodology will soon provide for a greater level of confidence in the overall population trend.

Apparent Trends by Cave 1965-2005: Missouri, Indiana, and Kentucky
Missouri, Indiana, and Kentucky have historically had the highest estimated numbers of hibernating bats (Figure 7); all had estimated populations of >100,000 bats in 1965. Over the period 1965-2005, estimated numbers of hibernating bats in Missouri and Kentucky clearly declined. Of Missouri hibernacula that were estimated to contain at least 10,000 bats at least once, all had estimates that declined steeply since 1985, although two hibernacula showed strong increases before that time (Figure 8). Kentucky hibernacula that sheltered at least 10,000 (estimated) bats at least once had less consistent patterns (Figure 9). One cave was almost emptied of bats between 1965 and the next survey in 1983, one rose and then declined, and the third had an overall decline with an apparent reversal in the early 1990s.

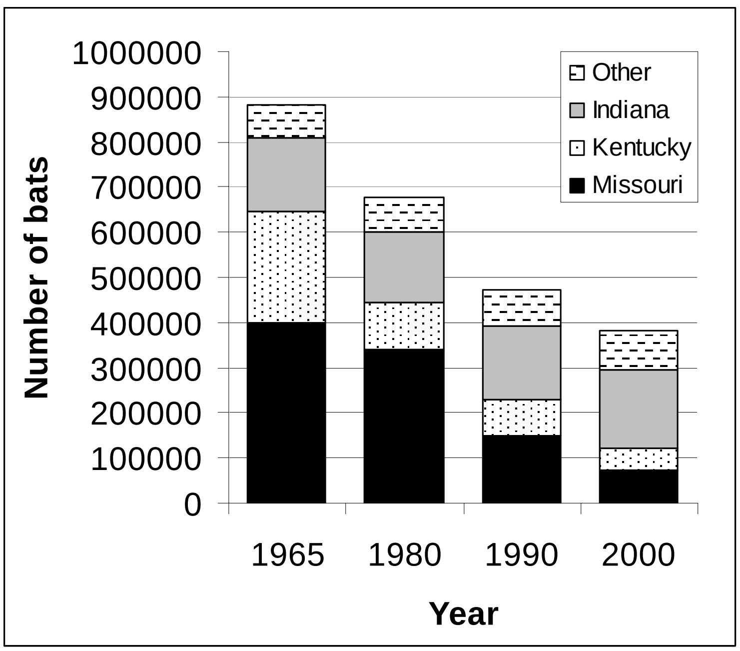


Figure 7. States with the largest numbers of Indiana bats in hibernacula. For years in which a hibernaculum was not yet known, the first post-discovery survey results were used (V. Meretsky, pers. comm., 2006).

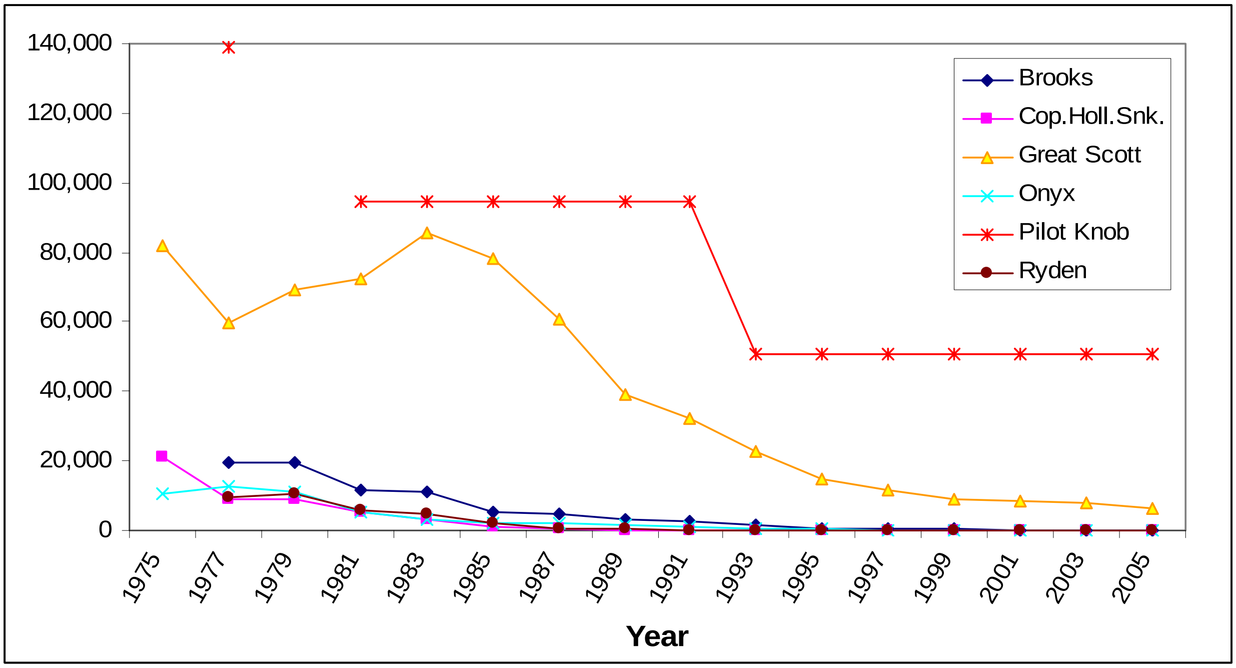


Figure 8. Estimated numbers of Indiana bats in P1A and P1B hibernacula in Missouri (USFWS, unpublished data, 2006).

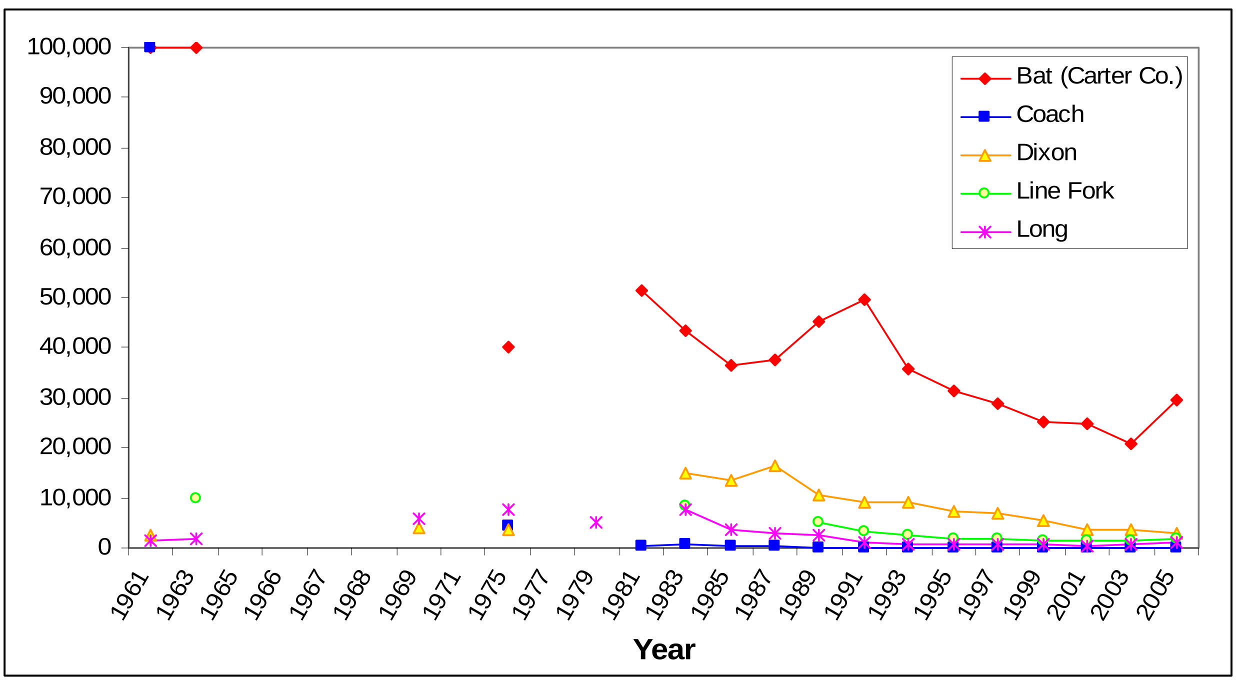


Figure 9. Estimated numbers of Indiana bats in P1A and P1B hibernacula in Kentucky (USFWS, unpublished data, 2006).

Indiana hibernacula that had at least one estimate of >10,000 hibernating bats also showed little consistency (Figure 10). Four of seven hibernacula seem to show periods of increase and periods of decrease, including the three hibernacula with the highest one-time counts. The other three hibernacula show consistent increases, two of them reaching 10,000 in the 2003 survey.

Population Patterns in States with <100,000 Bats

Among the group of states in which aggregate hibernaculum surveys have never reached 100,000 bats, hibernaculum surveys in Arkansas, Tennessee, and Virginia have consistently declined from 1965 to 2000 (Figure 11). Hibernacula surveys in Illinois, New York, Ohio, and West Virginia are greater in 2000 than in 1965, but trends are not entirely consistent through the period. Thus, the southern tier of states in the species' range shows declines in counts at hibernacula, whereas some states in the northern tier show increasing counts (Table 3). Connecticut and other states with very small populations were too small or too recently discovered to show graphically, and we do not discuss them here.

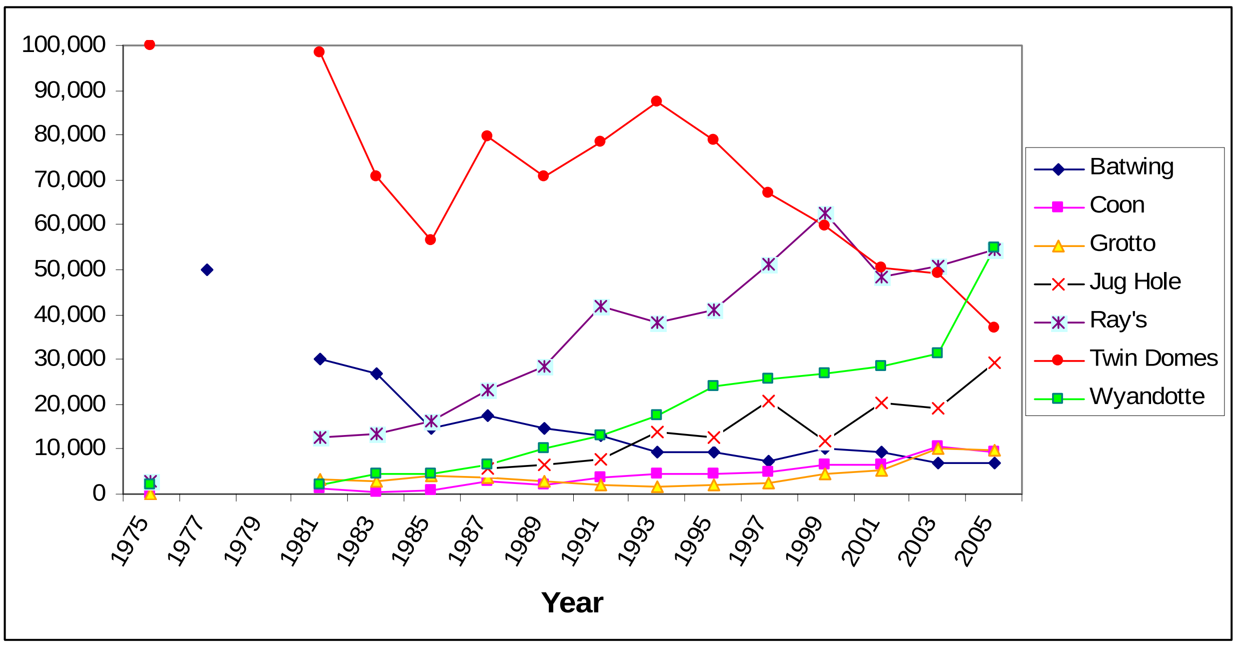


Figure 10. Estimated numbers of Indiana bats in P1A hibernacula in Indiana (USFWS, unpublished data, 2006).

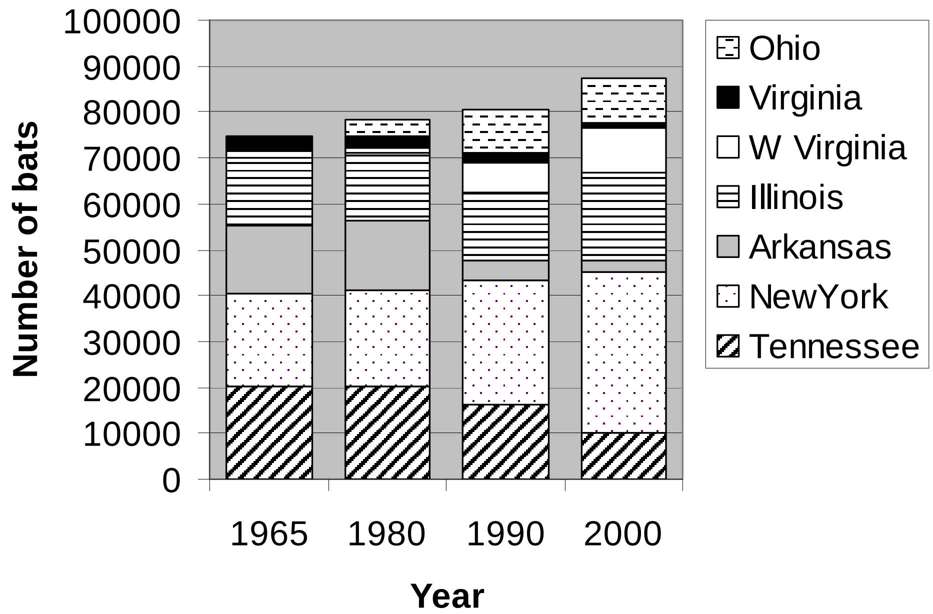


Figure 11. Estimated numbers of Indiana bats in states with counts always below 100,000 bats. For years in which a cave was not yet known, the first survey results for the cave are used. Counts for Alabama, Massachusetts, Pennsylvania, and Vermont were too small to show at this scale (V. Meretsky, pers. comm., 2006).

Apparent Regional Population Trends and Climate Change

It is nearly impossible to consider the geographic positions of states where Indiana bat populations are declining and states where they are stable or increasing without considering the possibility that regional and/or global climate change is driving some changes in Indiana bat populations. Table 3 reveals a clear division in apparent population trends between states in the northern portion of the Indiana bat's range versus states in the southern portion of the range (Clawson 2002). Steep declines in Kentucky and Missouri hibernacula have largely contributed to the apparent decline in the southern population during the 45-year period from 1960 through the present. In contrast, there apparently has been an overall increase in population in northern states over the same time period. The role of climate change and its effect on temperatures in hibernacula need investigation. Although current data are not sufficient to definitively determine the cause of apparent regional disparities, it appears that both protection of hibernacula and suitable temperature regimes may be key to understanding trends in the overall population and recovery of the species.

Life History/Ecology

The Indiana bat is a migratory bat, hibernating in caves and mines in the winter and migrating to summer habitat. Although some Indiana bat bachelor colonies have been observed (Hall 1962, Carter et al. 2001), males and nonreproductive females typically do not roost in colonies and may stay close to their hibernaculum (Brack 1983, Whitaker and Brack 2002) or migrate long distances to their summer habitat (e.g., Kurta and Rice 2002). Reproductive females may migrate great distances, up to 575 km (357 mi) (Winhold and Kurta 2006), to form maternity colonies to bear and raise their young. Both males and females return to hibernacula in late summer or early fall to mate and enter hibernation.

Demographics

Births, immigration, deaths, and emigration reflect the primary population processes responsible for changes in population size (Williams et al. 2002). Demographics include those biologically relevant parameters, such as total population size, age distribution, age-specific survival, sex ratio, sex-specific survival, and fecundity or reproductive rate, which influence population change by acting on one or more of these processes. These parameters are key components in understanding the extinction risk faced by the Indiana bat. Current demographic information for this species is mostly unknown.

In temperate-zone insectivorous bats, many young females mate their first autumn and have offspring the following year, whereas males usually do not sexually mature until the summer after their birth (Gustafson 1975, Schowalter et al. 1979, Racey and Entwistle 2000). The age of reproductive maturity or first breeding is important in determining reproductive potential (Racey and Entwistle 2003) and is highly variable in vespertilionids, ranging from 3 to 16 months in both sexes (Tuttle and Stevenson 1982). Guthrie (1933) reported that female Indiana bats are sexually mature by the end of their first summer, although there may be considerable intraspecific variation in the age of sexual maturity (Racey 1982). Butchkoski and Turner (2006) reported that one female Indiana bat in a Pennsylvania maternity colony, initially captured as a juvenile in July 2001 and recaptured each of the next four summers, did not reproduce until she was three years old. Age of reproductive maturity likely varies with latitude (Racey and Entwistle 2003). In a review of pertinent literature, Tuttle and Stevenson (1982) concluded that male vespertilionids rarely attain sexual maturity ahead of females.

Female Indiana bats, like most temperate vespertilionids, give birth to one young each year (Mumford and Calvert 1960, Humphrey et al. 1977, Thomson 1982). Seven pregnant Indiana bats examined by Easterla and Watkins (1969) had single embryos, supporting conclusions that most species of bats have low reproductive rates (Herreid 1964, Racey and Entwistle 2003, Barclay et al. 2004). The proportion of female Indiana bats that produce young is not well documented. At a colony in Indiana, 23 of 25 female Indiana bats produced volant young during one year, and 28 females produced at least 23 young the following year (Humphrey et al. 1977). Based on cumulative mist-netting captures over multiple years, Kurta and Rice (2002) estimated that 89 percent of adult females in Michigan maternity colonies were in reproductive condition (pregnant, lactating, or post-lactating). Reproductive rates of the closely related little brown bat often exceed 95 percent (i.e., 95 percent of females give birth), but location and environmental factors (e.g., amount of rainfall and temperature) can lead to lower rates (Kurta and Rice 2002, Barclay et al. 2004). Many studies of vespertilionid bats showed that within a species, the proportion of breeding females may vary dramatically among populations and between years, and this variation is typically due to climate (Racey and Entwistle 2000, Barclay et al. 2004).

The sex ratio of the Indiana bat is generally reported as equal or nearly equal, based on early work by Hall (1962), Myers (1964), and LaVal and LaVal (1980). Humphrey et al. (1977) observed a nearly even sex ratio (nine females, eight males) in a sample of weaned young

Indiana bats. However, differential survival in adults has been suggested (Humphrey and Cope 1977, LaVal and LaVal 1980).

No estimates of age structure have been made for winter populations, or for the population as a whole, due in part to the lack of an accurate technique for aging individuals once they are adults (Anthony 1988, Batulevicius et al. 2001). To date, published estimates of the lifespan of the Indiana bat are based on survival after banding, from bats captured in winter. Using winter sampling of unknown-age bats over a 23-year period, Humphrey and Cope (1977) estimated annual survival. Survival rates following weaning are unknown, although Humphrey and Cope (1977) surmised that the lowest survival occurred in the first year after marking. Those authors suspected their samples contained many young-of-the-year, but banding was conducted during the hibernation period when young were indistinguishable from adults.

Based on banding data, Humphrey and Cope (1977) proposed that the adult period of life is characterized by two distinct survival phases. The first is a high and apparently constant rate from 1 to 6 years after marking with 76 and 70 percent annual rates for females and males, respectively. The second phase is a lower constant rate after 6 years with annual survival of 66 percent for females up to 10 years and 36 percent for males. Following 10 years, the survival rate for females dropped to only 4 percent. Humphrey and Cope (1977) surmised that this lower rate may reflect an increased cost of migration and reproduction during old age, or may be attributable to sampling error, as a very small number of females remained alive after 10 years. However, individuals have been noted to live much longer, with the oldest known Indiana bat captured 20 years after it was first banded (LaVal and LaVal 1980). Humphrey et al. (1977) provided the only neonatal mortality estimate, 8 percent, based on one of two seasons of observation of one maternity colony. More research on differences in survival rate among life stages is needed.

In summary, the information necessary to model extinction risk and guide recovery of the Indiana bat is incomplete at this time. As referenced above, sex-specific survival, age structure, and age-specific survival data would vastly improve understanding of this species' demographics. The primary approach to gathering such information for other taxa requires capture-recapture methodologies that have not yet been applied to this species. Recent advances in marking and molecular genetic techniques, in combination with more powerful capture-recapture models, may offer the opportunity to close critical information gaps.

Chronology

Depending on local weather conditions, hibernation for Indiana bats typically lasts from October through April (Hall 1962, LaVal and LaVal 1980), although it may be extended from September to May in northern areas including New York, Vermont, and Michigan (Kurta et al. 1997, Hicks 2004). The nonhibernation season, which includes spring emergence, migration, reproductive activities, and fall swarming, varies depending upon the sex (males may enter hibernation later than females) and the location (northern latitudes may have shortened nonhibernation seasons) (Figure 12). The following sections describe the annual life cycle for the Indiana bat, beginning with the fall mating season.

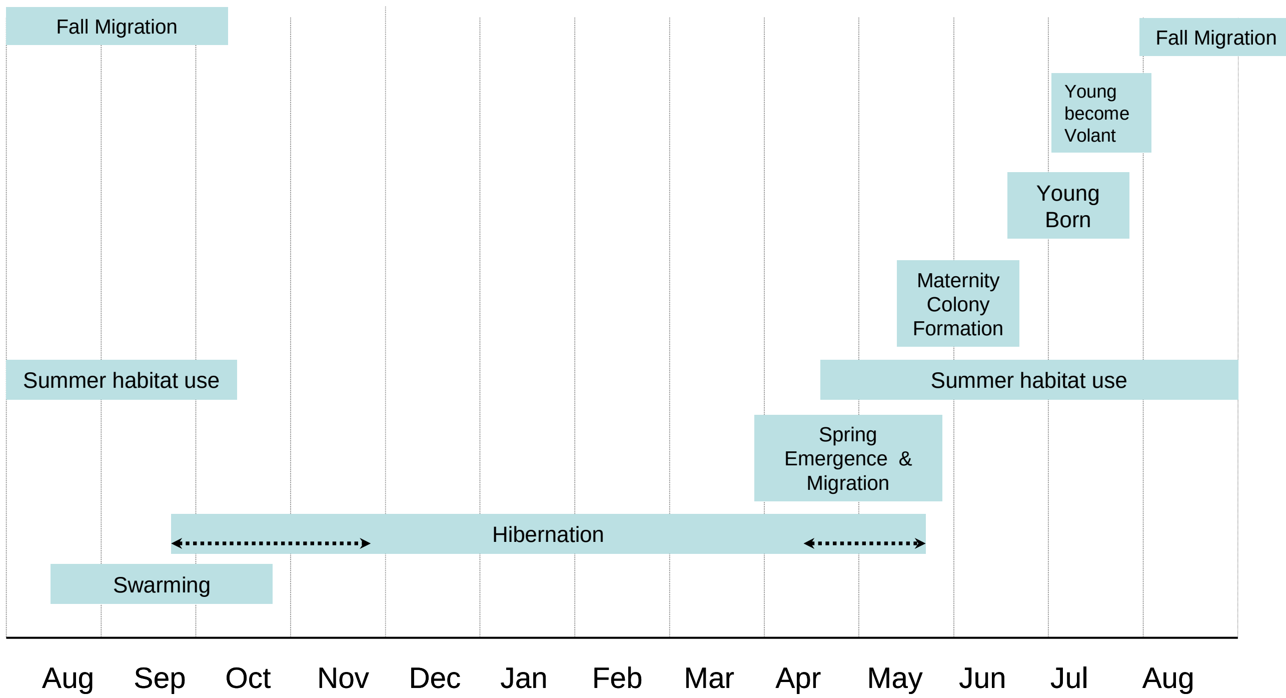


Figure 12. Indiana bat annual chronology.

<u>Fall Swarming and Mating</u>
Indiana bats arrive at their hibernacula in preparation for mating and hibernation as early as late July; usually adult males or nonreproductive females make up most of the early arrivals (Brack 1983). The number of Indiana bats active at hibernacula increases through August and peaks in September and early October (Cope and Humphrey 1977, Hawkins and Brack 2004, Rodrigue 2004, Hawkins et al. 2005). Males may remain active through mid-October or later, especially at southern sites. Upon arrival at a hibernaculum, Indiana bats "swarm," a behavior in which "large numbers of bats fly in and out of cave entrances from dusk to dawn, while relatively few roost in the caves during the day" (Cope and Humphrey 1977). Swarming continues for several weeks, and during this time mating occurs, generally in the latter part of the period. Adult females store sperm from autumn copulations throughout winter, and fertilization is delayed until soon after spring emergence from hibernation (Guthrie 1933). Limited mating activity occurs throughout winter and in spring as bats leave hibernation (Hall 1962).

Prior to hibernating Indiana bats must store sufficient fat to support metabolic processes until spring. During fall swarming, fat supplies for Indiana bats are replenished as they forage in the vicinity of the hibernaculum. Hall (1962) studied fall weight gain in Indiana bats returning to Coach Cave in Edmonson County, Kentucky (which at the time harbored a hibernating population of approximately 100,000 Indiana bats). He documented that bat weights were at the lowest point in the annual cycle when they returned to the vicinity of the hibernaculum in late August and September. Dissection revealed no stored fat in the bats at that time. Weight, in the form of fat, was gained rapidly in September and bats entering hibernation were at maximum weight. LaVal and LaVal (1980) also evaluated seasonal changes in weight, based on weights of 3,290 male and 2,180 female Indiana bats in Missouri. At Pilot Knob Mine, the largest of the Indiana bat hibernacula studied, the number of females active at the cave peaked in late August. Females (on average) achieved maximum weight in early October. Compared to females, peak activity of males was later, and maximum weight gain was achieved in late October. A similar pattern of prehibernation weight gain was observed in little brown bats in the vicinity of a hibernaculum in Vermont (Kunz et al. 1998).

Male Indiana bats may make several stops at multiple hibernacula during the fall swarming period and remain active over a longer period of time at cave/mine entrances than do females (Cope and Humphrey 1977, LaVal and LaVal 1980), most likely to mate with females as they arrive (Brack et al. 2005c). Bats traveling between hibernacula during fall swarming may also be assessing the relative suitability of potential hibernation sites (Parsons et al. 2003). Nightly activity is correlated with temperature; bats and their prey become constrained by falling temperatures as autumn progresses. During swarming, most male bats roost in trees during the day and fly to the cave or mine at night. At Priority 3 hibernacula in eastern 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 the hibernaculum, and Gumbert (2001) found an average of 1.9 km (1.2 mi) between roost trees and the hibernaculum for radiotagged Indiana bats (mostly males). Two male Indiana bats in Michigan roosted in trees 2.2 km (1.4 mi) and 3.4 km (2.1 mi) from their hibernaculum (Priority 4) during fall swarming (Kurta 2000). Brack (2006) found a range of 0.3 to 1.4 km (0.2 to 0.9 mi) between roost trees, used by male and female Indiana bats during fall swarming, and a Priority 3 hibernaculum in Virginia, although he could not follow bats if they left the "project area," so the range may actually have been greater.

Bat movement patterns in autumn often do not follow a simple linear pattern of migration from summer habitat to the hibernacula. Parsons et al. (2003) highlighted the transitory nature of bats at this time of year, noting that bats may travel relatively long distances from a swarming site during the swarming season; they observed bats roosting up to 27 km (17 mi) from swarming sites and completing the round trip between the swarming and roosting sites in one or two nights. Humphrey and Cope (1976) documented several little brown bats making movements up to 60 km (37 mi) (away from the hibernaculum where they were captured during swarming). Indiana bats have also been found making relatively long trips from hibernacula during fall swarming. C. Butchkoski (Pennsylvania Game Commission, pers. comm., 2006) documented a radiotagged male Indiana bat in Pennsylvania making two trips between the hibernaculum where it was captured to a site 14 km (9 mi) away over a period of two weeks. Hawkins et al. (2005) documented several Indiana bats radiotagged at Wyandotte Cave in Indiana traveling long distances from the cave during fall swarming, including two females that were relocated over 31 km (19 mi) from the cave. Brack (2006) suggested that competition for foraging resources may force bats to leave the immediate vicinity of the hibernacula to find prime foraging habitat to replenish their energy reserves, particularly at hibernacula that support large populations of Indiana bats and/or large populations of multiple species.

Most swarming studies have been conducted at relatively small hibernacula (see discussion of Priority 3 and 4 hibernacula above). During the fall of 2003 and 2004, a radiotelemetry study of Indiana bats during fall swarming was conducted at Wyandotte Cave, a Priority 1 hibernaculum in Indiana. Most radiotagged bats were never relocated; four of 18 were relocated in 2003 (Hawkins and Brack 2004) and 10 of 32 were relocated in 2004 (Hawkins et al. 2005). All of the relocations occurred late in the fall swarming season. Some Indiana bats were found to leave the hibernaculum, traveling as far as 31 km (19 mi) from the cave in a single night. Most radiotracking was done using ground tracking techniques, but these long distance movements were documented using aerial tracking. Researchers concluded that many of the radiotagged bats that were not relocated likely moved too far from the hibernaculum to be relocated using the ground tracking techniques that were employed during most tracking sessions. The long distances traveled by bats radiotagged near Wyandotte Cave, compared to smaller hibernacula, suggest that use of habitat near hibernacula during swarming may differ between caves that support large versus small populations of bats (Hawkins et al. 2005). Wyandotte Cave, which currently supports a hibernating population of over 50,000 Indiana bats, is part of a complex of hibernacula; within an approximately 16 km (10 mi) radius there are four Priority 1 hibernacula that collectively support 128,000 Indiana bats. If all species of bats hibernating in these caves are considered, the population may be near one million bats (Hawkins and Brack 2004). Additional study is needed to determine if fall swarming behaviors are affected by the size of a hibernating population.

Hibernation

Indiana bats tend to hibernate in the same cave or mine at which they swarm (LaVal et al. 1976), although swarming has been observed at hibernacula other than those in which the bats hibernated (Cope and Humphrey 1977; J. MacGregor, Kentucky Department of Fish and Wildlife Resources, pers. comm., 2005) and at caves that do not serve as hibernacula for the species (V. Brack, Indiana State University, pers. comm., 2006). It is generally accepted that Indiana bats, especially females, are philopatric; that is, they return annually to the same hibernacula (LaVal and LaVal 1980). However, exceptions have been noted (Hall 1962, Myers 1964). Some Indiana bats apparently also move from traditional hibernacula to occupy man-made hibernacula, primarily mines, as these become available (see discussion in the Population Distribution and Abundance section).

Most Indiana bats enter hibernation by the end of November (mid-October in northern areas) (Kurta et al. 1997), although populations of hibernating bats may increase throughout fall and into early January at some hibernacula (Clawson et al. 1980). Indiana bats usually hibernate in large, dense clusters ranging from 300 bats per square foot (LaVal and LaVal 1980) to 484 bats per square foot (Clawson et al. 1980, Hicks and Novak 2002), although cluster densities as high as 500 bats per square foot have been recorded (Stihler 2005). While the Indiana bat characteristically forms large clusters, small clusters and single bats also occur (Hall 1962, Hicks and Novak 2002).

Indiana bats often winter in the same hibernaculum with other species of bats and are occasionally observed clustered with or adjacent to other species, including gray bats, Virginia big-eared bats (*Corynorhinus townsendii virginianus*), little brown bats, and northern long-eared bats (Myers 1964, LaVal and LaVal 1980, Kurta and Teramino 1994). Additional habitat-specific information on Indiana bat hibernacula is found in the Hibernation Habitat section.

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 Microlimate 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. Chenger, 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 and 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 ± 2456 acres) for spring and fall (based on pooled data for nine bats–male and female) and 1,584 ± 1,424 ha (3,825 ± 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 5ºC, with energy use increasing at temperatures of both -5ºC and 10ºC (23.0ºF and 50.0ºF). However, Henshaw (1965) did not quantify energy expenditure by Indiana bats at intermediate temperatures (i.e., 1º to 4ºC and 6º to 9ºC (33.8º to 39.2ºF and 42.8º to 48.2ºF)). T. Tomasi (Missouri State University, unpublished data, 2006) collected metabolic data for Indiana bats hibernating in a laboratory at 1^o, 3^o, 5^o, 7^o, and 9^oC (33.8º, 37.4º, 41.0º, 44.6º, 48.2ºF) 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^oC (41.0ºF) 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., 3ºC versus 8ºC (37.4ºF versus 46.4ºF)) 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 2º to 4ºC), 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. lacinosa*) 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 females and young	Percent of trees used by adult females and young	Number of trees used by adult males	Percent of trees used by adult males	References [b]
Acer rubrum	Red maple	B, C	7	1.8	13	5.4	2, 4, 9, 12, 13, 16, 17
Acer saccharinum	Silver maple	B	25	6.4	1	0.4	5, 6, 8, 13, 18, 19
Acer saccharum	Sugar maple	B, C	18	4.6	2	0.8	1, 2, 8, 16-20
Acer sp.	Unidentified maple	B	9	2.3	0	0.0	13
Betula alleghaniensis	Yellow birch	?	2	0.5	0	0.0	2, 16
Betula lenta	Sweet birch	B	1	0.3	0	0.0	3
Carya cordiformis	Bitternut hickory	B	3	0.8	1	0.4	8, 11, 18, 19
Carya glabra	Pignut hickory	B	0	0.0	3	1.3	12, 17
Carya lacinosa	Shellbark hickory	B	4	1.0	0	0.0	18, 19
Carya ovata	Shagbark hickory	B	78	19.8	22	9.2	2, 5, 6, 8-13, 16-21
Carya tomentosa	Mockernut hickory	?	0	0.0	7	2.9	9
Celtis occidentalis	Northern hackberry	B	1	0.3	0	0.0	18, 19
Cornus florida	Flowering dogwood	?	0	0.0	4	1.7	9
Fagus grandifolia	American beech	?	1	0.3	0	0.0	2
Fraxinus americana	White ash	C	1	0.3	0	0.0	5
Fraxinus nigra	Black ash	B	4	1.0	3	1.3	13
Fraxinus pennsylvanica	Green ash	B, C	46	11.7	4	1.7	2, 6, 13, 18, 19
Gleditsia triacanthos	Honeylocust	B	2	0.5	0	0.0	7
Juglans cinerea	Butternut	B	1	0.3	0	0.0	20
Juglans nigra	Black walnut	B	1	0.3	0	0.0	18, 19
Liriodendron tulipifera	Tulip tree	B	1	0.3	6	2.5	9, 15
Ostrya virgiana	Hophornbeam	B	1	0.3	0	0.0	20
Oxydendrum arboreum	Sourwood	?	0	0.0	9	3.8	9, 12
Pinus echinata	Shortleaf pine	B	2	0.5	70	29.3	3, 9
Pinus rigida	Pitch pine	B	1	0.3	6	2.5	3, 9
Pinus sp.	Unidentified pine	B	1	0.3	4	1.7	3, 10, 21
Pinus strobus	White pine	B, C	8	2.0	0	0.0	16, 20
Pinus virginiana	Virginia pine	?	0	0.0	15	6.3	9, 12
Platanus occidentalis	Sycamore	C	2	0.5	0	0.0	14, 18, 19

Populus deltoides	Cottonwood	B, C	25	6.4	0	0.0	5, 6, 8, 13, 18, 19, 21
Populus sp.	Unidentified poplar	B	5	1.3	0	0.0	20
Populus tremuloides	Trembling aspen	B	5	1.3	0	0.0	2, 16
Quercus alba	White oak	B	15	3.8	18	7.5	5, 8, 9, 17, 21
Quercus coccinea	Scarlet oak	?	0	0.0	5	2.1	9, 12
Quercus falcata	Spanish oak	?	0	0.0	1	0.4	9
Quercus imbricaria	Shingle oak	B	0	0.0	1	0.4	8
Quercus palustris	Pin oak	B	8	2.0	0	0.0	6
Quercus prinus	Chestnut oak	?	0	0.0	6	2.5	9
Quercus rubra	Red oak	B	30	7.6	9	3.8	3, 4, 5, 8-10, 12, 13, 21
Quercus sp.	Unidentified oak	B	3	0.8	0	0.0	20
Quercus stellata	Post oak	B	3	0.8	2	0.8	8
Quercus velutina	Black oak	B	0	0.0	2	0.8	9, 17
Robinia pseudoacacia	Black locust	B, C	12	3.1	0	0.0	2, 20
Sassafras albidium	Sassafras	B, Ca	0	0.0	2	0.8	8
Tilia americana	Basswood	B	1	0.3	0	0.0	20
Tsuga canadensis	Eastern hemlock	B	3	0.8	0	0.0	2, 3, 20
Ulmus americana	American elm	B	35	8.9	14	5.9	2, 4, 8, 9, 13, 16-22
Ulmus rubra	Slippery elm	B, C	9	2.3	9	3.8	4, 7, 8, 9, 13, 21
Ulmus 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, Chenger 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**
Illinois	39 (47)	18 (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)		0-20 (23)[b]	Foster and Kurta, 1999; Kurta et al. 1996
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, Tennessee	46 (8)	18 (8)		46 (18)		Britzke et al., 2003
Ohio	38 (2)	21 (1)				Belwood, 2002
Vermont	50 (20)			77 (13)	88 (20)	Palm, 2003
Average ± SE[d]	45 ± 2	20 ± 1	9 ± 1	59 ± 5	50 ± 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 (%)[a]	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 ± SE[d]	33 ± 2	18 ± 1	10 ± 1	57 ± 1	63 ± 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; Chenger 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^{o}C, and that after construction temperatures increased to approximately 11^{o}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.

<u>Impacts of Forest Conversion on Summer Habitat</u>

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.

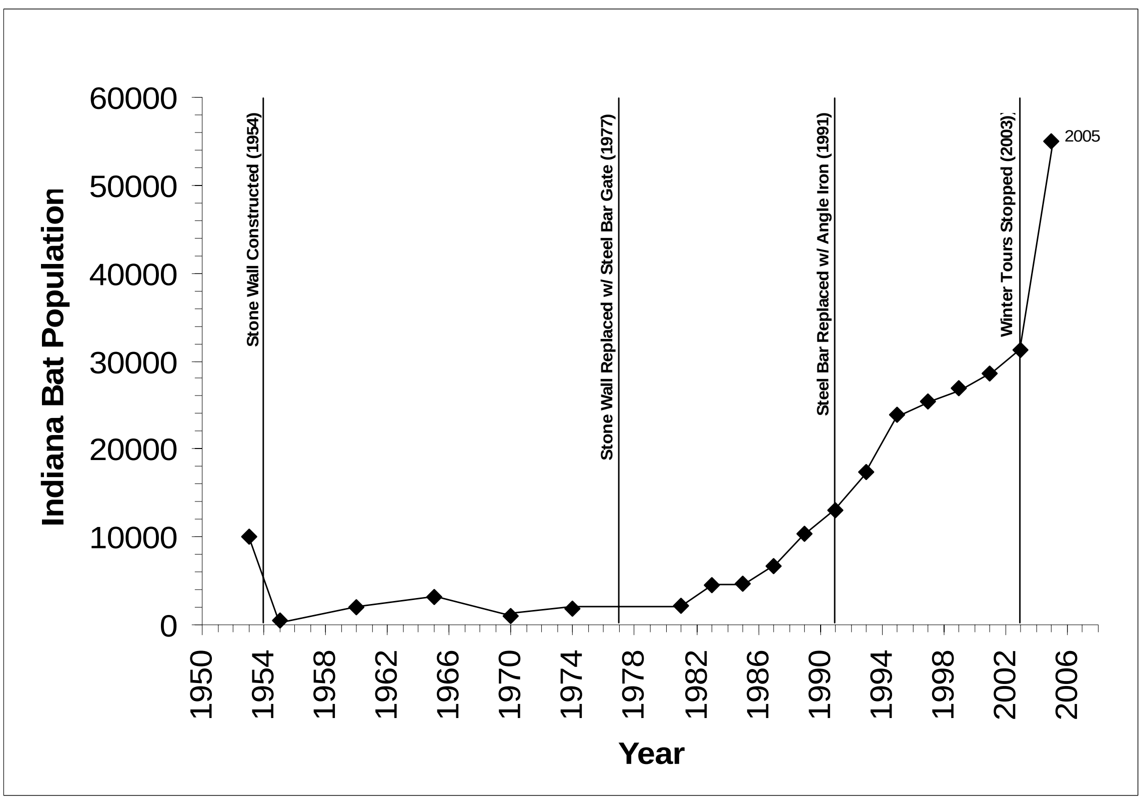


Figure 13. Changes in the population of hibernating Indiana bats in Wyandotte Cave, Crawford County, Indiana, relative to timing of structural changes to the cave and the cessation of winter tours.

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 LD_{50} (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 LD_{50} 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 (T_3) and thyroxine (T_4) 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 Krynitsky 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 Krynitsky 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 prevolant 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 Krynitsky 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).

<u>Adult Females</u>
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.

PART II. RECOVERY PROGRAM

Recovery Strategy

Species Status

The Indiana bat was originally listed in 1966 under a precursor to the ESA. Although the original listing rule for the species did not provide the reasons for listing, the general consensus among bat experts is that human disturbance of hibernating bats was a primary cause of pre-listing declines in Indiana bat populations; these declines in turn were the primary reason for listing (Barbour and Davis 1969, Mohr 1972, Greenhall 1973, L. Pruitt, pers. comm, 2006). Since the species' listing through 2001, hibernacula surveys have shown an apparent downward trend in overall population numbers (Figure 6). Although there is compelling evidence of a true decline, the statistical significance of the trend is unknown, because of error associated with hibernacula count techniques and apparent and contradictory population changes among hibernacula. The 2005 census estimated the population at 457,000 (USFWS, unpublished data, 2006; Table 3; Figure 6).

Threats to the species vary with its annual cycle. At the hibernacula, threats include modifications to the caves, mines, and surrounding areas that result in changes in airflow and alteration of the microclimates in the hibernacula (Humphrey 1978, Richter et al. 1993, Johnson et al. 2002). Human disturbance and vandalism pose significant threats to the species during hibernation by inducing arousal and consequent depletion of fat reserves (Thomas et al. 1990, Speakman et al. 1991, Thomas 1995) and through direct mortality (Greenhall 1973, Humphrey 1978, Murphy 1987). Natural catastrophes (flooding and freezing events) can also have a significant effect on the population during winter because of the large number of individuals that hibernate in a relatively few sites (Hall 1962, DeBlase et al. 1965, Humphrey 1978, Richter et al. 1993, Johnson et al. 2002). During summer months, possible threats relate to the loss and degradation of forested habitat (Gardner et al. 1990, Garner and Gardner 1992, Drobney and Clawson 1995, Whitaker and Brack 2002). Migration pathways and swarming sites can also be affected by habitat loss and degradation (Hall 1962, Fleming and Eby 2003). Habitats surrounding swarming sites may be particularly important in that these sites are discrete areas that apparently must be suitable to support large numbers of bats that, in addition to engaging in swarming activities, must forage to build up sufficient fat reserves to sustain them through the hibernation period (Hall 1962). In addition, the effects of environmental contaminants cannot be ignored and need further research. Climate change and wind turbines may present additional threats to the species; the full impact of these factors will be realized with time.

The Indiana bat's life history strategy leads to several intrinsic biological constraints that can be compounded by extrinsic threats. Examples of biologically intrinsic needs for this species are efficient use of fat during hibernation, obligate colonial roosting, high energy demands of pregnant and nursing females, and timely parturition and rapid weaning of young. Factors that may exacerbate the vulnerability to these constraints include energetic impacts of significant disruptions to roosting areas (both in hibernacula and maternity colonies), availability of hibernation habitat, connectivity and conservation of roosting-foraging and migration corridors, and conservation of habitat currently supporting or in proximity to maternity colonies. To ensure recovery, intrinsic factors, extrinsic factors, and resulting synergistic effects need to be considered during recovery planning and implementation and project evaluations.

Since listing, several conservation measures have been undertaken to arrest the decline, protect habitat, and increase numbers. Some of these conservation measures stem directly from the species' status as a Federally listed endangered species including cooperative grants to states, interagency consultations, prohibitions on take, and land acquisition. Other conservation efforts include the gating of caves and mines, biennial hibernacula counts to determine status, protection of maternity habitat, research, and public education.

Although this species has been Federally listed for almost four decades (32 FR 4001, March 11, 1967), significant information gaps remain that hinder sound decision-making about how best to manage and protect the species. Furthermore, the Service's Federal and State partners have indicated that a coordinated and complete research plan for the species is needed to ensure that each partner's research efforts complement and not duplicate other research and that all information gaps are being addressed. Research is necessary in numerous key areas including but not limited to the following:

- rangewide demographic data (to model extinction risk, detect regional and age class differences in survival, etc.);
- ideal microclimate for hibernation;
- importance of optimum hibernation microclimate throughout its range;
- characteristics of a maternity colony with positive recruitment;
- specific habitat quality and quantity parameters necessary for a self-sustaining maternity colony;
- effect and exposure of Indiana bats to various classes of contaminants throughout the annual cycle;
- response of Indiana bat to perturbations in summer habitat;
- understanding the role that habitats near hibernacula play in swarming;
- the role of caves used for swarming that are not hibernacula;
- aspects of migration, including timing, energetics, and habitat use; and
- effect of global warming on the species' distribution and hibernacula.

Focus of Recovery Program

Given the above described population trends, threats, biological constraints, ongoing conservation measures, and information needs, the recovery program for this species has four broad components: 1) rangewide population monitoring at the hibernacula with improvements in census techniques, 2) conservation and management of habitat (hibernacula, swarming, and to a degree, summer), 3) further research into the requirements of and threats to the species, and 4) public education and outreach. This recovery program continues to have a primary focus on protection of hibernacula (U.S. Fish and Wildlife Service 1983) but also increases the focus on summer habitat and proposes use of Recovery Units. This increased focus is based on the principles of conservation biology and research on the importance of addressing both core and peripheral populations in conservation strategies for rare species.

Representation, Redundancy, and Resiliency

Conservation programs including recovery programs for listed species are strengthened by adherence to three primary principles of conservation biology: representation, resiliency, and redundancy (Shaffer and Stein 2000). Each concept focuses on a different aspect of ensuring a species long-term survival. Representation involves conserving the breadth of the genetic makeup and natural variation across a species' range to conserve adaptive capabilities; the principle of representation suggests that the unit of conservation should be complexes of populations. Resiliency ensures that each population is viable and sufficiently large to withstand stochastic events. Redundancy protects an adequate number of populations to provide a margin of safety for the species to withstand catastrophic events (Shaffer and Stein 2000). In addition to these three principles, past research has shown the importance of conserving both core and peripheral populations of a species.

Core and Peripheral Populations

Understanding rangewide patterns in species abundance in core and peripheral populations is important to understanding evolutionary and ecological processes, such as gene flow and species response to changing environmental conditions (Sagarin and Gaines 2002). Although various patterns are conceivable (Vucetich and Waite 2003), in general, species abundance often peaks at the geographic range center and gradually decreases towards the edges (Hengveld and Haeck 1982, Brown 1984, Lomolino and Channell 1995, Rodriguez 2002, Vucetich and Waite 2003, Guo et al. 2005). Populations in the areas of highest abundance are considered the species core, while populations in the areas of lowest abundance are considered peripheral.

Core populations tend to exhibit high levels of genetic diversity (Lesica and Allendorf 1995) and may be the most stable segment of a species' range. Core populations are characterized by high abundance with little fluctuation in numbers (Lomolino and Channell 1995). In addition, core populations are thought to occupy the species' optimal habitat (Brown 1984, Gaston 1990, Brown et al. 1995).

Peripheral populations tend to exhibit relatively low and more variable species abundances (Henveld and Haeck 1982, Brown 1984, Vucetich and Waite 2003) and low genetic diversity (Lesica and Allendorf 1995, Garner et al. 2003). Peripheral populations also tend to occupy atypical or less favorable habitats that are isolated from the core of the species' range (Brown 1984, Lomolino and Channell 1995, Channell and Lomolino 2000a). These factors are thought to increase the extinction risk of peripheral populations (Brown 1984, Lesica and Allendorf 1995).

Peripheral populations can play an important role in conservation. Their relative isolation and lower abundance typically results in less genetic diversity than core populations due to genetic drift caused by reduced gene flow and founder effects (Lesica and Allendorf 1995, Vucetich and Waite 2003). However, concomitant processes in peripheral populations may also produce distinctive genetic characteristics. Pressures applied by natural selection in peripheral populations are focused on colonization ability and adaptation to different environmental factors (Remington 1968, Scudder 1989, Lesica and Allendorf 1995). These processes often result in peripheral populations that are genetically divergent from those in the core (Lesica and Allendorf 1995). Therefore, although core populations may hold greater genetic diversity, peripheral populations may harbor important adaptive genetic variation (Scudder 1989, Guo et al. 2005, Lesica and Allendorf 1995).

Geographical isolation from core populations may influence peripheral populations in other ways. Studies of numerous species have shown that range collapse frequently originates in the core or area of high abundance, contracting to remaining peripheral populations (Lomolino and Channell 1995, Channell and Lomolino 2000a, Rodriguez 2002). This pattern appears to result from anthropogenic threats (e.g., habitat loss, exotic species invasion) that overwhelm normal species abundance patterns (Channell and Lomolino 2000a, 2000b). These threats often spread across the landscape like a contagion, with those populations that are exposed last persisting the longest (Channell and Lomolino 2000b). Peripheral populations may be sufficiently isolated from the threats affecting the species' core that the populations are buffered from negative impacts (Araujo and Williams 2001). Therefore, the edge of a species range may provide important refugia for rare or imperiled species (Lomolino and Channell 1995).

As previously discussed, peripheral populations may occupy atypical or less favorable habitats (Lomolino and Channell 1995, Channel and Lomolino 2000a, 2000b). To persist, these individuals must adapt to different and possibly more extreme environmental factors and selective forces. Additionally, peripheral populations may be genetically and ecologically different from other peripheral populations and the core populations (Lomolino and Channell 1995). Further, peripheral populations may be better adapted to long-term rangewide environmental changes, such as global climate change (Hunter 1991, Araujo and Williams 2001). These individuals may be best adapted to establishing themselves in the shifting habitats created by changing climate (Fraser 2000).

Thus, both core and peripheral populations make contributions to a species' persistence due to their different characteristics. Because of the relationship that exists among core and peripheral populations within a species' range, conservation and management of both should be considered equally important (Brown 1984, Pulliam 1988, Furlow and Armijo-Prewitt 1995, Lesica and Allendorf 1995, Lomolino and Channell 1997).

Justification for Recovery Units

Research on core and peripheral populations and the importance of population representation in species conservation suggest that maintaining the current distribution avoids extinction and ensures long-term survival (Furlow and Armijo-Prewitt 1995, Lesica and Allendorf 1995, Channell and Lomolino 2000a, Shaffer and Stein 2000). Humphrey (1992) proposed that Indiana bats are separated into interbreeding populations and that management programs should be developed according to these delimitations (Humphrey 1992). Recovery Units are a tool developed to maintain the distribution of wide-ranging species that have multiple populations or varying ecological pressures in different parts of the range (National Marine Fisheries Service 2004). Recovery Units are geographically or otherwise identifiable and are essential to conserve genetic robustness, demographic robustness, or other necessary biological features. Recovery Units may not be reclassified or delisted separately.

As proposed in this Plan, Recovery Units protect both core and peripheral populations. Furthermore, Recovery Units address the principle of representation by aiding conservation of natural variation across populations. As discussed in the Population Distribution and Abundance section of this plan, preliminary evidence suggests that the Northeast populations of the species have different levels of genetic diversity than the rest of the Indiana bat population and also are of more recent origin; additionally, data from two hibernacula in the Appalachian region also suggest recent divergence and isolation (M. Vonhof, pers.comm., 2006). Research is needed to confirm this pattern and to further explore possible genetic variation across the species range. Such variation is possible given suggestions of population discreteness from banding return data (Hall 1962, Barbour and Davis 1969, Gardner and Cook 2002). Variation in habitat and environmental conditions between core and peripheral populations of the species may also have resulted in differences in adaptive capabilities (Lomolino and Channell 1995, Channel and Lomolino 2000a, 2000b). Protecting populations across the species' range ensures preservation of these adaptive capabilities.

Recovery Units also allow for adherence to the tenets of redundancy and resiliency. Population redundancy is addressed in this plan by protecting 80 percent of the Priority 1 hibernacula and 50 percent of the Priority 2 hibernacula in each Recovery Unit (see Reclassification Criterion 1 and Delisting Criterion 1). The principle of redundancy is also addressed by requiring that Indiana bat population levels in each Recovery Unit have a positive population growth rate over five survey periods (see Reclassification Criterion 3 and Delisting Criterion 3). Tracking measures of population redundancy and resiliency will also be helpful in monitoring the population in the Ozark-Central region, where the population has declined significantly since 1990 (see Figure 7 and Population Trends in Hibernacula section of this plan).

We are unable to assess—and thus address— population resiliency at this time because the characteristics of a viable population or maternity colony are not known. However, research actions described within this Recovery Plan will produce results that will facilitate this endeavor.

Delineation of Recovery Units

As alluded to above, the delineation of Recovery Units relies on a combination of preliminary evidence of population discreteness and genetic differentiation, differences in population trends, and broad-level differences in macrohabitats and land use. When Recovery Unit delimitations suggested by these factors were geographically close to state boundaries, the Recovery Unit borders were shifted to match the state boundaries in order to facilitate future conservation and management. This draft revised plan proposes four Recovery Units for the species: Ozark-Central, Midwest, Appalachian Mountains, and Northeast (Figure 14). The proposed delineations will be revised as additional information becomes available from research outlined in the Recovery Actions portion of this document.

Banding returns suggest the Indiana bat population is not panmictic (Hall 1962, Barbour and Davis 1969, Gardner and Cook 2002). Banding data by Hall (1962) showed that individuals hibernating in Kentucky migrated north to Indiana and western Ohio during the summer. Barbour and Davis (1969) determined that female bats and most male bats banded in Kentucky migrate north in the spring to Indiana, western Ohio, and southern Michigan. Gardner and Cook (2002) summarized banding returns reported in Kurta 1980, LaVal and LaVal 1980, Bowles 1981, Walley 1981, and Kurta and Murray 2002. Mature female bats from hibernacula in Kentucky and Indiana summered in western Ohio, Indiana, and Michigan (Gardner and Cook

2002), whereas individuals hibernating in southern Missouri migrated north to northern Missouri and Iowa during the summer (Myers 1964, LaVal and LaVal 1980, Gardner and Cook 2002). Recoveries at White Oak Blowhole Cave (Tennessee) of Indiana bats banded during the summer at Great Smoky Mountains National Park, Tennessee, Nantahala National Forest, North Carolina, and Cherokee National Forest, Tennessee, suggest that the bats are residents of the Appalachian region year-round and do not migrate long distances to their hibernacula (Harvey 2002). Winhold and Kurta (2006) also report on Indiana bats that were banded in Michigan and later found hibernating in caves in Indiana and Kentucky. Although data from banding returns are limited, at this time it is the best information available; delineation lines will be revised, if necessary, as additional data become available.

Recent population genetics research also supports the premise of population discreteness. With the exception of one hibernaculum in the Northeast Recovery Unit (Jamesville Quarry Cave), populations in the proposed Northeast and Appalachian Mountain Recovery Units have very different frequencies of haplotypes than populations in the Midwest Recovery Unit (M. Vonhof, pers.comm., 2006).. Additionally, populations in the Northeast Recovery Unit have significantly less genetic diversity than those in the Appalachian Mountain, Midwest, and Ozark-Central Recovery Units and are likely of more recent origin

The delineations suggested by traditional taxonomic studies, banding returns and rangewide genetic variation are similar to the Divisions and Provinces of Bailey's Ecoregions (Figure 14; Bailey 1997). Bailey's Ecoregional Divisions and Provinces suggest broad-level differences in habitat type among Indiana bat populations that further correspond with differences in land use and threats to the species (e.g., differing significance of mining and agriculture between the Appalachian Mountain and Midwest Recovery Units). In this way, the proposed units facilitate the development and implementation of Recovery Actions that are specific to different macrohabitat types, land uses, and threats.

Proposed Recovery Units for the Indiana bat coincide with Bailey's Ecoregional Divisions and Provinces in the following ways. The proposed delineation of the Appalachian Mountain Recovery Unit is based on Bailey's Central Appalachian Broadleaf Forest Province with the exception of the eastern-most counties in Tennessee included to account for the significantly different frequency of haplotype between White Oak Blowhole Cave and hibernacula in the Midwest Recovery Unit (M. Vonhof, pers. comm., 2006). The Northeast Recovery Unit corresponds primarily with the Eastern Broadleaf Forest Province and Laurentian Mixed Forest Province. The proposed Midwest Recovery Unit corresponds with Bailey's Eastern Broadleaf Forest Province, and the Ozark-Central Recovery Unit is composed primarily of the Eastern Broadleaf Forest and Prairie Parkland provinces.

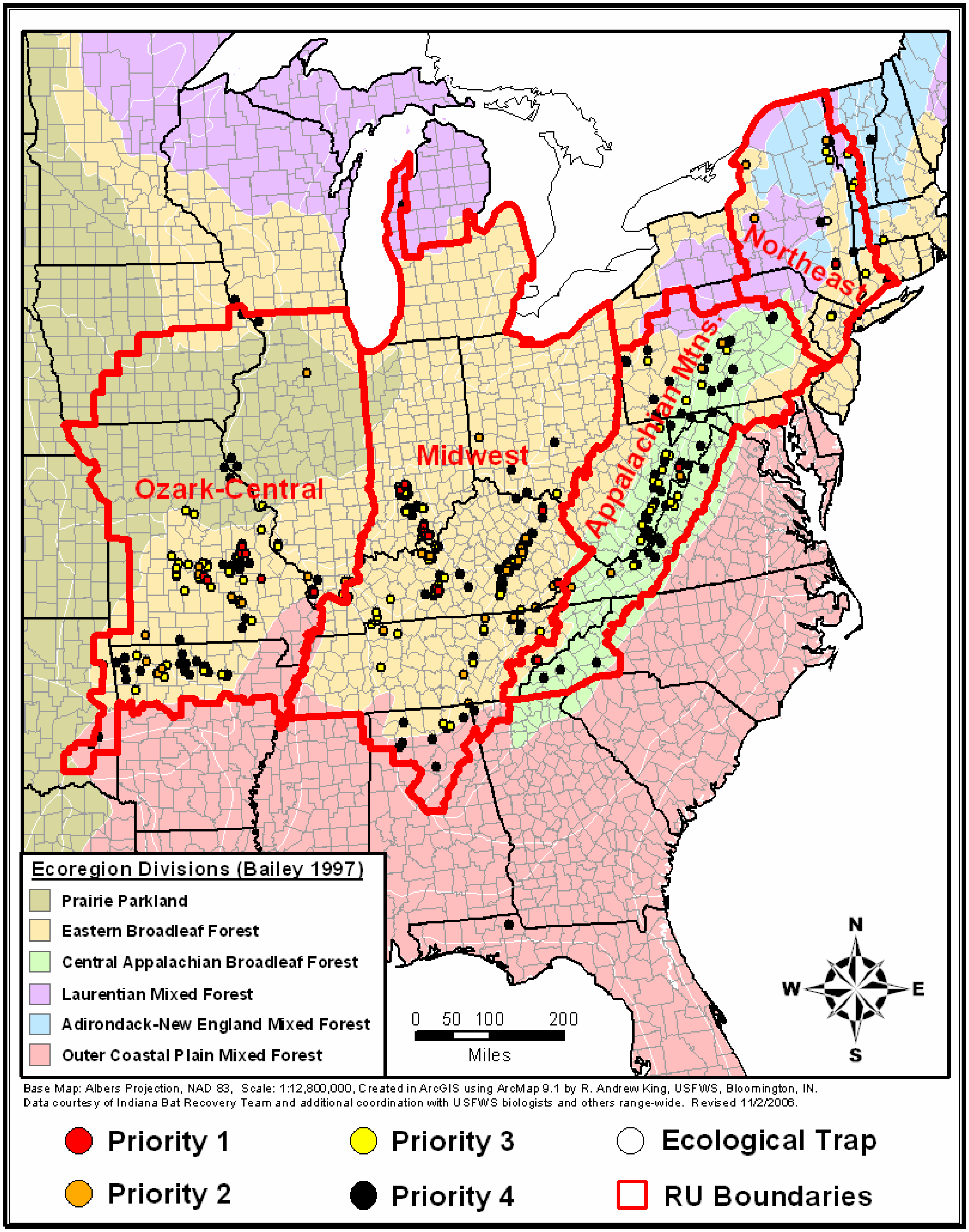


Figure 14. Indiana Bat Recovery Units. Hibernacula located outside of the Recovery Unit boundaries have not had an Indiana bat record for over 50 years.

Recovery Goals

The recovery program for the Indiana bat is intended to alleviate threats to the species so that protections under the ESA are no longer necessary. The ultimate goal of this Recovery Plan is to remove the species from the Federal list of Endangered and Threatened Wildlife (50 CFR 17.11). The intermediate goal is reclassification of Indiana bat to threatened status.

Recovery Objectives

Reclassification for this species will be attained through addressing the following parameters: 1) permanent protection of 80 percent of Priority 1 hibernacula, 2) a minimum overall population number equal to the 2005 estimate (457,000), and 3) documentation of a positive population growth rate over five sequential survey periods. If identified research on summer habitat characteristics and requirements indicates the quality and quantity of maternity habitat is threatening recovery of the species, the Service will amend these objectives and the following criteria.

The delisting recovery goal for this species will be attained through addressing the following parameters: 1) permanent protection of 50 percent of Priority 2 hibernacula, 2) a minimum overall population number equal to the 2005 estimate, and 3) continued documentation of a positive population growth rate over an additional five sequential survey periods. If identified research on summer habitat characteristics and requirements indicates the quality and quantity of maternity habitat are threatening recovery of the species, the Service will amend these objectives and the following criteria. These delisting parameters must be met in addition to the reclassification parameters before delisting can occur.

Recovery Criteria

Reclassification Criteria:

Reclassification Criterion 1: Permanent protection at 80 percent of all Priority 1 hibernacula in each Recovery Unit, with a minimum of one Priority 1 hibernaculum protected in each unit. (In the Northeast and Appalachian Mountain Recovery Units, 80 percent protection would translate to 100 percent protection because these units have one and two Priority 1 hibernacula, respectively.)

Greater than 80 percent of the Indiana bat population hibernates in the Priority 1 hibernacula. Thus, by achieving this criterion, a significant proportion (but not necessarily 80%) of the Indiana bat rangewide population will be protected from disturbance in its winter habitat and from anthropogenic changes to the thermal regime of the hibernacula. Protection of hibernacula includes conserving a buffer zone around each hibernacula and restoration of hibernacula if necessary.

Protection of hibernacula was and remains a primary focus of the recovery plan for this species (U.S. Fish and Wildlife Service 1983). To be considered protected, the hibernacula can be publicly or privately owned, but there must be a long-term voluntary landowner agreement, such as a stewardship plan, conservation easement, habitat management plan, or memorandum of agreement that protects the hibernacula in perpetuity. Protection of hibernacula includes assuring minimal disturbance to the bats during the season of hibernation (e.g., only authorized surveys or other conservation-related activities). While it is advisable to avoid disturbance between mid-August and mid-May, entry to hibernacula should be prohibited between September 1 to April 30 in most of the species' range, and September 1 to May 31 in the northern portion of the range (Connecticut, Massachusetts, Michigan, New York, and Vermont).

The protection of hibernacula also involves conserving a buffer zone around each hibernaculum to prevent adverse impacts to the physical structure or microclimate. In general, conservation of buffer zones ensures the elimination of the negative effects of disturbances such as land clearing or development. Specific management plans for each P1 hibernaculum will be developed (see Recovery Action 1.1.1.2.2 and 1.1.1.2.3) that include recommendations on size and management actions for a buffer zone.

Reclassification Criterion 2: A minimum overall population estimate equal to the 2005 population estimate of 457,000.

Because of lack of information on the species' demographic parameters, it is not possible to calculate a minimum viable population number for this species or to justify biologically an overall numerical population goal. Furthermore, a low population number was not one of the reasons that the bat was originally listed as endangered; the species was listed because of vulnerability to human and environmental disturbance and subsequent large-scale declines (Barbour and Davis 1969; Mohr 1972; Greenhall 1973; L. Pruitt, pers. comm., 2006). Species experts consider the 2005 population estimate of 457,374 to be an adequate number for recovery as long as the threats to the species have been alleviated, the population growth rate has been positive, and there is a rangewide distribution that incorporates the need for redundancy, resiliency, and representation.

Pilot Knob Mine is a P1A hibernaculum in Missouri that can no longer be safely entered to conduct a traditional winter bat survey. Therefore, Clawson (2002) relied on capture rates of Indiana bats at the mine entrance in 2001 and rates from previous years to estimate the mine's bat population at 50,550 bats. Subsequently, this estimate has been used for Pilot Knob Mine in the 2003 and 2005 rangewide population estimates. Although we are currently unable to determine an accuracy level for the population estimates of Indiana bats hibernating within Pilot Knob Mine, we intend to include this mine's estimate as part of the 2005 rangewide population estimate used in Reclassification Criterion 2 and future rangewide population estimates. However, if improved survey techniques or future field tests (see Recovery Action 1.3.7) reveal that the 50,500 estimate for Pilot Knob Mine contained a large amount of error, then we will adjust this mine's previous estimates accordingly through time and reassess whether an adjustment is needed to the numerical goal of this criterion.

At the present time, hibernaculum counts comprise the only data that can be used as a basis for reclassification and delisting of the Indiana bat. Given the progress that has been made to date in securing hibernacula and in analyzing information needs for the species, and given the recent apparent trends in species numbers, reclassification on the basis of hibernaculum data represents an acknowledgement of progress made towards recovery.

Reclassification Criterion 3: Documentation using statistically reliable information that indicates important hibernacula within each Recovery Unit, on average, have positive annual population growth rates and minimal risk of population declines over the next 10-year period. Using population estimates from the most recent 10 years (i.e., five sequential biennial surveys), linear regression lines will be calculated for each of the most populous hibernacula and/or hibernaculum complexes (P1s and largest P2s) that collectively account for 80% or more of their respective Recovery Units' estimated total number of bats. Each hibernaculum's regression line and 90% confidence interval will be projected through the most recent five data points and extended into the next 10-year period as a means of estimating future potential population levels. For reclassification, the slope of each hibernaculum's regression line must be positive or neutral and the lower bound of the 90% confidence interval must not fall below the minimum threshold set at 90% of the hibernaculum's 2005 population estimate by the end of the predicted 10-year period (see Figure 15).

In other words, a 90% confidence interval for the regression extended forward 10 years will need to sit above 90% of a given hibernaculum's 2005 population estimate.

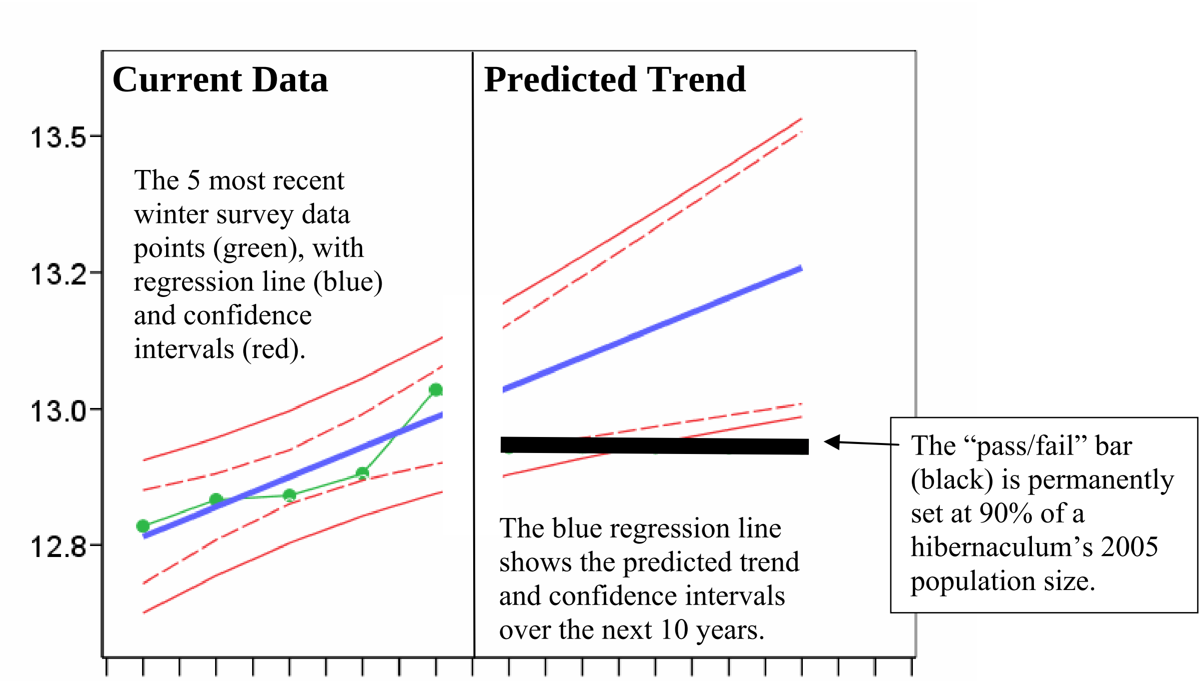


Figure 15. Example regression (blue line) and confidence intervals (red; 90% - broken lines, 95% solid lines) using a 10-year data set that would "pass" Reclassification Criterion 3. Note: The Y axis is population size in natural logarithms so that constant growth becomes a straight

line, instead of an exponential curve. The X axis is the year. The left side shows the 10-year data set that generates the regression line and confidence intervals. The right side is the continuation of the regression line and confidence intervals 10 years into the future, and compares the predicted trend (blue line) to the "pass/fail” bar, which is permanently set at 90% of a hibernaculum’s 2005 population size.

The data in Figure 15 would pass Reclassification Criterion 3 because the 90% confidence interval around the projected regression line rises above the bar by the end of the 10-year period. Therefore, we have a relatively high level of confidence that this example hibernaculum would continue to maintain a positive population growth rate and would not drop below the pass/fail bar over the next 10 years.

Meeting Reclassification Criterion 3 requires a positive population growth rate within each RU and allows only a small statistical possibility of a future population decline to a size that is at or below the 2005 population level. Criterion 3 complements Criterion 2, which requires the population to be larger (i.e., to be estimated to be larger) than the 2005 population estimate. Criterion 3 is a conservative extension of this requirement because it also requires that each hibernaculum’s predicted estimate of population size 10 years after downlisting be so far above its 2005 population estimate that a 90% confidence limit on the predicted estimate must also be greater than 90% of each hibernaculum’s 2005 population estimate.

The 80% requirement within Reclassification Criterion 3 allows some P1 hibernacula or hibernaculum complexes in the Midwest RU to have less strong trends. In the Northeast and Appalachian Mountain RUs, which have few P1 hibernacula, the 80% requirement will require that all of their Priority 1 hibernacula meet the trend requirement, because even one hibernaculum with a lower trend will drop the proportion in the region below the 80% mark. For the Ozark-Central RU to meet this criterion with a reasonable confidence level, the estimated number of bats hibernating in Pilot Knob Mine will need to be confirmed as previously discussed. Because Pilot Knob Mine is assumed to account for the majority of hibernating bats in the Ozark-Central RU, an inability to accurately estimate numbers there could be an obstacle to future downlisting. Again, we propose that Pilot Knob Mine’s estimated population remain in future regional and rangewide population estimates and count towards meeting the recovery criteria unless improved survey techniques and/or field tests for improved accuracy indicate otherwise.

In 2005, approximately 80% of each RUs bats overwintered in a combined total of 12 hibernacula and hibernaculum complexes that would each need to pass Reclassification Criterion 3. The current list of hibernacula needing to pass this criterion includes:

- Ozark-Central RU – Pilot Knob Mine (MO), Magazine Mine (IL), and Great Scott Cave (MO)
- Midwest – Wyandotte Complex (IN; includes Bat Wing, Jug Hole, Twin Domes, and Wyandotte caves), Ray’s Cave (IN), Coon-Grotto Complex (IN) and Bat Cave (Carter Co., KY)
- Appalachian Mountain – Hellhole Cave (WV) and White Oak Blowhole Cave (TN)
- Northeast – Ulster County Complex (NY; includes Walter Williams Preserve Mine and Williams Hotel Mine), Barton Hill Mine (NY), and Jamesville Quarry Cave (NY).

Based on the five most recent winter survey data points (1997, 1999, 2001, 2003, and 2005), five out of these 12 hibernacula/complexes currently would pass this criterion and several others are likely to pass it over the next one or two survey periods, provided that their population numbers continue to increase.

The use of linear regression to assess population trends is often discouraged quite correctly on the grounds that series of population estimates are not independent data points–next year's population size is limited in how different it can be from this year's population size. The property, called temporal autocorrelation, is likely to be stronger the closer in time that data points occur. Tests on data from the P1 hibernacula show very low temporal autocorrelation, reducing anxiety about use of linear regression. Low temporal autocorrelation is likely due, at least in part, to two main factors. The data are at two-year intervals rather than at yearly intervals. And in the present data, variability in counts from year to year is made up both of true population variability and estimation variability.

As estimation variability decreases due to changes in methodology, temporal autocorrelation of the data should be tracked. But it is likely that as survey methodology changes, more sophisticated statistical techniques will also become available, and the issue may become moot.

As measures of certainty become available for the individual hibernacula estimates, it will be desirable to investigate the use of components of variance analyses that permit variation in estimates to be partitioned into variation resulting from sampling methods (which is unavoidable, even with photography) and variation resulting from changes in population size.

As mentioned above, Reclassification Criterion 3 allows a small possibility of modest population decline over the predicted 10-year period. As Schwartz et al. (2006) point out in their discussion of grizzly bear recovery, once populations reach carrying capacity they are relatively stable (i.e., slope of regression lines ≈ 0), and out of necessity have confidence intervals about their trend lines that are fully 50% in negative numbers. The only way for a population to continue to fulfill Criterion 3 is either for it to continue to grow indefinitely, or for confidence intervals around its trend line to be quite small. It is possible or likely that neither of these requirements will be achievable continuously for all necessary hibernacula. Therefore, if rangewide recovery of the bat is prolonged and some hibernacula had fully met Criterion 3 at some point during their "recovery phase" and then subsequently stabilized near their 2005 population level, then the Service may still consider those populations as having passed this criterion.

We do not currently know what "normal" fluctuations in population size might be for the various RUs, and such fluctuations may well vary among RUs. Thus, writing strict requirements for delisting is inappropriate at this time. In addition, as discussed earlier, delisting requirements based exclusively on hibernaculum survey data are also inappropriate. Given that trend information, even high-quality trend information, becomes less, rather than more positive as a species reaches carrying capacity, multiple lines of evidence are the best insurance against overly optimistic delisting decisions. We provide here an initial delisting requirement, and add adaptive requirements for continuously improving the delisting requirement as data become available.

Delisting Criteria

The Indiana bat will be considered for delisting when the Reclassification Criteria have been met, and the following additional criteria have been achieved.

Delisting Criterion 1: Protection of a minimum of 50 percent of Priority 2 hibernacula in each Recovery Unit.

Greater than 14 percent of the Indiana bat population hibernates in the Priority 2 hibernacula. By achieving this criterion, a significant proportion (but not necessarily 14%) of Indiana bats rangewide will be protected from disturbance in winter habitat and from anthropogenic changes to the thermal regime of hibernacula. Protection of hibernacula includes conserving a buffer zone around each hibernacula and restoration of hibernacula if necessary.

See Reclassification Criterion 1 for further detail and justification.

Delisting Criterion 2: A minimum overall population estimate equal to the 2005 population estimate of 457,000.

See Reclassification Criterion 2 for justification.

Delisting Criterion 3: Documentation using statistically reliable information that shows a positive population growth rate over an additional five sequential survey periods (i.e., 10 years). The protocol will attempt to include methods for estimating variances in counts, ideally allowing partitioning of variance into components based on population growth processes and on sampling variance. Each Priority 1A hibernaculum will be analyzed independently for trends in growth, with the exception of hibernacula that act as a composite unit (e.g., Wyandotte, Twin Domes, Batwing), in which case all hibernacula within the composite unit will be analyzed collectively. Documented increases at 80% of hibernacula are needed for reclassification. An increase will be measured using linear regression through the data points; a slope greater than 1.0 will be considered an increase. If improvement in the precision of hibernacula sampling techniques falls short of that desired, we will attempt to determine the population growth rate based on concordance of estimates from two data sets developed independently. The second data set, proposed to be developed from implementation of the recovery actions related to population demographic research, will result in a demographically based life-history model for population growth rate. The model will be derived from reproduction data and survival rate estimates based on individual animal capture-recapture histories in the field.

See Reclassification Criterion 3 for further detail and justification.

Recovery Action Outline

1 Hibernacula-related recovery actions.

1.1 Conserve and manage hibernacula and their winter populations.

1.1.1 Reduce current threats at known hibernacula.

1.1.1.1 Assess current threats and conservation measures at all P1 and P2 hibernacula and develop a prioritized list of hibernacula in need of remedial actions.

1.1.1.2 Develop site-specific Hibernacula Management Plans (HMPs) for important hibernacula.

1.1.1.2.1 Develop guidance and template for how to complete an HMP.

1.1.1.2.2 Develop HMPs for all P1A hibernacula (n=16).

1.1.1.2.3 Develop HMPs for all P1B hibernacula (n=7).

1.1.1.2.4 Develop HMPs for at least 50% of P2 hibernacula (n=50% of 53=27).

1.1.1.2.5 Develop HMPs for P3 or P4 hibernacula as warranted.

1.1.1.2.6 Implement HMPs and associated remedial measures at all publicly owned P1 hibernacula (n=15).

1.1.1.2.7 Implement HMPs and associated remedial measures at all privately owned P1 hibernacula (n=8) where landowner cooperation is obtained.

1.1.1.2.8 Implement HMPs and associated remedial measures at publicly owned P2 hibernacula (n=18) that are recognized as a high priority for alleviating disturbance.

1.1.1.2.9 Implement HMPs and associated remedial measures at privately owned P2 hibernacula (n=34) that are recognized as a high priority for alleviating disturbance and where landowner cooperation is obtained.

1.1.1.2.10 Implement HMPs and associated remedial measures at P3 and P4 hibernacula, as warranted.

1.1.1.3 Investigate and pursue conservation and management at Rocky Hollow Cave, Virginia, as warranted.

1.1.1.4 Collate existing or develop new technical guidance for installing bat-friendly gates and other human barriers and deterrents (e.g., signs and alarm systems), including a pre- and post-gating monitoring protocol.

1.1.1.5 Develop rangewide protocols for assessing general suitability of potential hibernacula and for conducting presence/probable absence surveys at potential hibernacula (e.g., pre-closure surveys of abandoned mines).

1.1.1.6 Minimize human disturbance of hibernating bats related to survey and research activities.

1.1.1.6.1 Refine winter bat survey protocols to ensure that disturbance associated with surveys is minimized (see Recovery Action 3.1.2.3).

1.1.1.6.2 Evaluate and standardize all research conducted at hibernacula during the hibernation period through enhancement of survival permits under section 10(a)(1)(A) of the ESA and Section 6 authorities granted to states.

1.1.1.7 Provide guidance to local management authorities on procedures for alleviating human disturbance at hibernacula within their jurisdictions.

1.1.1.8 Coordinate with Federal, state, and local law enforcement authorities and jointly develop procedures to conserve hibernacula deemed at risk.

1.1.2 Reduce the threat of natural disturbances and mortality events at hibernacula identified as ecological traps.

1.1.2.1 Develop evaluation procedures and criteria that will be used to designate hibernacula as Ecological Traps (ET).

1.1.2.2 Conduct an ecological benefit/risk analysis to determine the advisability of excluding Indiana bats from hibernacula identified as being ecological traps (n=3) in order to promote recovery.

1.1.2.3 Design and implement site-specific actions to exclude bats from Ecological Traps where feasible and deemed beneficial to recovery.

1.1.3 Reduce threats by purchasing from willing sellers or leasing at-risk privately owned P1 and P2 hibernacula to assure long-term protection.

1.1.3.1 Assess needs and develop a prioritized list of privately owned P1 (n=8) and P2 (n=34) hibernacula that indicates whether acquisition of the cave or mine entrance and adjacent areas from willing sellers is a high priority goal or whether the development of management agreements should be pursued.

1.1.3.2 Purchase from willing sellers or implement long-term agreements at high-priority hibernacula, using information obtained from 1.1.3.1.

1.1.4 Conserve and manage areas surrounding hibernacula.

1.1.4.1 Characterize land use and land-use trends surrounding all P1 and P2 hibernacula via a GIS-based analysis.

1.1.4.2 Identify and prioritize P1 and P2 hibernacula with inadequately managed surroundings and buffers.

1.1.4.3 Work with partners to complete high-priority remedial actions designed to conserve and manage high-priority hibernacula identified on the list developed in 1.1.4.2.

1.1.4.4 Purchase from willing sellers or lease privately owned lands surrounding P1 and P2 hibernacula identified as having inadequate buffers.

1.1.4.4.1 Purchase from willing sellers or conserve through long-term agreements areas surrounding high-priority P1 hibernacula identified on the list developed in 1.1.4.2.

1.1.4.4.2 Purchase from willing sellers or conserve and manage through long-term agreements important areas surrounding high-priority P2 hibernacula identified on the list developed in 1.1.4.2.

1.1.4.5 Coordinate with private landowners and encourage voluntary enrollment into conservation incentive programs.

1.1.4.6 Develop and distribute outreach materials containing Best Management Practices (BMPs) for hibernacula owners or managers and adjacent landowners.

1.1.5 Pursue Habitat Conservation Plans (HCPs) at or near private or state-owned hibernacula where unauthorized take is occurring or anticipated.

1.1.6 Pursue Safe Harbor Agreements (SHAs) at private or state-owned hibernacula if beneficial to the species and owners.

1.2 Restoration and creation of hibernacula.

1.2.1 Research and develop cave and mine restoration guidance.

1.2.2 Identify, assess, and prioritize hibernacula that warrant restoration actions in each Recovery Unit.

1.2.3 Develop site-specific restoration plans for the highest priority sites identified in 1.2.2 and implement restoration work.

1.2.4 Investigate and pursue additional restoration work at Mammoth Cave, Kentucky.

1.2.5 Identify and assess the potential of abandoned mines to serve as hibernacula and develop a prioritized list.

1.2.6 Investigate and pursue enhancement of microclimate at Lewisburg Limestone Mine, Ohio.

1.3 Monitor winter populations of Indiana bats.

1.3.1 Survey winter populations of Indiana bats at known hibernacula

1.3.1.1 Survey extant populations in all P1 (n=23) and P2 hibernacula (n=53) every two years.

1.3.1.2 Survey extant and uncertain populations in P3 (n=135) and P4 (n=167) hibernacula approximately every four years or as funding allows.

1.3.1.3 Survey historically occupied hibernacula, as warranted.

1.3.2 Search for new winter populations and historically important Indiana bat winter roost sites.

1.3.3 Cooperate with BCI's Appalachian Saltpeter Caves Project to identify historically important hibernacula.

1.3.4 Research, develop, and field test alternative methods of surveying Pilot Knob Mine in Missouri.

1.3.5 Calculate and report rangewide population estimate based upon biennial winter surveys.

1.3.6 Annually review and reassign hibernacula priority numbers based upon winter survey results.

1.3.7 Update Indiana bat range maps with generalized hibernacula locations and priority numbers every two years.

1.4 Manage hibernacula-related information.

1.4.1 Establish a comprehensive Indiana bat hibernacula database.

1.4.2 Maintain the Indiana bat hibernacula database.

1.4.3 Coordinate with partners and develop a hibernacula data-sharing policy.

2.0 Conserve and manage summer habitat to maximize survival and fecundity.

2.1 Manage habitat on private lands.

2.1.1 Develop Indiana bat habitat restoration and maintenance guidelines.

2.1.1.1 Ozark-Central Recovery Unit.

2.1.1.2 Midwest Recovery Unit.

2.1.1.3 Appalachian Mountain Recovery Unit.

2.1.1.4 Northeast Recovery Unit.

2.1.2 As necessary, develop agreements with landowners to conserve and manage maternity colonies and summer habitat on private lands.

2.1.3 Encourage activities that enhance or improve summer habitat on private lands.

2.2 Conserve and manage Indiana bats and their habitat on Federal lands.

2.2.1 Develop guidelines for Indiana bat habitat management to be used on Federally owned lands throughout the species range.

2.2.1.1 Ozark-Central Recovery Unit.

2.2.1.2 Midwest Recovery Unit.

2.2.1.3 Appalachian Mountain Recovery Unit.

2.2.1.4 Northeast Recovery Unit.

2.2.2 Develop conservation programs on Federal lands for the recovery of Indiana bats pursuant to sections 2(c)(1) and 7(a)(1) of the ESA.

2.3 Conserve and manage Indiana bats and their habitat on state, county, and municipal lands.

2.3.1 Ozark-Central Recovery Unit

2.3.2 Midwest Recovery Unit.

2.3.3 Appalachian Mountain Recovery Unit.

2.3.4 Northeast Recovery Unit.

2.4 Monitor and manage known maternity colonies.

2.4.1 Estimate numbers, survivorship, and demographic characteristics.

2.4.2 Identify and conserve foraging habitat, water sources, and travel corridors.

2.4.3 Identify and manage, as practicable, threats, constraints, and limiting factors.

2.5 **Develop guidelines for protection of Indiana bats from pesticide or other chemical exposure.**

2.6 **Minimize adverse impacts to the Indiana bat and its habitat during review of Federal, state, county, municipal, and private activities under the ESA, National Environmental Policy Act, Fish and Wildlife Coordination Act, and Section 404 of the Clean Water Act.**

2.6.1 **Section 7 (a)(2) for Federal responsibilities.**

2.6.2 **Section 10(a)(1) for scientific permits and incidental take statements.**

2.7 **Refine and develop standardized monitoring protocols.**

2.7.1 **Refine mist netting protocols.**

2.7.2 **Developed standardized protocols for:**

2.7.2.1 **Conducting telemetry on Indiana bats.**

2.7.2.2 **Conducting exit counts on Indiana bats.**

2.7.2.3 **Collection of summer habitat information.**

2.7.2.4 **Banding and reporting band recoveries.**

2.7.2.5 **Artificial roosts (and monitoring of artificial roosts) for Indiana bats.**

2.7.2.6 **Use of bat detection systems to survey for Indiana bats.**

3.0 **Plan and conduct research essential for the recovery of Indiana bats.**

3.1 **Conduct research on the population biology of Indiana bats.**

3.1.1 **Convene a working group of research scientists to guide future research on the population biology of Indiana bats.**

3.1.2 **Improve methods for estimating and monitoring Indiana bat colony sizes at hibernacula.**

3.1.2.1 **Develop new standardized winter bat survey techniques.**

3.1.2.2 **Field test new winter bat survey techniques during biennial survey of P1 and P2 hibernacula in winter 2006-2007**.

3.1.2.3 Revise the winter bat survey protocol to include newly developed survey techniques.

3.1.3 Investigate marking methods for application in estimating survival rates.

3.1.4 Design long-term protocols for sampling and analysis for adult survival rate estimation.

3.1.5 Determine reproductive traits of female Indiana bats and their variability, and assess early survival of young.

3.1.6 Develop models of Indiana bat population dynamics as tools to assess progress towards recovery in different geographic areas, to determine sensitivities of various life history attributes contributing to population growth rates, and to evaluate the impact of catastrophic losses at key hibernacula on time to recovery.

3.1.7 Establish and maintain a central location for records of marked individual bats from life history and ecology studies of the Indiana bat.

3.2 Conduct research on the physiological and ecological requirements of Indiana bats in relation to hibernation, and characterize the most important features of key hibernacula.

3.2.1 Conduct laboratory studies to determine metabolic rates, water balance, and thermal requirements of Indiana bats during hibernation, including determination of optimal conditions for minimizing energy expenditure.

3.2.2 Characterize and monitor temperature, humidity, and air flow conditions in all Priority 1 hibernacula, and in selected Priority 2 and Priority 3 hibernacula using a standard methodology. Determine aspects of hibernation behavior of bats at a subset of these sites.

3.2.2.1 Develop standard methods for characterizing and monitoring temperature, humidity, and airflow in hibernacula, and design a sampling strategy for Priority 1 hibernacula and for selected Priority 2 and Priority 3 hibernacula based on geographic factors, winter population trends, and potential for modification and management.

3.2.2.2 Characterize and monitor temperature, humidity, and airflow in Priority 1 and selected Priority 2 and Priority 3 hibernacula.

3.2.2.3 Select sites for remote monitoring of Indiana bats to determine arousal frequencies, duration, clustering, and other aspects of hibernation behavior. Implement remote monitoring in at least three hibernacula based on geographic location, population status, potential for modification and management, and findings regarding internal conditions in 3.2.2.2.

3.2.3 **Model the potential impact of climate change, alterations to physical structure, and surrounding habitat modifications on projected use of hibernacula by Indiana bats.**

3.2.4 **Predict and monitor responses of Indiana bats to efforts to restore or create appropriate conditions for hibernation.**

3.3 **Conduct research on the summer habitat requirements and distribution of Indiana bats.**

3.3.1 **Investigate the feasibility of developing sampling designs that can utilize site-occupancy models to assess long-term changes in use of summer habitat by reproductively active female Indiana bats, and to determine important habitat variables associated with occupancy of areas throughout the species distribution in summer.**

3.3.2 **Assess habitat requirements for maternity colonies over multiple years at multiple locations across the range of the species.**

3.3.3 **Determine the amount of spatial overlap among maternity colonies, and variability in colony densities and distributions across the landscape over time for a range of habitat types.**

3.3.4 **Define the range of variability in characteristics of maternity colonies across broad segments of the species distribution.**

3.3.5 **Develop means to estimate persistence of maternity colonies.**

3.3.6 **Assess diet and foraging requirements for reproductive females and young at multiple locations across the range.**

3.3.7 **Improve understanding of the importance of autumn swarming.**

3.3.8 **Maintain, update, and periodically synthesize the geographic records of occurrence of reproductive female and juvenile Indiana bats.**

3.3.9 **Determine land management practices that will increase or maintain suitability of habitat for maternity colonies of Indiana bats, and the impacts of habitat perturbations on persistence of maternity colonies.**

3.3.10 **Estimate the amount of suitable habitat occupied in the summer distribution.**

3.4 **Conduct research on the potential impacts of environmental contaminants on Indiana bats.**

3.4.1 **Assess exposure of Indiana bats to environmental contaminants through analysis of carcasses, guano, and other biological samples.**

3.4.2 **Assess geographic patterns in use of chemicals of concern in areas of importance to Indiana bats, including assessment of contamination of prey**.

3.4.3 **Determine sensitivity of bats to exposure to contaminants of concern in controlled laboratory experiments on captive colonies.**

3.5 **Conduct other biological research of potential importance to Indiana bat recovery.**

3.5.1 **Determine the prevalence and potential impacts of disease in Indiana bats.**

3.5.2 **Determine genetic structuring within maternity colonies across the summer distribution.**

3.5.3 **Conduct additional studies of Indiana bat population genetics based on sampling at hibernacula.**

3.6 **Develop a post-delisting monitoring plan.**

4 **Develop and implement a public information and outreach program.**

4.1 **Develop and implement outreach activities to enhance specific recovery tasks for the Indiana bat, including development of guidelines, best management practices, land acquisition/easements efforts, landowner incentives programs, Endangered Species landowner programs, research activities, and Federal review activities. Employ appropriate communications goals and messages as outlined in comprehensive Indiana bat outreach plan.**

4.2 **Develop a comprehensive, ongoing outreach program to raise awareness of the Indiana bat among selected audiences.**

4.2.1 **Assemble an outreach planning and implementation team to conduct audience analysis, develop communications goals, develop needed products and coordinate implementation of recommended outreach strategies and actions.**

4.2.2 **Highlight the Indiana bat's association with unique environments–cave/karst–and their importance to the well-being of the human environment as well as for wildlife.**

4.2.3 **Seek opportunities to raise awareness of the Indiana bat's special characteristics; foster a sense of appreciation for the bat, its habitat, and the unique life history of bats in general.**

4.2.4 Organize, with partners, discussion opportunities (e.g., symposia, roundtables) with industry groups and/or transportation and energy agencies to provide information and to listen to concerns.

4.2.5 Use Service websites as a repository of information about the Indiana bat. This information should be organized so that it is easily located and accessible and specific to key audiences (i.e., educators, planners, industry representatives, consultants).

Recovery Action Narrative

1 Hibernacula-related recovery actions.

1.1 Conserve and manage hibernacula and their winter populations.

Conservation and management of important hibernacula across the Indiana bat's range is essential to the species' continued existence, recovery, and long-term conservation. Therefore, specific efforts need to be made to ensure all important hibernation sites are adequately conserved and to take steps to correct deficiencies on a case-by-case basis. In some cases, actions in this section may be dependent on the outcome of other actions (e.g., additional research may be needed).

1.1.1 Reduce current threats at known hibernacula.

1.1.1.1 Assess current threats and conservation measures at all P1 and P2 hibernacula and develop a prioritized list of hibernacula in need of remedial actions.

The Service has nearly completed data gathering for a preliminary threats assessment aimed at identifying the primary human and natural threats to all known P1 and P2 hibernacula as judged by species' experts that responded to the Service's June 2005 hibernacula data request. The data request was completed by knowledgeable biologists in each state within the Indiana bat's range. Additional coordination with local cave managers, researchers, and bat surveyors is needed to further document known and/or perceived human threats and natural threats (e.g., risk of collapse, flooding, freezing, predation) and to complete data gaps.

The Service will use responses to the previous data request and subsequent information to prioritize P1 and P2 hibernacula in need of urgent remedial actions according to their relative threat levels, current population numbers, and feasibility of implementing the needed actions (e.g., gates, fences, signs). High priority remedial actions will be taken as soon as possible and as funding and other resources allow. Trusted partners seeking to take proactive actions to further the bat's recovery will have access to the Service's prioritized "to-do list" of remedial actions and will be encouraged to contribute in whatever manner they can.

1.1.1.2 Develop site-specific Hibernacula Management Plans (HMPs) for important hibernacula.

Partnering Federal, state, and other government agencies and private organizations and individuals will coordinate with the Service to develop and implement site-specific, Indiana-bat friendly Hibernaculum Management Plans (HMP) at each important hibernaculum throughout the range. Our goal is to implement a Service-approved HMP at all P1 hibernacula (n=23) and at least 50% of P2 hibernacula (n=50% of 53=27) within the next 5 to 6 years. The priority for pursuing and completing HMPs will be largely based on the outcome of action 1.1.1.1, but crucial remedial actions will not be delayed while an HMP is being completed. For those publicly and privately owned hibernacula that already have some form of a written management plan in place, the level of effort needed to develop an HMP should be greatly reduced. Each HMP will recognize that not only do Indiana bats need protection from disturbances while they occupy hibernacula, but the physical structures themselves and the environmental conditions that provide favorable roosting microclimates for the bats need to be clearly identified and conserved, as well. Each management plan will also address the swarming needs of the hibernating population, and strive to provide for management of sufficient area surrounding a hibernaculum to meet those needs. All HMPs will include an educational outreach component and a monitoring program for gauging the success of implemented management activities. Managers should take an adaptive management approach that allows for changes to be made once the effectiveness of previously implemented measures can be discerned. In short, the goal of each HMP will be to ensure the integrity of a hibernaculum's unique system and to conserve and manage the Indiana bats that depend on it.

1.1.1.2.1 Develop guidance and template for how to complete an HMP.

The Service, along with species' experts and other partners, will develop technical guidance and an example HMP to serve as a template for the development of other HMPs as prescribed in 1.1.1.2. In addition to the template, the HMP guidance will include a checklist of items that should be considered and addressed when developing each HMP and will include best management practices (BMPs) for hibernacula and surrounding areas. Once completed, the guidance will be made available on the Indiana bat webpage on the Service's Region 3 website (www.fws.gov/midwest).

Traditional and new BMPs that are likely to appear in the forthcoming HMP guidance include:

- Preventing unauthorized entry by humans. Preventing unauthorized entry by humans is the best way to curtail disturbance at these sites. Because use of caves by Indiana bats is seasonal, conservation and management should focus on the season of hibernation. Disturbance between mid-August and mid-May should be avoided. Except for legitimate activities such as monitoring, entry to hibernacula should be prohibited at least from September 1-April 30 in most of the range/September 1-May 31 in the northern portion of the range (Connecticut, Massachusetts, Michigan, New York, and Vermont).

- Erecting warning signs. Signs may be used at caves to discourage entry. Signs should be used in conjunction with gates to inform the public. Signs should be placed inside cave entrances so that they do not attract potential violators to the cave, but should not block bat movements or airflow. The use of signs to help control access to privately owned caves should be coordinated with the landowners. Informative signs may elicit cooperation from uninformed people, especially if a time is identified when access is allowed. The wording of the sign should be similar to the following: "ATTENTION! DO NOT ENTER THIS CAVE BETWEEN SEPTEMBER 1 AND APRIL 30. The endangered Indiana bat hibernates in this cave and must survive the winter on stored fat. Any disturbance that causes the bats to arouse will deplete this limited fat supply and they could die. To enter when Indiana bats are present is a violation of Federal and state law(s), punishable by arrest, a fine of up to $50,000 for each violation, and possible imprisonment."

- Erecting barriers: gate or fence. Structures such as an angle-iron gate in an entrance or a fence around an entrance help prevent unauthorized human access. The structure must permit Indiana bats to pass without danger and must not alter airflow. Plans to gate or fence hibernacula must be reviewed by personnel from the Service and state agencies to ensure that gates are designed and constructed properly. Individuals contemplating construction of a gate should refer to plans and descriptions of proper gate designs and applications from the American Cave Conservation Association and others (Powers 1993, Tuttle and Taylor 1998, Currie 2002). Caves prone to flash flooding should be evaluated carefully before barriers are constructed, especially if bats roost in areas where they could be affected if water were impounded by a gate. Special care must be taken to prevent debris from accumulating against gates, which could block airflow or increase water levels during subsequent flood events.

Because Indiana bats hibernate exclusively in caves and mines, a substantial measure of protection is afforded the species if important hibernacula are managed to reduce human disturbance and adverse modification. To assure that these sites remain available to Indiana bats, all P1 hibernacula should be conserved and managed through gates, fences, and other means. P2 hibernacula should be conserved if populations have declined, if an appropriate management agency is capable of accepting responsibility for management of the site, and if the needed degree of conservation is feasible. Local management authorities should evaluate the need and opportunity for conserving P3 Indiana bat hibernacula within their jurisdictions.

- <u>Patrolling caves</u>. Educating and requesting appropriate law enforcement officers to regularly patrol entrances to hibernacula during the closed period will help conserve hibernating bats. Local authorities can best decide the level of effort needed to safeguard hibernacula, depending upon site-specific factors such as accessibility, past history of disturbance, strength of protective barrier, etc. "Speloggers" or other devices may aid monitoring or apprehension of violators by law enforcement personnel.

- <u>Deterring human access in vicinity of hibernacula</u>. In addition to gating/fencing and posting of signs at hibernacula, roads and trails leading to hibernacula may be blocked or obliterated to further discourage access. Decisions on closure should be made locally in consultation with the Service, the appropriate state agency, and the landowner/land manager, and should reflect site-specific considerations such as maintaining public access during the non-hibernation season, ensuring that trail closure does not create controversy between managers and resource users, and following wishes of landowners. Closing or patrolling traditional parking areas may also help reduce unauthorized visitation.

- <u>Working with private landowners</u>. Information and technical assistance should be provided to private landowners to help them conserve important Indiana bat hibernacula, including erection of protective barriers. Posting privately owned caves with informative signs that outline reasons for bat conservation and dates when entry is prohibited also would help safeguard bats.

- <u>Identifying and mapping cave passages and likely recharge areas of cave streams and other karst features that are hydrologically connected to a hibernaculum</u>. Clearly identifying, delineating, and conserving subterranean and surface features/areas that may directly or indirectly influence a hibernaculum's hydrology, microclimate, or structural integrity is crucial to the long-term conservation of important hibernacula. Hibernacula passages should be explored and mapped during the non-closure season so that all entrances are identified and managed appropriately. Detailed maps and aerial photos depicting cave passages, overlying topography, recharge areas, forests, streams/surface water, and extent of protective buffers should be included in each HMP.

- Ensuring compatible forest/timber management around hibernacula. Quality habitat around hibernacula is very important to roosting and foraging Indiana bats, particularly during the fall swarming period. To conserve Indiana bats and their hibernacula, adjacent and nearby forests typically need some special management to ensure that a continual supply of roost trees and foraging habitat are maintained and to avoid the potential for take occurring during timber harvests or prescribed burns. Quality forest stand conditions benefit the bats by providing a buffer from roads and developments, conserving water quality, and stabilizing soils that otherwise are prone to erosion and may plug sinkhole/cave entrances, which could subsequently affect microclimates within hibernacula.

- Soliciting cooperation of the organized caving community. Members of national, state, and local caving organizations (e.g., National Speological Society and its affiliated local grottos and state/regional cave/karst conservancies) frequently are conservation-minded and highly knowledgeable of past and current levels of recreational use at hibernacula in their area and know what previous conservation measures have worked or failed at a particular site. Newsletters, websites, and other internal communications within these groups let members know which caves are closed and when. When relations with the Service are good, it is often concerned cavers that are first to report seeing or hearing about "clusters" of bats in local caves that often leads to the discovery of new or repopulated Indiana bat hibernacula. When properly informed about the needs of bats, cave and karst organizations and their dedicated members often become strong advocates for cave closures and bat conservation.

1.1.1.2.2 Develop HMPs for all P1A hibernacula (n=16).

Highest priority will be assigned to developing HMPs at P1A hibernacula, because proper (or improper) management of these caves and mines will have the largest impact to the species' population and recovery.

1.1.1.2.3 Develop HMPs for all P1B hibernacula (n=7).

Because all seven P1B hibernacula are already gated, most (6 out of 7) are publicly owned (i.e., fewer threats), and all currently have relatively small winter populations, development of HMPs at these sites has a lower priority than at P1As and some P2s.

1.1.1.2.4 Develop HMPs for at least 50% of P2 hibernacula (n=50% of 53=27).

The Service will coordinate with its partners to set priorities for developing HMPs for P2 hibernacula within each Recovery Unit. Priorities will primarily reflect current population sizes and threat levels.

1.1.1.2.5 Develop HMPs for P3 or P4 hibernacula as warranted.

HMPs may be completed at some subset of P3 hibernacula that are deemed to have local or regional importance to the species; presumably most P4s will not merit completion of a formal HMP. Compliance with BMPs in the forthcoming HMP guidance is encouraged for all managers of Indiana bat hibernacula regardless of their priority number because they conserve other bat species as well.

1.1.1.2.6 Implement HMPs and associated remedial measures at all publicly owned P1 hibernacula (n=15).

Because managers of publicly owned properties often face different challenges than privately owned hibernacula, we have opted to split implementation of HMPs between publicly and privately owned hibernacula. See Appendix 2 for hibernacula names and ownership information.

1.1.1.2.7 Implement HMPs and associated remedial measures at all privately owned P1 hibernacula (n=8) where landowner cooperation is obtained.

See Appendix 2 for hibernacula names and ownership information.

1.1.1.2.8 Implement HMPs and associated remedial measures at publicly owned P2 hibernacula (n=18) that are recognized as a high priority for alleviating disturbance.

See Appendix 2 for hibernacula names and ownership information.

1.1.1.2.9 Implement HMPs and associated remedial measures at privately owned P2 hibernacula (n=34) that are recognized as a high priority for alleviating disturbance and where landowner cooperation is obtained.

See Appendix 2 for hibernacula names and ownership information.

1.1.1.2.10 Implement HMPs and associated remedial measures at P3 and P4 hibernacula as warranted.

See Appendix 2 for hibernacula names and ownership information.

1.1.1.3 Investigate and pursue conservation and management at Rocky Hollow Cave, Virginia, as warranted.

Rocky Hollow Cave in Virginia needs further investigation to determine whether conservation and management efforts are warranted (see Tuttle 1999).

1.1.1.4 Collate existing or develop new technical guidance for installing bat-friendly gates and other human barriers and deterrents (e.g., signs and alarm systems), including a pre- and post-gating monitoring protocol.

Some very good technical information regarding effective bat gate designs, construction, and related topics has become available over the past 30 years (Hunt and Stitt 1975, Tuttle 1977, Powers 1993, Tuttle and Taylor 1998, Currie 2002, Kurta and Kennedy 2002). For example, the proceedings from the bat gate design forum sponsored by the Department of Interior, Office of Surface Mining (OSM), U.S. Fish and Wildlife Service, and Bat Conservation International (BCI) in 2002 contains a wealth of information (Vories and Throgmorton 2002, http://www.mcrcc.osmre.gov). Even with this information, there still remains a need for both basic (i.e., novice level) and advanced, user-friendly, A-Z manuals designed to assist public land managers and private hibernacula owners who are contemplating the appropriate deterrent system for their particular circumstance, whether it be erecting a gate, a fence, signs, or using alternative measures, such as an alarm system. Guidance materials should also include appropriate wording and suggestions for posting signs at hibernacula, how to install alternative deterrents such as alarm systems, and techniques for monitoring human disturbance levels (see Johnson et al. 2002). Lastly, a standardized pre- and post-gating/deterrent monitoring protocol also needs to be developed to ensure that newly erected structures or other deterrents are not adversely affecting the bats' behavior or ability to freely ingress and egress (see Spanjer and Fenton 2005), are not changing air flow/microclimates, and are effectively deterring human disturbance.

1.1.1.5 Develop rangewide protocols for assessing general suitability of potential hibernacula and for conducting presence/probable absence surveys at potential hibernacula (e.g., pre-closure surveys of abandoned mines).

Federal agencies and various state agencies are required by Federal or state law (e.g., ESA Section 7) to assess whether any of their proposed actions or activities may affect Indiana bats or their habitat, including actions that may impact potential hibernacula (e.g., natural caves or abandoned mines/tunnels that have potential to shelter hibernating populations of bats). A standardized protocol will be developed for assessing and determining the general suitability of a potential Indiana bat hibernaculum based upon its known physical attributes (e.g., entrance size, length and configuration of passages, air flow) and known history. Secondly, a standardized protocol will be developed for conducting presence/probable absence surveys at hibernacula deemed to have at least some minimal level of suitability. This protocol would be analogous to the Indiana Bat Mist-Netting Guidelines (see Appendix 5) used to determine presence/probable absence of Indiana bats in summer habitat. The Service will also develop rangewide guidance on how to appropriately interpret survey results of potential hibernacula.

1.1.1.6 Minimize human disturbance of hibernating bats related to survey and research activities.

1.1.1.6.1 Refine winter bat survey protocols to ensure that disturbance associated with surveys is minimized (see Recovery Action 3.1.2.3).

As the winter bat survey protocol is being updated and revised to improve accuracy levels, an attempt will also be made to ensure that changes will not cause a net increase in disturbance, but rather will minimize the amount and duration of survey-related disturbances within hibernacula.

1.1.1.6.2 Evaluate and standardize all research conducted at hibernacula during the hibernation period through enhancement of survival permits under section 10(a)(1)(A) of the ESA and Section 6 authorities granted to states.

Only research that is essential to the survival or recovery of the species should be conducted within hibernacula during the hibernation period. To ensure that the Service provides consistent guidance on research-related disturbance (through enhancement of survival permits under section 10(a)(1)(A) of the ESA and Section 6 authorities granted to states), the Service will develop hibernacula research policies to be implemented across the range of the species.

1.1.1.7 Provide guidance to local management authorities on procedures for alleviating human disturbance at hibernacula within their jurisdictions.

Guidance developed in 1.1.1.4 will be distributed to pertinent local management authorities, who will be encouraged to implement techniques appropriate to the hibernacula that they oversee.

1.1.1.8 Coordinate with Federal, state, and local law enforcement authorities and jointly develop procedures to conserve hibernacula deemed at risk.

In situations where human disturbance has been identified as being a primary threat to particular hibernacula, appropriate law enforcement agencies will be coordinated with to develop a strategy and procedures for reducing threat levels.

1.1.2 Reduce the threat of natural disturbances and mortality events at hibernacula identified as Ecological Traps (ETs).

1.1.2.1 Develop evaluation procedures and criteria that will be used to designate hibernacula as ETs.

Three caves have preliminarily been designated as ETs based on the recommendations of Indiana bat experts familiar with these caves, and on the history of Indiana bat mortality in these caves. Formal procedures for evaluating potential ETs and criteria for designating caves as ETs are needed.

1.1.2.2 Conduct an ecological benefit/risk analysis to determine the advisability of excluding Indiana bats from hibernacula identified as being ETs (n=3) to promote recovery.

Because hibernacula designated as ETs likely pose a long-term threat to local and regional Indiana bat populations, hibernacula-specific studies are needed to determine whether it would be more beneficial to the Indiana bat's recovery to close a particular ET or to allow it to remain open. Any proposed closures would also have to balance benefits to Indiana bats against potential adverse impacts on other cave-dependent species, including other species of bats.

1.1.2.3 Design and implement site-specific actions to exclude bats from ETs where feasible and deemed beneficial to recovery.

If it is agreed that one or more ETs analyzed in action 1.1.2.2 warrant closure, then site-specific plans will be developed in coordination with states, species' experts, landowners/managers, and other partners. Closure of ETs would only be considered as a last resort for hibernacula that could not otherwise be restored to a low or non-threatening level.

1.1.3 Reduce threats by purchasing from willing sellers or leasing at-risk privately owned P1 and P2 hibernacula to assure long-term protection.

1.1.3.1 Assess needs and develop a prioritized list of privately owned P1 (n=8) and P2 (n=34) hibernacula that indicates whether acquisition of the cave or mine entrance and adjacent areas from willing sellers is a high priority goal or whether the development of management agreements should be pursued.

Currently, 8 P1 and 34 P2 hibernacula are privately owned. The owners and managers of some of these very important hibernacula have (1) failed or chosen not to control human access or reduce disturbance to hibernating bats, (2) failed to conserve the integrity of hibernacula entrances or physical structures themselves, and (3) failed to manage surrounding habitats in a bat-friendly manner. Highest priorities for potential acquisition of privately owned hibernacula will be assigned to those with the largest past or current bat populations and the highest relative level of threat stemming from ownership/mismanagement issues. Land/hibernacula acquisition would only be pursued from willing sellers.

1.1.3.2 Purchase from willing sellers or implement long-term agreements at high-priority hibernacula, using information obtained from 1.1.3.1.

Long-term conservation may be accomplished if access to hibernacula is ultimately controlled through fee acquisition, lease, conservation easement, cooperative agreement, or other arrangement, provided that management and enforcement personnel may legally take steps to eliminate disturbance to bats.

1.1.4 Conserve and manage areas surrounding hibernacula.

Hibernacula are highly vulnerable to changes made on the land's surface, especially areas that drain into them. Some caves have secondary entrances far removed from the main entrances, which must remain open to allow the crucial chimney-effect airflow to occur. Activities such as road construction, urban development, surface mining/remining, logging, and other activities that convert forests to other land uses, may cause increased storm-water runoff and siltation to enter a cave and increase the likelihood of flooding, or otherwise adversely change temperature and humidity regimes. Conservation and management of surface areas above hibernacula is also warranted where there is a potential risk of contaminants flowing into or being accidentally spilled into them (e.g., chemical runoff from agricultural fields). Further, forested buffer areas surrounding known hibernacula should be established. Current understanding of the species' biology may warrant buffers as large as 0.4 km (0.25 mi) in diameter. However, boundaries of forested buffer zones ideally should be custom designed to conform to the unique topography and natural features surrounding each hibernaculum rather than drawn as a generic circle. The goal of these buffer areas is to conserve the integrity of the entrance and hibernacula.

1.1.4.1 Characterize land use and land-use trends surrounding all P1 and P2 hibernacula via a GIS-based analysis.

Before potential land-use threats to Indiana bat hibernacula can be clearly identified or addressed, GIS-based analyses are needed to establish existing baseline conditions and to allow changes in surrounding land use to be more easily tracked over time. In 2006, the DOD, namely the U.S. Army Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL), initiated a rangewide, GIS-based land-use and -cover change (LUCC) analysis to determine the extent to which P1 and P2 hibernacula currently may be threatened by urbanization or other LUCC and to model potential future threats. ERDC-CERL anticipates publishing their findings in a peer-reviewed journal.

1.1.4.2 Identify and prioritize P1 and P2 hibernacula with inadequately managed surroundings and buffers.

A rangewide prioritized list of P1 and P2 hibernacula needing additional conservation and management within their surrounding buffers will be developed. A recommended remedial measure(s) will be developed for each hibernaculum on the list. Priorities will be largely based on the findings of actions 1.1.1.1 and 1.1.4.1 above and will be assigned on a rangewide basis and by a Recovery Unit basis. Needed remedial measures will also be identified and addressed in appropriate HMPs. This list will be reviewed and updated as needed on an annual basis.

1.1.4.3 Work with partners to complete high-priority remedial actions designed to conserve and manage high-priority hibernacula identified on the list developed in 1.1.4.2.

The Service will collaborate with partners with the goal of completing at least one or more high-priority remedial actions at one or more P1 or P2 hibernacula within each Recovery Unit.

1.1.4.4 Purchase from willing sellers or lease privately owned lands surrounding P1 and P2 hibernacula identified as having inadequate buffers.

1.1.4.4.1 Purchase from willing sellers or conserve through long-term agreements area surrounding high-priority P1 hibernacula identified on the list developed in 1.1.4.2.

The Service will collaborate with partners with the goal of purchasing, leasing, or otherwise conserving lands surrounding one or more of the highest-priority P1 hibernacula identified on the prioritized list in 1.1.4.2.

1.1.4.4.2 Purchase from willing sellers or conserve and manage through long-term agreements important areas surrounding high-priority P2 hibernacula identified on the list developed in 1.1.4.2.

The Service will collaborate with partners with the goal of purchasing (either fee simple or conservation easement), leasing, or otherwise conserving important lands surrounding one or more of the highest-priority P2 hibernacula identified on the prioritized list in 1.1.4.2.

1.1.4.5 Coordinate with private landowners and encourage voluntary enrollment into conservation incentive programs.

Private owners of high-quality, adjacent forested parcels will be encouraged to voluntarily enroll their land into incentive programs that would promote conservation of Indiana bat habitat and sustainable land-use practices. Potential programs may include state-sponsored classified forest and wildlife programs, the U.S. Forest Service's Forest Legacy Program, and others.

1.1.4.6 Develop and distribute outreach materials containing BMPs for hibernacula owners and managers and adjacent landowners.

Although many hibernacula currently are managed in a bat-friendly manner, others are not. This may be partly due to a lack of appropriate educational outreach materials. Therefore, a standard set of BMPs needs to be developed and made readily available to both public land managers and private owners of hibernacula and surrounding lands. BMPs will ideally address means of controlling human access to hibernacula, sink-hole management, stream management, erosion control, timber management, use of prescribed fire, pesticide and herbicide usage, invasive species control, trash dumping, etc... The BMPs may be distributed as a brochure or handbook and, once completed, will be made available on the Service's Region 3 website (www.fws.gov/midwest).

1.1.5 Pursue Habitat Conservation Plans (HCPs) at or near private or state-owned hibernacula where unauthorized take is occurring or anticipated.

Private landowners, corporations, state or local governments, or other non-Federal landowners who wish to conduct activities on their land that might incidentally harm (or "take" as defined by the Endangered Species Act) Indiana bats (or other Federally listed species) must first obtain an incidental take permit from the Service. To obtain a permit, the applicant works with their local Service office to develop an HCP designed to offset any harmful effects the proposed activity might have on the species. The HCP process is mutually beneficial in that it allows activities or developments to legally proceed while promoting listed species conservation. Landowners can contact their local Service office to determine whether a contemplated activity is likely to require an incidental take permit. If incidental harm is likely, the Service office can assist the landowner with the HCP application process. Frequently asked questions and an HCP handbook containing more details can be found at the Service's national website (www.fws.gov/endangered/hcp/).

1.1.6 Pursue Safe Harbor Agreements (SHAs) at private or state-owned hibernacula if beneficial to the species and owners.

Because many important Indiana bat hibernacula occur on privately owned property, we believe it is critical to involve private landowners in the species' conservation and recovery. Many property owners, however, are concerned about land use restrictions that may occur if listed species colonize their property or increase in numbers as a result of bat-friendly management practices. Thus, they may avoid or limit management practices that could enhance, maintain, or create new habitat.

To assist in such situations, the Service may encourage private or state property owners to pursue an SHA, which is a voluntary arrangement between the Service and cooperating non-Federal landowners. The SHA policy's main purpose is to promote voluntary management for listed species on non-Federal property while giving assurances to participating landowners that no additional future regulatory restrictions will be imposed. Before entering into an SHA, the Service must agree that, in this case, the Indiana bat will receive a "net conservation benefit" from the agreement's management actions. Following development of an agreement, the Service will issue an "enhancement of survival" permit, to authorize any necessary future incidental take. Participating landowners will be provided with assurances that, when the agreement's term ends, they may use the property in any otherwise legal manner that does not move it below baseline conditions determined in the agreement. Net conservation benefits must contribute, directly or indirectly, to the recovery of the covered species. Additional details are available at the Service's national website (www.fws.gov/endangered/landowner/index.html).

1.2 Restoration and creation of hibernacula.

Restoration of currently or historically important hibernacula is sometimes warranted, particularly where previous modifications have led to suboptimal microclimates and severely reduced populations of hibernating Indiana bats. Conversely, some hibernacula that still have appropriate microclimates have apparently been abandoned or have severely reduced populations because of high human disturbance levels. In such cases, eliminating the human disturbance would likely facilitate recolonization of these sites over time without the need for any physical modifications. Hibernacula with poorly designed gates that are impeding airflow at otherwise suitable sites should be removed or replaced with appropriate structures to restore the sites' microclimate. Hibernacula that have been modified to the extent that they no longer support Indiana bat hibernation, or support much reduced populations, should have the highest priority for restoration.

Because many Indiana bat hibernacula have multiple entrances that are important in regulating a hibernaculum's winter microclimate, all entrances should be assessed and periodically monitored for changes. Whether natural or the result of human activity, changes at entrances (or changes within hibernacula passages) that alter airflow amounts or patterns can adversely affect hibernating bats. Preventing such changes or acting quickly when they do occur will help ensure the bat's recovery. Entrance stabilization projects have successfully protected Indiana bats using the Magazine Mine in southern Illinois (Kath 2002) and at an important little brown bat hibernaculum in a Wisconsin mine (Tuttle 1996). Stabilization of Missouri's Pilot Knob Mine and other sites should be investigated and pursued where warranted.

Lastly, the potential for purposefully creating new hibernacula by producing favorable microclimates within abandoned mines or other structures merits further consideration. If feasible, creation of hibernacula may be justified in areas where natural hibernacula are limited in number, have been degraded or destroyed, or cannot otherwise be protected from threats. Because most mines within the range of the Indiana bat were designed and engineered for short-term resource extraction (e.g., coal, silica, gypsum, iron) and not long-term stability, extreme caution and forethought must be used before intentionally attracting bats to any collapse-prone structures.

1.2.1 Research and develop cave and mine restoration guidance.

In March 2005, Service biologists and other bat experts participated in an Indiana Bat Risk Assessment Workshop and agreed that conservation and restoration of Indiana bat hibernacula with ideal temperatures should be a top priority Recovery Action to prevent extinction or irreversible population declines (USFWS 2006). While the concept of cave restoration as a recovery tool is generally accepted, its appropriateness and application at currently occupied hibernacula has been the subject of debate in recent years. Some biologists believe that this field of study holds great promise towards recovering the Indiana bat while others remain skeptical or uncertain, or believe its risks outweigh the potential benefits, particularly at hibernacula that already contain large winter populations. Clearly, additional research on the optimal hibernating conditions/microclimate for Indiana bats will improve our understanding and help managers decide if and under what circumstances that cave microclimate restoration efforts are appropriate. Some restoration efforts have already been successfully initiated at Indiana bat hibernacula (e.g., BCI's efforts at Saltpeter Cave, KY), and other opportunities are being investigated. As this recovery tool evolves, there is a growing need for standardized guidance to be developed. Initial guidance may be in the form of a technical handbook for land managers that includes an overview of current restoration techniques, a bibliography, and contact information for organizations and individuals with technical expertise in cave restoration (e.g., cave climatologists, bat experts). Once developed, guidance would be made available at the Service's Region 3 website (www.fws.gov/midwest).

1.2.2 Identify, assess, and prioritize hibernacula that warrant restoration actions in each Recovery Unit.

This task will be completed by the Service, regional bat experts, and other partners within each Recovery Unit. Highest priorities will be assigned to hibernacula having the greatest needs and those having the greatest potential for successful restoration and recolonization or population increase.

1.2.3 Develop site-specific restoration plans for the highest priority sites identified in 1.2.2 and implement restoration work.

Where warranted, restoration plans will be developed and tailored to the specific needs of each hibernaculum. All restoration plans will have a strong monitoring component and use an adaptive management approach as restoration proceeds. When possible, restoration plans will be jointly developed and integrated with remedial actions outlined in the HMPs described in 1.1.1.2.

1.2.4 Investigate and pursue additional restoration work at Mammoth Cave, Kentucky.

Mammoth Cave, in what is today Mammoth Cave National Park in Edmonson County, Kentucky, was once a major hibernaculum for Indiana bats and other bat species (Tuttle 1997, Toomey et al. 2002), but it has not contained a viable winter population of Indiana bats since the species was first described in 1928 (Miller and Allen 1928; U.S. Fish and Wildlife Service, unpublished data, 2006). Ecologists at Mammoth Cave have undertaken efforts to restore the ecotone and microclimate conditions in the cave's Historic Entrance area and are investigating additional restoration opportunities in areas that historic and paleontological evidence suggest were important Indiana bat hibernation sites (e.g., Vespertilio Hall; Olson 1996, Toomey et al. 2002).

1.2.5 Identify and assess the potential of abandoned mines to serve as hibernacula and develop a prioritized list.

In the past 10 to 15 years, some of the largest discoveries of previously unknown hibernating populations of Indiana bats have occurred in abandoned mines (e.g., Magazine Mine, IL, and Lewisburg Limestone Mine, OH; USFWS, unpublished data, 2006). The status and whereabouts of many abandoned mines are often unknown by Service biologists because these mines are unregulated and receive relatively little attention from the caving community. Mines and other man-made structures having potential to serve as hibernacula need to be sought and identified within each Recovery Unit. When feasible, field investigations should be conducted to determine winter presence of hibernating Indiana bats. An initial goal is to complete winter bat surveys at a minimum of five highest priority/potential mines/structures in each Recovery Unit.

1.2.6 Investigate and pursue enhancement of microclimate at Lewisburg Limestone Mine, Ohio.

Winter temperatures within a large portion (approx. 40%) of the extensive Lewisburg Limestone Mine (total ≈ 34 km (21.1 mi) of mine passages) currently are too warm to support hibernating Indiana bats (King et al. 2001). However, drilling one or more small holes from the surface down through the ceiling into the warm section of the mine would allow warm air to escape (i.e., enhance chimney-effect airflow) and could be thermostatically controlled to maintain optimum conditions in a larger portion of the mine. Further investigation is warranted.

1.3 Monitor winter populations of Indiana bats.

1.3.1 Survey winter populations of Indiana bats at known hibernacula.

To measure effectiveness of Recovery Actions, the status of the populations needs to be routinely monitored by conducting standardized winter population surveys within all known Indiana bat hibernacula. Monitoring allows managers to evaluate conservation and management efforts at hibernacula, as well as the status of the species throughout its range. Decreasing populations will signal the need for additional action(s), and stable or increasing populations should be used to measure progress toward the prime objective of removing the Indiana bat from the endangered species list. All survey data should be consistently provided to the Service's Bloomington, Indiana, Field Office, which has been assigned the lead for recovery of the Indiana bat.

Monitoring at hibernacula should be conducted with sufficient regularity to determine population trends, but not so frequently that it causes undue stress on winter populations. In addition, only research essential to survival or recovery of the species should be conducted within hibernacula during the hibernation period.

1.3.1.1 Survey extant populations in all P1 and P2 hibernacula every two years.

To minimize disturbance from monitoring, yet maintain data on population levels and trends, winter bat surveys at all P1 and P2 hibernacula should be conducted in alternate years (i.e., odd years). The Service should continue to coordinate with state biologists and bat surveyors to ensure to the extent possible that all accessible P1 (n=23) and P2 (n=53) hibernacula are surveyed every 2 years (see Appendix 4: Indiana Bat Hibernacula Survey Guidelines). Only experienced bat biologists should conduct the surveys to maintain accuracy levels. For consistency of data, individual surveyors of P1 hibernacula should remain consistent from one survey period to the next. Although surveys of P2 hibernacula are more likely to be conducted by personnel from many different state and Federal agencies, they too should only be surveyed by individuals with prior experience conducting winter bat surveys and who are familiar with the hibernacula. Upon completion, all data should be provided to the Service's Bloomington Field Office.

1.3.1.2 Survey extant and uncertain populations in P3 (n=135) and P4 (n=167) hibernacula approximately every four years or as funding allows.

If resources allow, P3 and P4 hibernacula should be surveyed the same years as P1 and P2s. If resources are limited, then P3 and P4 hibernacula should be surveyed at least once every four years, but not more frequently than every two years. See Appendix 2 for definitions of "extant" and "uncertain."

1.3.1.3 Survey historically occupied hibernacula as warranted.

If suitable hibernation microclimates still exist in historically occupied hibernacula, then these should be surveyed for presence of Indiana bats every 4 to 5 years or as funding allows.

1.3.2 Search for new winter populations and historically important Indiana bat winter roost sites.

Although locations of many (presumably the majority of) Indiana bat hibernacula are known, further surveys of caves and abandoned mines are warranted. Communication with recreational cavers, karst conservancy members, or other private individuals is encouraged, as they are often first to discover additional caves or mines occupied by Indiana bats. Because Indiana bats may colonize new sites and recolonize formerly occupied sites within their range, strategic searches for undocumented and historic hibernacula may be prudent. Likewise, maintaining open communication with the organized caving community (e.g., National Speleological Society-affiliated grottos) is encouraged because NSS and local grotto members are typically an important resource for locating, evaluating, and conserving important Indiana bat caves. Both positive and negative winter survey results should be reported to the Service's Bloomington Field Office.

1.3.3 Cooperate with BCI's Appalachian Saltpeter Caves Project to identify historically important hibernacula.

Bat Conservation International (BCI) has begun an Appalachian Saltpeter Caves Project whereby they intend to investigate and assess larger caves where saltpeter (i.e., potassium nitrate) had historically been mined to determine whether these "saltpeter" caves may also have been major historic bat roosts prior to mining and subsequent disturbance and physical alterations (Kennedy 2005). If roost stains are present, then past bat population sizes will be estimated by examining the extent of roost stains left on cave ceilings. BCI will try to determine whether bats abandoned a cave because of human disturbance, or if other factors were involved, such as alteration of the cave's microclimate due to the mining activity. They intend to work with landowners and other experts to produce better management plans for those believed to be the most important caves to re-establish formerly important hibernacula and hopefully increase Indiana bat numbers. Databases and local contacts have identified well over 650 caves with "saltpeter" in their names or a known history of saltpeter mining within the bats' range. The initial phase of this project is focused on caves in Kentucky (n >150 caves) and if successful, then similar initiatives will be pursued in other states.

1.3.4 Research, develop, and field test alternative methods of surveying Pilot Knob Mine in Missouri.

Traditional winter bat surveys can no longer be safely conducted within Pilot Knob Mine, an abandoned iron mine and P1 hibernaculum in Missouri (R. Clawson, pers. comm., 2006). Therefore, recent population estimates for this mine have been derived from bat capture rates using a harp trap placed at the mine entrance during the fall swarming period. The accuracy of this technique is unknown and cannot be easily evaluated, thus the need for a more reliable technique for estimating the number of Indiana bats. Alternative methods for surveying Pilot Knob Mine need to be researched, developed, and tested. These methods may also be useful at other hibernacula that cannot be safely entered or contain extensive inaccessible areas.

1.3.5 Calculate and report rangewide population estimate based upon biennial winter surveys.

Every two yea`rs, the Service's Bloomington Field Office will calculate and report the current rangewide population estimate based upon biennial winter surveys reported from each state. The rangewide estimate will be made available on the Service's Region 3 website (www.fws.gov/midwest).

1.3.6 Annually review and reassign hibernacula priority numbers based upon winter survey results.

Current, hibernacula-specific, winter population data submitted by states and individual bat surveyors across the range will be annually reviewed by the Service's Blommington, Inidana, Field Office and priority numbers (i.e., P1-P4) for individual hibernacula will be reassigned as necessary. All winter survey data will be entered into the Indiana Bat Hibernacula Database described in 1.4.1.

1.3.7 Update Indiana bat range maps with generalized hibernacula locations and priority numbers every two years.

Approximately every two years, range maps depicting generalized hibernacula locations, priority numbers, and Recovery Unit boundaries (e.g., Figures 4 and 14) will be updated and posted on the Service's Region 3 website (www.fws.gov/midwest).

1.4 Manage hibernacula-related information.

1.4.1 Establish a comprehensive Indiana Bat Hibernacula Database.

In June 2005, the Service's Bloomington, Indiana, Field Office e-mailed an Indiana bat hibernacula data request to over 75 individuals, including Service biologists, Recovery Team Members, bat researchers, state and Federal agency biologists, consultants, and other bat conservation partners in 27 States, who in turn forwarded the request to other colleagues. The Bloomington, Indiana, Field Office used responses to this data request and additional information obtained during subsequent coordination to build a comprehensive, GIS-compatible, electronic database of all known hibernacula having current and/or historic winter records of Indiana bats. A few states are still populating the database, but the initial data entry phase is nearly complete. The database currently contains information on each hibernaculum's structure, location, ownership, bat population records, conservation measures, and threats. Additional data fields will be added as needed. The database currently contains (as of October 2006) draft entries for 442 hibernacula that now need to be reviewed.

1.4.2 Maintain the Indiana bat hibernacula database.

The Service's Bloomington, Indiana, Field Office will maintain and manage the Indiana Bat Hibernacula Database described in 1.4.1 on an ongoing basis. Other Service field offices, bat experts, and state biologists, throughout the species' range will be periodically solicited for updates and corrections to the database.

1.4.3 Coordinate with partners and develop a hibernacula data-sharing policy.

Due to the sensitive nature of some of the data contained within the Indiana Bat Hibernacula Database (e.g., cave location information, gating/barrier status), the Service plans to coordinate with data contributors (n≈25) to develop a data-sharing policy that facilitates valid research and management needs without needlessly exposing the bats or their hibernacula to further threats. During the interim period and until a data-sharing policy has been formally adopted, the Service is considering sensitive data in its possession as being "on loan" at the request of those that originally submitted it. Therefore, the Service will only comply with valid data requests from researchers, planners, and land managers on a case-by-case basis and must have prior approval from the original data contributor(s) before any sensitive data will be released. When completed, the policy will describe how data will be used, shared, and distributed to verified users.

2 Conserve and manage summer habitat to maximize survival and fecundity.

Sustaining summer habitat with known maternity colonies will help ensure habitat availability for the bat and address the potential threat posed by habitat loss and degradation.

2.1 Manage habitat on private lands.

Given that a significant portion of the known maternity colonies and suitable summer habitat are privately owned, survival of the Indiana bat depends, in large part, on private lands.

2.1.1 Develop Indiana bat habitat restoration and maintenance guidelines.

Develop guidance that addresses the special management needs of private landowners and incorporate specific guidelines that can be tailored to individual parcels of land. The guidance should address the primary components of Indiana bat habitat, including, but not limited to, 1) recruitment and sustained supply of suitable maternity roost sites, 2) management and maintenance of foraging habitat, and 3) management and maintenance of travel corridors.

Guidance should be drafted by Recovery Unit, addressing the appropriate land management actions that Indiana bats are exposed to, such as agriculture, forestry, mining, and development. Where necessary, guidance should direct the creation and/or maintenance of water sources for Indiana bats. Guidance should address the appropriate and necessary conservation measures for Indiana bats for activities that could adversely impact Indiana bats or their prey and minimization of potential disturbance of roosting bats in that Recovery Unit. Guidance should incorporate results of Indiana bat research as it becomes available.

2.1.1.1 Ozark-Central Recovery Unit.

2.1.1.2 Midwest Recovery Unit.

2.1.1.3 Appalachian Mountain Recovery Unit.

2.1.1.4 Northeast Recovery Unit.

2.1.2 As necessary, develop agreements with landowners to conserve and manage maternity colonies and summer habitat on private lands.

Agreements should be long-term and allow monitoring and implementation of the appropriate Indiana bat management guidelines.

2.1.3 Encourage activities that enhance or improve summer habitat on private lands.

The Service and its partners should work with private landowners to develop HCPs or SHAs to facilitate the conservation and management of Indiana bats that occur on privately owned land to ensure summer habitat does not become a future concern. The Service's Partners for Fish and Wildlife and other private lands programs should assist with projects that will benefit Indiana bats.

2.2 Conserve and manage Indiana bats and their habitat on Federal lands.

Federal agencies will be essential partners in the conservation and management of Indiana bats and their habitat.

2.2.1 Develop guidelines for Indiana bat habitat management to be used on Federally owned lands throughout the species range.

Work with Federal agencies that manage Indiana bat habitat, such as the Forest Service and Department of Defense. The guidance should address the primary components of Indiana bat habitat, including, but not limited to, 1) recruitment and sustained supply of suitable maternity roost sites, 2) management and maintenance of foraging habitat, and 3) management and maintenance of travel corridors.

Guidance should be drafted by Recovery Unit, addressing the appropriate land management actions that Indiana bats are exposed to, such as agriculture, forestry, mining, and development. Where necessary, guidance should direct the creation and/or maintenance of water sources for Indiana bats. Guidance should address the appropriate and necessary conservation measures for Indiana bats for activities that could adversely impact Indiana bats or their prey and minimization of potential disturbance of roosting bats in that Recovery Unit. Guidance should incorporate results of Indiana bat research as it becomes available.

2.2.1.1 Ozark-Central Recovery Unit.

2.2.1.2 Midwest Recovery Unit.

2.2.1.3 Appalachian Mountain Recovery Unit.

2.2.1.4 Northeast Recovery Unit.

2.2.2 Develop conservation programs on Federal lands for the recovery of Indiana bats pursuant to sections 2(c)(1) and 7(a)(1) of the ESA.

As directed by sections 2(c)(l) and 7(a)(1) of the ESA, Federal agencies who have Federally listed species under their jurisdictional and management authorities must carry out programs for the conservation of such species. A conservation program that outlines actions that will benefit the Indiana bat and implements the Indiana bat management guidance as appropriate will enable the Federal agency to contribute to its responsibilities under these sections of the ESA. As directed in the ESA, these programs should be developed in consultation with the Service.

2.3 Conserve and manage Indiana bats and their habitat on state, county, and municipal lands.

Indiana bats summer on state, county, and municipal lands throughout their range. State, county, and municipal agencies will be essential partners in the conservation and management of Indiana bats and their habitat. In particular, state involvement may be guided by each state's comprehensive wildlife conservation plan. Guidelines should be developed for Indiana bat habitat management to be used on state, county, and municipal forest lands throughout the species range. The guidance should address the primary components of Indiana bat habitat, including, but not limited to, 1) recruitment and sustained supply of suitable maternity roost sites, 2) management and maintenance of foraging habitat, and 3) management and maintenance of travel corridors.

Guidance should be drafted by Recovery Unit, addressing the appropriate land management actions that Indiana bats are exposed to, such as agriculture, forestry, mining, and development. Where necessary, guidance should direct the creation and/or maintenance of water sources for Indiana bats. Guidance should address the appropriate and necessary conservation measures for Indiana bats for activities that could adversely impact Indiana bats or their prey and minimization of potential disturbance of roosting bats in that Recovery Unit. Guidance should incorporate results of Indiana bat research as it becomes available.

2.3.1 Ozark-Central Recovery Unit

2.3.2 Midwest Recovery Unit.

2.3.3 Appalachian Mountain Recovery Unit.

2.3.4 Northeast Recovery Unit.

2.4 Monitor and manage known maternity colonies.

Conserving and managing maternity colonies is essential to sustaining Indiana bat reproduction and maximizing fecundity and will help maintain the species' summer range and distribution.

2.4.1 Estimate numbers, survivorship, and demographic characteristics.

Information regarding numbers, survivorship, and demographic characteristics of a maternity colony are essential to understanding the overall condition or fitness of a colony and may be used to identify potential problems.

2.4.2 Identify and conserve foraging habitat, water sources, and travel corridors.

Foraging habitat, water sources, and travel corridors are critical components of a maternity colony's home range. Identification of these resources will facilitate their conservation and management and will decrease the potential for loss of the colony due to anthropogenic causes.

2.4.3 Identify and manage, as practicable, threats, constraints, and limiting factors.

Identification of the threats, constraints, and limiting factors is critical to understanding the fitness of a maternity colony. This information will help identify and guide any necessary management activities for the colony.

2.5 Develop guidelines for protection of Indiana bats from pesticide or other chemical exposure.

Develop guidance that identifies chemicals of concern for Indiana bats and prescribes ways to avoid adverse impacts. Guidance should be applicable to all Indiana bat habitat landowners.

2.6 Minimize adverse impacts to the Indiana bat and its habitat during review of Federal, state, county, municipal, and private activities under the ESA, National Environmental Policy Act, Fish and Wildlife Coordination Act, and Section 404 of the Clean Water Act.

Review Federal, state, county, municipal, and private activities that may affect Indiana bats or their habitat under Federal and state law. Take appropriate measures to conserve and manage the bat and its habitat from adverse impacts from the proposed activities.

2.6.1 Section 7 (a)(2) for Federal responsibilities.

Section 7(a)(2) requires Federal agencies to consult with the Service to insure that any action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of listed species, nor destroy or adversely modify critical habitat. Federal programs and consultations with the Service should strive to implement recovery goals for the Indiana bat to the maximum extent possible. Consultations will continue with Federal agencies whose projects occur within the range of the Indiana bat.

2.6.2 Section 10(a)(1) for scientific permits and incidental take statements.

Enhancement of survival permits under section 10(a)(1)(A) of the ESA are issued by the Service to researchers for scientific purposes or to private individuals who wish to enhance the propagation or survival of the listed species through a SHA. Research permits should be designed to minimize harm to the species and reviewed by appropriate experts to ensure meaningful results. The Service anticipates that several section 10(a)(1)(A) permits will be issued in the near future to address research and management needs. To date, the Service has not completed a SHA for the Indiana bat.

Section 10(a)(1)(B) permits of the ESA provide for the issuance of incidental take permits for the take of Federally listed species for non-Federal actions. Applicants for an incidental take permit must develop an HCP. The Service has issued one incidental take permit, in response to an HCP, which conserves and manages a maternity colony of Indiana bats located on lands immediately adjacent to the Indianapolis International Airport. The HCP addresses the impact of commercial and airport development and road construction and provides for future conservation of the bat and its habitat near the airport and includes provisions for conservation of existing bat habitat, planting and conservation 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. A copy of the HCP can be accessed at http://www.fws.gov/midwest/endangered/mammals/ind_bat-hcp.html.

2.7 Refine and develop standardized monitoring protocols.

Provide protocols that offer guidance and consistency for researchers and managers.

2.7.1 Refine mist netting protocols.

2.7.2 Developed standardized protocols for:

2.7.2.1 Conducting telemetry on Indiana bats.

2.7.2.2 Conducting exit counts on Indiana bats.

2.7.2.3 Collection of summer habitat information.

2.7.2.4 Banding and reporting band recoveries.

2.7.2.5 Artificial roosts (and monitoring of artificial roosts) for Indiana bats.

2.7.2.6 Use of bat detection systems to survey for Indiana bats.

3 Plan and conduct research essential for the recovery of Indiana bats.

A long-term, integrated research program must be designed and implemented to provide the necessary data to assess progress towards recovery. In particular, much research will be needed on population status and vital parameters. The susceptibility of large proportions of the population to catastrophic mortality at key hibernacula was a major factor influencing the original categorization of the species as endangered, and declines in numbers at some hibernacula continue to be substantial. Research on the hibernation physiology of Indiana bats, detailed characterization of physical conditions within hibernacula, and projecting future trends in these conditions among hibernacula will be important. Results should increase understanding of causes of trends in winter counts, and may illuminate the degree of future threat to populations that rely on these hibernacula for survival. Information on the ecology of Indiana bats at times of the year other than winter has been rudimentary until recently, but much additional research on this species during spring, summer, and autumn is needed. Topics that must be emphasized include long-term studies of reproduction and the dynamics and distribution of maternity colonies, associated factors, habitat usage and response to habitat manipulations, and impacts of environmental contaminants. Other important research questions need to be addressed as well.

3.1 Conduct research on the population biology of Indiana bats.

Recovery of Indiana bats will require an in-depth and long-term understanding of their population status and population dynamics. This can only be achieved by developing improved methods of well-designed field sampling to determine key parameters of their population dynamics and to assess population status (declining, stable, or increasing). Field methods and sampling must be accompanied by use of appropriate techniques for modeling and assessment that are based on strong underlying theory.

3.1.1 Convene a working group of research scientists to guide future research on the population biology of Indiana bats.

The life histories of Indiana bats have complexities that make assessment of population status difficult. Quantitative wildlife population dynamics research can provide appropriate tools to improve these assessments using modern sampling and analysis theory. A small working group of research scientists should be established that includes nationally recognized experts in Indiana bat ecology, and experts in quantitative assessment of wildlife population dynamics with strong backgrounds in theory and methods of population analysis. This group should help the Service develop a long-term integrated research plan for assessing the population status of Indiana bats, assist in implementing such a plan, and periodically assess progress in reaching goals of the plan. A plan should include specification of means to estimate key parameters of vital rates and to select appropriate models as tools for assessing population status, including topics outlined below (objectives 3.1.2 through 3.1.6, objective 3.3.1).

3.1.2 Improve methods for estimating and monitoring Indiana bat colony sizes at hibernacula.

Current interpretation of the population status of Indiana bats rests on index counts (i.e., surveys) made at key hibernacula. The Service currently has no means of estimating variability of these counts. The counts provide an historical framework for comparisons, but can suffer from multiple sources of error of incompletely known magnitude and direction. These include changes in detectability, which historically have not been estimated. Development of improvements in estimating and monitoring Indiana bat colony sizes in hibernacula will allow assessment of impacts of various habitat management practices and environmental conditions on Indiana bats (e.g., 3.2.3 and 3.2.4)

3.1.2.1 Develop new standardized winter bat survey techniques.

To allow for estimates of variability and to improve accuracy levels in winter population surveys, the Service has been collaborating with Dr. Vicky Meretsky, a biostatistician and associate professor at Indiana University. In January 2006, the Service sponsored and Dr. Meretsky led the five primary Indiana bat survey teams (representing IL, IN, KY, MO, and NY) through a winter survey exercise at the Magazine Mine in Illinois (King 2006). The results of this exercise and additional input from the primary surveyors will help the Service identify and quantify different sources of variability (i.e., error) associated with population estimates calculated using different survey techniques (e.g., *in situ* visual estimates of bat cluster sizes/densities vs. *ex situ* counts/estimates of bats within clusters captured in digital photographs). The findings will be used to decide whether a reasonable confidence interval can be assigned to the 2005 rangewide population estimate and future estimates and to assist in the development of a new and improved winter survey protocol. Efforts should also be made to critically examine underlying assumptions of survey techniques and to improve sampling protocols and methods of data analysis.

3.1.2.2 Field test new winter bat survey techniques during biennial survey of P1 and P2 hibernacula in winter 2006-2007.

The new and improved winter survey techniques (e.g., increased use of digital photography) will be field tested in the winter of 2006-2007 during the regularly scheduled biennial survey of P1 and P2 hibernacula.

3.1.2.3 Revise the winter bat survey protocol to include newly developed survey techniques.

Based on findings from the January 2006 Indiana bat survey exercise at Magazine Mine in Illinois, subsequent statistical analysis, and field test in Recovery Action 3.1.2.2., new and improved survey techniques will be incorporated as part of a revised winter bat survey protocol. The revised protocol will be completed prior to the winter 2008 - 2009 surveys and will establish appropriate survey techniques and proper reporting procedures with the Service.

3.1.3 Investigate marking methods for application in estimating survival rates.

Survival is a key demographic trait likely to have a strong influence on population growth rates in bats, particularly in view of the reproductive traits typical of this group. Survival rates can also be evaluated in relation to the effects of various environmental factors and individual traits of bats. Thus, development of an accurate method of estimation of survival is critical for evaluating the population status of Indiana bats. Capture-recapture (or "mark-resight") techniques allow such estimation when sampling approaches and techniques meet valuable underlying assumptions. Past methods for obtaining survival estimates used banding records and life table approaches. Banding has a number of drawbacks, including possible injury and the need for repeated handling, and life table approaches are inferior to estimates of survival using maximum likelihood based capture-recapture methods. Alternative means of permanently marking large numbers of Indiana bats need to be developed, tested, and applied to obtain mark-recapture estimates of annual survival with minimal handling requirements.

3.1.4 Design long-term protocols for sampling and analysis for adult survival rate estimation.

Following development and adoption of technology for marking and resighting or recapturing bats, a program for marking and sampling Indiana bats in the field should be implemented at key sites. Sampling design and protocols should be established by the working group of Indiana bat and population biology researchers, and include establishment of a sampling frame and site selection. Survival rates should be determined and monitored over a long-term (e.g., ten-year) period. When possible, sampling should strive to assess use of different summer areas as covariates to annual survival. Maximum likelihood-based estimators of survival should be employed rather than the *ad hoc* life table and intuitive regression approaches used in the past. Understanding variability in survival may ultimately allow assessment of impacts of various habitat management practices and environmental condition on Indiana bats.

3.1.5 Determine reproductive traits of female Indiana bats and their variability, and assess early survival of young.

The parameters of female reproduction in bats are typically thought of as being relatively fixed. However, some reproductive traits show variability in bats, and the degree to which such variability occurs in Indiana bats must be assessed to understand their potential impact on population growth and recovery. Reproductive rates (proportion of females reproducing) can vary among years in many species of bats, depending on environmental conditions. Few data are available on reproductive rates in Indiana bats. The age at first reproduction in bats may vary somewhat among individuals (with some female bats failing to produce young at one year). Variation is also likely in survival of offspring prior to weaning and over their first year. Litter size is unlikely to vary in Indiana bats, but few direct observations have been made to affirm this. Annual and geographic variation in reproductive traits and survival of young should be assessed for Indiana bats using marked individuals at maternity colony sites selected in conjunction with summer roosting habitat studies. Evaluation of reproductive status of Indiana bats captured in summer away from maternity colonies should also be attempted. This will allow an assessment of bias of reproductive rate estimates based on sampling at maternity colonies. Determination of roosting habits of non-reproductive females would assist in ascertaining if this component of the population is consistently present within maternity colonies. Methodology used in studies across the species distribution should be consistent for eventual pooling of data across individual projects. Understanding variability in traits of reproduction may ultimately allow assessment of impacts of various habitat management practices and environmental conditions on Indiana bats.

3.1.6 Develop models of Indiana bat population dynamics as tools to assess progress towards recovery in different geographic areas, to determine sensitivities of various life history attributes contributing to population growth rates, and to evaluate the impact of catastrophic losses at key hibernacula on time to recovery.

The application of population models to the study of bats has been very limited, due in part to difficulties in estimating life history parameters such as survival and reproduction. The working group of research scientists should be charged with establishing a modeling framework that will be used as a tool to assess sensitivity of population growth rates to variability in life history traits of survival and reproduction, particularly those traits that might be enhanced through management actions. Models should also be used to estimate population growth rates as an indicator of population status and progress towards recovery over different Recovery Units, and to evaluate the impact of potential catastrophic events (such as mass mortality due to flooding at key hibernacula) on time to recovery.

3.1.7 Establish and maintain a central location for records of marked individual bats from life history and ecology studies of the Indiana bat.

A large number of records will accrue with the development and adoption of techniques for individually marking Indiana bats. Multiple investigators will be handling and marking bats in numerous states across the distribution in a variety of studies implemented throughout the year. A central database should be maintained and all records of marked individual Indiana bats submitted to the database routinely as a stipulation of research permits. A database should be developed that is accessible on the worldwide web and contains relevant biological information associated with each marked bat. Access for adding records and database queries should be password-protected and limited to bona fide Indiana bat researchers and managers. Eventually this database should also strive to include all banding records from studies that began as early as the 1950s.

3.2 Conduct research on the physiological and ecological requirements of Indiana bats in relation to hibernation, and characterize the most important features of key hibernacula.

Indiana bats were originally categorized as endangered in part because large segments of the population are limited to a few hibernacula that provide the conditions necessary for successful overwinter survival. It is important to continue to refine our understanding regarding the following: (1) to what degree conditions of temperature, humidity, and airflow in hibernacula relate to Indiana bat physiological requirements; (2) how variation in these factors across hibernacula relate to trends in counts; and (3) how anticipated changes in future environmental conditions may impact recovery of Indiana bat populations.

3.2.1 Conduct laboratory studies to determine metabolic rates, water balance, and thermal requirements of Indiana bats during hibernation, including determination of optimal conditions for minimizing energy expenditure.

Research is needed to clarify factors influencing the energy and water balance of hibernating Indiana bats under different microclimatic conditions. Laboratory studies should focus on metabolic rates of bats at multiple temperatures between 0˚ and 10˚C (32.0° and 50.0ºF) to resolve differing interpretations of temperatures considered optimal for hibernation. These laboratory studies should quantify the energetic costs not only of hibernation bouts (periods of hibernation), but also of arousal and maintenance of normothermic body temperatures during arousal. Such studies cannot account for ecological contraints that may influence behaviors such as avoiding areas that may freeze or flood or may be susceptible to predation. These studies may also not account for social interactions and behaviors. Laboratory studies should also seek to improve understanding of clustering behavior of Indiana bats and its impacts on heat loss, heat generation, and energy expenditure during arousal. Arousal frequency may be related to water needs under different conditions of humidity within hibernacula. Therefore, laboratory studies are needed that measure water loss during torpor as a function of humidity, and arousal frequency as a function of water vapor pressure deficit. Body condition may also influence arousal frequency and microclimate selection, and should be incorporated into both field and laboratory research on Indiana bat hibernation physiology. Studies under this objective should be designed to ultimately enable construction of energy and water balance models for hibernating Indiana bats.

3.2.2 Characterize and monitor temperature, humidity, and air flow conditions in all Priority 1 hibernacula, and in selected Priority 2 and Priority 3 hibernacula using a standard methodology. Determine aspects of hibernation behavior of bats at a subset of these sites.

Characterization of the suite of ambient conditions that allow successful overwintering of hibernating Indiana bats has not been carried out consistently across Indiana bat hibernacula. Such characterizations are important because they may provide information on correlates to survival and population status, and may allow projection of trends in climates of important winter roosts. Temperature and humidity dataloggers are commercially available for such applications, and should be deployed at multiple critical locations in multiple hibernacula over several years. Standardized methods for their deployment must be developed and applied. Additionally, a subset of these sites should be chosen for remote monitoring of hibernating Indiana bats to determine arousal frequencies and duration using technology such as infrared video and ultrasonic recording.

3.2.2.1 Develop standard methods for characterizing and monitoring temperature, humidity, and airflow in hibernacula, and design a sampling strategy for Priority 1 hibernacula and for selected Priority 2 and Priority 3 hibernacula based on geographic factors, winter population trends, and potential for modification and management.

Protocols for deploying instruments and dataloggers for monitoring and characterizing temperature, humidity, and air flow should be developed that are consistently applied in all studies of hibernacula. This should include guidelines for their placement for measuring the most relevant microclimatic conditions, sampling frequencies, calibration standards, conversions, and format for managing and maintaining data files. All Priority 1 hibernacula should be characterized, and about 15 Priority 2 and 15 Priority 3 hibernacula considered. A sampling strategy for deciding which Priority 2 and 3 hibernacula should be characterized must be developed based on geographic considerations, winter population trends (both positive and negative) and the ability to monitor these trends, and potential for modification or management of hibernacula conditions.

3.2.2.2 Characterize and monitor temperature, humidity, and airflow in Priority 1 and selected Priority 2 and Priority 3 hibernacula.

Implement the sampling strategy devised above and characterize and monitor conditions in the selected hibernacula for at least a five-year period. Synthesize and provide an interim report on preliminary results after three years, with management recommendations for modifications if necessary.

3.2.2.3 Select sites for remote monitoring of Indiana bats to determine arousal frequencies, duration, clustering, and other aspects of hibernation behavior. Implement remote monitoring in at least three hibernacula based on geographic location, population status, potential for modification and management, and findings regarding internal conditions in 3.2.2.2.

Indiana bats can modify aspects of thermoregulation and energy expenditure through clustering behavior. Clustering behavior, arousal frequencies, and arousal durations may depend in part on temperature and humidity. Information on these aspects of hibernation behavior should be obtained in conjunction with measurements of the physical environment to improve understanding and predictive modeling of responses to changing environmental conditions. Technology such as infrared video and thermal imaging and ultrasonic recording should be applied to assist in achieving this objective for three sites over a two-year period, to be selected based on the interim synthesis of information on climatic conditions under 3.2.2.2 and other criteria.

3.2.3 Model the potential impact of climate change, alterations to physical structure, and surrounding habitat modifications on projected use of hibernacula by Indiana bats.

Alterations to cave and mine entrances have been generally recognized to change temperature and other conditions within hibernacula, as gross modifications to surrounding habitat (e.g., deforestation, construction of buildings). Recent scientific studies have also called attention to the likelihood that global climate change is influencing the distribution of bats, including the geographic distribution of hibernacula. An improved understanding of Indiana bat physiological requirements for hibernation and characteristics of hibernacula will be achieved under objectives 3.2.1 and 3.2.2. Based on these studies, modeling efforts should be conducted that consider the influence of structural alterations, surrounding habitat modifications, and climate change on the future suitability of hibernacula used by Indiana bats throughout the species current and projected future distribution.

3.2.4 Predict and monitor responses of Indiana bats to efforts to restore or create appropriate conditions for hibernation.

Results of modeling under 3.2.3 should help guide efforts to reestablish optimal conditions at hibernacula that were well-used in the past but are presently poorly occupied, and in constructing artificial hibernacula. The responses of Indiana bats to hibernacula restoration efforts, including microclimate selection and numerical changes in wintering populations, should be monitored and results used to refine models of optimal hibernation conditions.

3.3 Conduct research on the summer habitat requirements and distribution of Indiana bats.

Most of the studies on summer habitat requirements of Indiana bats have focused on determining variables of importance in selection of diurnal roost sites by maternity colonies of Indiana bats. These studies provide inferences about roost selection at specific study areas and typically are limited in duration. Very little information is available to assist in extending inferences about summer habitat requirements across broader geographic regions, and about long-term dynamics and persistence or viability of maternity colonies. Even less information is available about habitats used by males, by females during periods other than pregnancy and lactation, and by all sex and age groups during seasonal migrations. Research that falls under this heading will help fill these information gaps, and will enable development and refinements of methods used by management to assess and monitor habitat suitability and trends in habitat availability.

3.3.1 Investigate the feasibility of developing sampling designs that can utilize site-occupancy models to assess long-term changes in use of summer habitat by reproductively active female Indiana bats, and to determine important habitat variables associated with occupancy of areas throughout the species distribution in summer.

Ecologists have recently developed methods that estimate the presence/absence of a species or colonies of species among spatial sampling units. These site-occupancy models may have promise in monitoring changes in the use of summer habitat by Indiana bats across the species distribution. The effect of habitat variables associated with presence or absence can also be evaluated using these techniques. The working group established under recovery objective 3.1.1 should investigate the feasibility of developing sampling designs for application of these models. Consideration should be given to using the existing database of habitat types and occurrence records for reproductively active female and juvenile Indiana bats as a potential sampling frame, and also including recent location-of-occurrence information acquired during radiotracking studies of roost utilization by maternity colonies. The feasibility of using advanced echolocation recording technology to determine presence of Indiana bats should be assessed periodically.

3.3.2 Assess habitat requirements for maternity colonies over multiple years at multiple locations across the range of the species.

In recent years there have been several studies aimed at assessing characteristics of roost trees and landscape elements associated with small numbers of maternity colonies at specific study sites. Such research should be expanded to include additional areas throughout the species range (with about four ongoing studies taking place within each of four Recovery Units), include studies following selected maternity colonies over extended durations for multiple years, and should incorporate additional components aimed at improving understanding other aspects of Indiana bat biology, such as reproductive biology (see Recovery Action 3.1.5), colony dynamics (see Recovery Action 3.3.4), and foraging requirements (see Recovery Action 3.3.6). Characteristics of foraging areas used by members of maternity colonies should document habitat composition, use of corridors, and connectedness of key habitat elements. Maternity colony habitat requirement studies should be carried out such that aspects of sampling are coordinated across studies, so that results can be subjected to future meta-analyses for determination of key factors associated with successful colonies across and within Recovery Units.

3.3.3 Determine the amount of spatial overlap among maternity colonies, and variability in colony densities and distributions across the landscape over time for a range of habitat types.

Currently it is unclear from the literature to what degree Indiana bat maternity colonies show spatial isolation or overlap in their distributions across the landscape. Summer habitat studies should be carried out over broad areas of differing habitat types across and within Recovery Units that will allow assessment of colony distribution patterns. These studies will require intensive sampling, radiotracking, and marking of individuals over multiple years, and should concentrate on habitat types thought to be favorable for use by maternity colonies. This research should also be designed to determine shifts in habitat use and changes in colony status as habitats improve or degrade.

3.3.4 Define the range of variability in characteristics of maternity colonies across broad segments of the species distribution.

There has been an increased understanding of the range in maternity colony size and daily variations in sizes of roosting groups within colonies based on radiotelemetry and observational studies conducted over the past 10 to 15 years. However, it is unknown to what extent colony sizes may vary geographically, by habitat type, over periods of multiple years, and with varying environmental conditions. Factors and mechanisms promoting growth in maternity colony size, formation of new maternity colonies, and extinction or coalescence of small colonies are unknown. The degree of genetic relatedness and variability in age distributions within and among colonies are also poorly known (see Recovery Action 3.5.2). Long-term studies should be directed at determining the importance of such factors to the persistence of maternity colonies in a variety of habitat types across the species distribution.

3.3.5 Develop means to estimate persistence of maternity colonies.

Based on results of studies in 3.3.3 and 3.3.4, a means to estimate likely persistence times for maternity colonies should be developed and tested.

3.3.6 Assess diet and foraging requirements for reproductive females and young at multiple locations across the range.

Information is now emerging on variation in the diet of Indiana bats and characteristics of foraging areas used by members of maternity colonies in a few areas. Such studies should be expanded to include additional colonies across a range of habitat types, and should be coordinated so that a standard methodology is used. Documentation of the diet (through fecal analysis) in relation to prey availability should be made in conjunction with telemetry studies of foraging habitat use by members of maternity colonies. Factors promoting abundance of important prey should be determined and studies should be designed so that the impacts of habitat change on foraging requirements of Indiana bat maternity colonies can be projected.

Specific aspects of the natural history of female Indiana bats in migration and during periods leading up to or immediately following hibernation and the maternity period are poorly known, and little is known about the ecology of adult males outside of hibernation. Efforts should be directed at determining or verifying the timing and possible routes of migration, and characteristics of roosting and foraging habitats used by female Indiana bats in migration and during periods between hibernation and the maternity season. Additional information on the summer habitat requirements of males is also desirable.

3.3.7 Improve understanding of the importance of autumn swarming.

Indiana bats engage in autumn swarming at a limited number of caves and mines, typically sites that are also utilized for hibernation. Mating also occurs at these times. Sites for autumn swarming may therefore be critical for reproductive success and maintenance of genetic diversity in Indiana bats. Thus loss of swarming sites has the potential for major impacts on Indiana bat recovery. Additional research is needed to: improve the understanding of habitat characteristics important for maintenance of swarming sites and the possible impacts of threats to these sites; characterize bat movements, turnover, foraging, and roosting habits during the swarming period; and assess the reproductive and genetic importance of swarming in relation to population recovery.

3.3.8 Maintain, update, and periodically synthesize the geographic records of occurrence of reproductive female and juvenile Indiana bats.

The geographic records of occurrence of reproductive female and juvenile bats have been useful in ascertaining factors related to distribution, coarse features of habitat selection throughout the species range, and other aspects of Indiana bat ecology. They may also provide a basis for designing studies to monitor changes in geographic distribution, and are useful for management decisions regarding surveys and permits. These records should be maintained, updated, and periodically synthesized. Increased cooperation should be sought with state and local public health authorities throughout the species distribution to allow identification of Indiana bats among bat specimens submitted for rabies diagnoses, and their localities of occurrence, age, sex, and reproductive condition (see also Recovery Actions 3.4.1, 3.5.1).

3.3.9 Determine land management practices that will increase or maintain suitability of habitat for maternity colonies of Indiana bats, and the impacts of habitat perturbations on persistence of maternity colonies.

Based in part on results of the above intensified studies of Indiana bat habitat use, models for land management practices designed to benefit Indiana bat recovery should be developed and tested through manipulative experiments and field studies. Research should focus on practices related to forest management, agriculture and mining, and the importance of various degrees of habitat fragmentation. Applied research on effects of perturbations by specific large-scale projects should be encouraged and designed to maximize information that can assist in meeting recovery objectives. Efforts to restore woodland habitats in various parts of the species summer distribution should include well-designed components to determine the responses of Indiana bats to such restorations.

3.3.10 Estimate the amount of suitable habitat occupied in the summer distribution.

Based on information obtained during other summer research, efforts should be made to develop spatial models of the extent of suitable summer habitat available throughout the range, and to estimate the amount of available habitat that remains unoccupied by Indiana bats.

3.4 Conduct research on the potential impacts of environmental contaminants on Indiana bats.

Environmental contaminants can have a wide variety of negative impacts on mortality and reproduction of wildlife. A number of species of bats, including endangered gray bats and Indiana bats, experienced lethal impacts of organochlorine pesticides in past decades. Currently there are no comprehensive data on exposure of Indiana bats to modern insecticides or other contaminants that they are likely to encounter across the landscape. There are no experimental data based on captive studies of bats to judge the impacts of most contemporary contaminants on their survival and reproduction.

3.4.1 Assess exposure of Indiana bats to environmental contaminants through analysis of carcasses, guano, and other biological samples.

Research on contaminant concentrations in tissues and guano of Indiana bats during the 1970s indicated likely mortality from certain organochlorine insecticides. Since then organophosphate, carbamate, and pyrethroid insecticides have been widely used in place of organochlorines, but levels of exposure and effects of these chemicals in bats are poorly known. The exposure of Indiana bats to toxic elements and industrial contaminants (e.g., polychlorinated biphenyls) has also not been well determined. Research is needed to determine the degree of exposure to these contaminants that Indiana bats currently experience. Assessment should be based on studies of chemical residues in guano of Indiana bats sampled throughout the species distribution during ongoing studies of maternity colonies and at hibernacula. Indiana bat carcasses should be salvaged from public health agencies that conduct diagnostic rabies testing and from specimens found dead during field studies. In areas where toxic elements are of concern, consideration should be given to sampling hair from living Indiana bats. Care should be taken to follow strict protocols in sampling, storage, preparation, and analysis of specimens. Samples should be analyzed periodically for exposure to selected groups of contaminants based on input from Indiana bat experts, environmental contaminant specialists, and professionals knowledgeable in regional use and occurrence of specific chemicals. Biomarkers of exposure should also be sampled from Indiana bats when feasible and appropriate. More robust sampling of surrogate species (i.e., other species of *Myotis*) can be conducted to determine exposure in critical areas where Indiana bats co-occur and specific chemical contamination is known or suspected (see Recovery Action 3.4.2).

3.4.2 Assess geographic patterns in use of chemicals of concern in areas of importance to Indiana bats, including assessment of contamination of prey.

Geographic patterns in past and present use of chemicals of concern should be investigated in areas of importance to Indiana bats, including assessment of contamination of prey (as defined under 3.3.6) and investigations of contamination in areas with differing Indiana bat survival (3.1.4) and reproduction (3.1.5 and 3.2). These studies should perform appropriate spatial analyses using records of chemical use from various government offices as well as results of monitoring of other environmental and biological sampling throughout the species distribution.

3.4.3 Determine sensitivity of bats to exposure to contaminants of concern in controlled laboratory experiments on captive colonies.

Based on assessments made under 3.4.1 and 3.4.2 above, laboratory studies should be conducted to assess effects of exposure to selected contaminants on captive colonies of surrogate species of bats (i.e., other bats of the genus *Myotis*). These studies should include investigation of impacts on reproduction and survival of young, and sublethal effects that may render bats more susceptible to mortality. The latter may include effects on ability to fly and forage, and effects on physiological systems that could alter energy budgets for hibernation. Dosing of captive bats should include environmentally relevant exposures. In cases where serious impacts are found in surrogate species, consideration may be given to replication of experiments using captive Indiana bats to ascertain pertinent differences in species sensitivity.

3.5 Conduct other biological research of potential importance to Indiana bat recovery.

In addition to the detailed research related to population assessment and winter and summer ecology described above, additional studies are needed to improve the understanding of Indiana bat biology in relation to recovery.

3.5.1 Determine the prevalence and potential impacts of disease in Indiana bats.

Very little is known about diseases other than rabies in bats, and virtually nothing about disease in Indiana bats. However, disease can be an important factor influencing wildlife population dynamics. Efforts should be made to begin screening Indiana bats for the presence of disease agents using a variety of approaches. Specimens found dead during field studies can be utilized for such purposes, as can samples obtained through rabies diagnostic laboratories at public health agencies. Biological samples can also be obtained from Indiana bats captured and released during habitat and population studies. Cooperating wildlife disease specialists should be recruited to select, oversee, and coordinate various screening and diagnostic procedures and to periodically synthesize and report findings.

3.5.2 Determine genetic structuring within maternity colonies across the summer distribution.

Ongoing research on the genetic structure of Indiana bat populations have focused on sampling bats at hibernacula. Genetic analyses based on obtaining wing-punch biopsies of bats sampled at maternity colonies will provide additional information on genetic makeup and relatedness within and among colonies, and may reveal additional aspects of overall population genetic structure across the summer distribution.

3.5.3 Conduct additional studies of Indiana bat population genetics based on sampling at hibernacula.

Recent research is nearing completion that will provide the first assessment of genetic diversity and genetic structuring in Indiana bats based on sampling at hibernacula. Attention should also be given to designing future genetic studies to answer new questions raised by this recent work.

3.6 Develop a post-delisting monitoring plan.

The ESA (4)(g)(1) requires the Service to "…implement a system in cooperation with the states to monitor effectively for not less than five years the status of all species which have recovered to the point at which the measures provided pursuant to this Act are no longer necessary." Accordingly, a plan should be developed to describe how the status of the Indiana bat will be monitored after the species has been delisted; cooperating parties should consider monitoring for at least ten years.

4 Develop and implement a public information and outreach program.

The success of recovery efforts for the Indiana bat depends in part on public acceptance of Recovery Actions and public awareness and understanding of the species, its needs, its importance to the ecosystem, and its importance to the human environment. Threats to the bat include modification of summer and winter habitat, which occurs on a mosaic of public and private land. Recovery activities have implications for public and private land managers, transportation and energy agencies, forest products industries and mining interests, state and local governments, state and Federal resource management agencies, Federal and state land-holding agencies, members of the conservation community (NGOs), forest industry groups, mining industry groups, consultants, and development groups, among others. Outreach efforts should address broad outreach needs (raising awareness for the species in general) as well as specific Recovery Actions identified in the recovery plan that would be enhanced through outreach.

4.1 Develop and implement outreach activities to enhance specific recovery tasks for the Indiana bat, including development of guidelines, best management practices, land acquisition/easements efforts, landowner incentives programs, Endangered Species landowner programs, research activities, and Federal review activities. Employ appropriate communications goals and messages as outlined in comprehensive Indiana bat outreach plan.

Guidelines: Develop fact sheets, questions and answers, and web-based and other background material for use with Federal, state and local land managers, and others who will be affected by issuance of guidelines for Indiana bat summer habitat management on Federally owned forests and other forested lands managed by states, counties, or municipalities. Information should also be provided to those stakeholders indirectly affected by implementation of guidelines, such as forest products groups and forest conservation organizations. Ensure audiences receive timely and accurate information as guidelines are developed and issued by holding information sessions with affected groups. Follow up with audiences after guidelines are in place to ensure understanding and resolve questions.

Best management practices: Develop information materials–including fact sheets, questions and answers, and visual presentations (video or power-point) explaining best management practices for use with owners of land with hibernacula or adjoining lands. Emphasize benefits not only to the Indiana bat but to the ecosystem and the health of the human environment. This may be done in partnership with other organizations which may already be engaged in such outreach (e.g., karst or cave conservation groups).

Land acquisition/conservation/management: When identifying areas (summer habitat, hibernacula, or adjoining lands) under consideration for purchase, lease, or conservation through easement, consider how such actions will be perceived, not only by the potential seller/participant, but by the community at large. Ensure through one-on-one discussions or other contacts that misinformation about land acquisition processes, leasing, and conservation easements are addressed early. Develop information sheets on these processes that are directly related to Indiana bat habitat.

Landowner incentive programs: Work with U.S. Forest Service and state resource management agencies to promote use of landowner incentive programs such as the Federal Forest Stewardship Program and state-administered classified forest programs. Use existing promotional information developed by state and Federal agencies; create flyers or other information sheets to be used at gatherings of potential participants. Flyers/information sheets should tie the benefits of the incentive programs to the need or benefit of conserving Indiana bat habitat. Seek opportunities to distribute information and engage landowner interest at venues such as forestry and agriculture interest group meetings and special events.

Endangered Species landowner programs: Make use of existing information materials (*Conservation Profiles: Landowners Help Imperiled Wildlife; Our Endangered Species Program and How it Works with Landowners* and others) developed by the Service to promote use of HCPs and SHAs for owners of land containing summer habitat and/or hibernacula and adjoining lands. Supplement this existing information with detailed information sheets outlining how landowners may use these programs in relation to the Indiana bat. Seek opportunities to distribute information and engage landowner interest at venues such as forestry and agriculture interest group meetings and special events.

Research activities: Seek opportunities to enhance research efforts through outreach by addressing issues such as access to private lands for monitoring and survey work. Through one-on-one communication or through use of information materials (such as a question and answer sheet), ensure private landowners understand the importance of research activities. Provide specific information on activities to be conducted and address any concerns before carrying out activities. Encourage involvement and participation by landowners to the extent possible to foster support and participation.

Federal review activities: Outreach must be conducted not only to Federal agencies involved in particular reviews affecting the Indiana bat, but to all potential stakeholders who may be affected by Service decisions. Identify all potential stakeholders during Section 7 or other reviews or during consideration of applicants for incidental take permits. Directly communicate with stakeholders throughout the review process to ensure they are informed of the progress and that they are prepared to address issues that might affect future activities. Provide background information (Service has many existing resources on Section 7, incidental take and HCPs, for example) to stakeholders; be accessible for answering questions and addressing potential conflicts.

4.2 Develop a comprehensive, ongoing outreach program to raise awareness of the Indiana bat among selected audiences.

4.2.1 Assemble an outreach planning and implementation team to conduct audience analysis, develop communications goals, develop needed products, and coordinate implementation of recommended outreach strategies and actions.

This team should include representatives from both Ecological Services and External Affairs from Service regions with significant responsibility for Indiana bat conservation and should also include participation from species experts and stakeholders.

4.2.2 Highlight the Indiana bat's association with unique environments–cave and karst–and their importance to the well-being of the human environment as well as for wildlife.

Seek partners to assist in developing and implementing awareness programs for use with key audiences. Develop information products that focus on cave/karst habitats, including fact sheets, power point presentations, and other products that may be used when communicating with key audiences. Ensure these products are specific to the audience.

4.2.3 Seek opportunities to raise awareness of the Indiana bat's special characteristics; foster a sense of appreciation for the bat, its habitat, and the unique life history of bats in general.

For example, pursue opportunities such as the Bat Education Trunk developed by the Service's Bloomington Field Office and partnerships with local newspaper and schools to foster appreciation and raise awareness. Expand this and similar programs to other areas within the Indiana bat's range.

4.2.4 Organize, with partners, discussion opportunities (e.g., symposia, roundtables) with industry groups and/or transportation and energy agencies to provide information and to listen to concerns.

Foster a "listen and learn" environment to encourage participation with stakeholders who may perceive the Indiana bat as a potential threat to activities.

4.2.5 Use Service websites as a repository of information about the Indiana bat. This information should be organized so that it is easily located and accessible and specific to key audiences (i.e., educators, planners, industry representatives, consultants).

PART III: IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows outlines actions and estimated costs for the recovery program for the Indiana bat, as set forth in this recovery plan. It is a guide for meeting the recovery goals outlined in this plan. This schedule indicates action priorities, action numbers, action descriptions, action durations, responsible parties (either to fund or carry out), and estimated costs. Parties with authority, responsibility, or expressed interest to implement a specific Recovery Action are identified in the Implementation Schedule. The listing of a party in the Implementation Schedule does not require the identified party to implement the action(s) or to secure funding for implementing action(s).

The table includes the following five elements:
1. Priority. The actions identified in the implementation schedule are those that, in our opinion, are necessary to bring about the recovery of these species. However, the actions are subject to modification as dictated by new findings, changes in species status, and the completion of Recovery Actions. The priority for each action is given in the first column of the implementation schedule, and is assigned as follows:
Priority 1: An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.
Priority 2: An action that must be taken to prevent a significant decline in species population/habitat quality or some other significant negative impact short of extinction.
Priority 3: All other actions necessary to provide for full recovery of the species.

2. Action Number and Description (from narrative outline). The action number and description are extracted from the recovery narrative section of the recovery plan. Please refer back to this narrative for a more detailed description of each action.

3. Action Duration. The action duration column indicates the number of years estimated to complete the action if it is a discrete action, or whether it is a continual or ongoing action. Continuous and ongoing actions are defined as follows:
Continuous: Action will be implemented on a regularly scheduled basis once it is begun.
Ongoing: Action is currently being implemented and will continue until no longer necessary for recovery.

4. Recovery Partners. In the table, we have identified agencies and other parties that may be primary stakeholders in the recovery process. Stakeholders are those agencies who may voluntarily participate in any aspect of implementation of particular actions listed within this recovery plan. Stakeholders may willingly participate in project planning, funding, provide technical assistance, staff time, or any other means of implementation. The list of potential stakeholders is not limited to the list below; other stakeholders are invited and encouraged to participate. The following abbreviations are used to indicate stakeholders for Recovery Actions for the Indiana bat.
ACCA - American Cave Conservation Association
BCI - Bat Conservation International
CERL - Construction Engineering Research Laboratory
CONS - Consultants

CORPS - U.S. Army Corps of Engineers
DOD - Department of Defense
EA – USFWS External Affairs Program
EPA - U.S. Environmental Protection Agency
ES – USFWS Ecological Services Program
KARS - Karst Organizations
MUNI - Municipalities
NGO - Non-governmental organizations (e.g., Bat Conservation International, The Nature Conservancy)
NPS - National Park Service
NRCS - Natural Resources Conservation Service
NSS - National Speleological Society
ODNR - Ohio Department of Natural Resources
OSM - Office of Surface Mining
PFW – USFWS Partners for Fish and Wildlife Program
PRIV - Private landowners
UNIV - University or academic researchers
TBD - To be determined
TNC - The Nature Conservancy
USFS - U.S. Forest Service
USFWS - U.S. Fish and Wildlife Service
USGS - U.S. Geological Survey
VADGIF - Virginia Department of Game and Inland Fisheries
WKU - Western Kentucky University

Other acronyms used in the Implementation Table are the following:
ESA – Endangered Species Act of 1973, as amended
HMP – Hibernacula Management Plan
P1 – Priority 1 (a hibernaculum with a current or historically observed winter population of ≥ 10,000 Indiana bats and a suitable and stable microclimate)
P1A – Priority 1A (a Priority 1 hibernaculum that has had <5,000 Indiana bats throughout the past 10 years)
P1B – Priority 1B (a Priority 1 hibernaculum that has had ≥5,000 Indiana bats during one or more winter surveys conducted during the past 10 years)
P2 – Priority 2 (a hibernaculum with current or historically observed population of ≥ 1,000 but <10,000 and an appropriate microclimate)
P3 – Priority 3 (current or historically observed populations of 50-1,000 Indiana bats)
P4 – Priority 4 (current or historically observed populations of <50 Indiana bats)

5. Cost Estimates. Cost estimates are shown for most Recovery Actions for the first four years after release of the recovery plan, years 5-20, and the total estimated cost of recovery. Costs of some Recovery Actions cannot be estimated at this time. The costs in this table represent the entire cost of each action, including costs of both the USFWS and all potential partners and funds that are appropriated to these agencies and organizations to carry out their missions.

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
1	1.1.1.1	Assess current threats and conservation measures at all P1 and P2 hibernacula and develop a prioritized list of hibernacula in need of remedial actions.	3	ES	States, BCI, USFS, NPS, DOD, NGO, TNC, KARS	27	9	9	9	-	-	
1	1.1.1.2.1	Develop guidance and template for how to complete an HMP.	1	ES	States, KARS, NGO, UNIV, CONS, BCI, USFS, DOD, NPS	8	8	-	-	-	-	
1	1.1.1.2.2	Develop HMPs for all P1A hibernacula (n=16).	2	ES	States, NPS, KARS	31	-	16	15	-	-	
1	1.1.1.2.6	Implement HMPs and associated remedial measures at all publicly owned P1 hibernacula (n=15).	3	ES	States, USFS, NPS, DOD, TNC, KARS, BCI	75	-	-	25	25	25*	*$25/yr in yr. 5. Assumed $5/hib.
1	1.1.1.2.7	Implement HMPs and associated remedial measures at all privately owned P1 hibernacula (n=8) where landowner cooperation is obtained.	4	ES	PRIV	40	-	-	-	10	30*	*$10/yr in yrs. 5-7.
1	1.3.1.1	Survey extant populations in all P1 (n=23) and P2 (n=53) hibernacula every two years.	Ongoing	ES	States, BCI, USFS, NPS, DOD, KARS, TNC	600	50	10	50	10	480	Most are traditionally surveyed on odd years.
1	3.1.1	Establish population status expert working group	5	ES	UNIV, NGO, CONS, states, USGS, USFS, DOD	390	90	75	75	75	75	
1	3.1.4	Design and implement sampling protocol for survival studies	10	ES	UNIV, CONS, NGO, states, USGS, USFS, DOD	7,930	-	-	1,640	850	5,440	Costs supplemented by expenditures in 3.1.1. and 3.1.3

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
1	3.1.6	Develop population dynamics models	3	ES	UNIV, CONS, NGO, states, USGS, USFS, DOD	295	-	-	-	115	180	Costs supplemented by expenditures in other tasks
1	3.2.1	Laboratory studies of hibernation physiology and energetics	3	ES	UNIV, CONS, USGS	185	-	95	45	45	-	
1	3.2.2.1	Develop standard methods for monitoring temperature, humidity, and airflow in hibernacula; design sampling strategy	2	ES	UNIV, CONS, states, NGO, USGS, BCI	40	-	20	20	-	-	
1	3.2.2.2	Characterize and monitor temperature, humidity, and airflow in hibernacula.	5	ES	UNIV, CONS, states, NGO, USGS,	745	-	-	-	245	500	Contingent on completion of 3.2.2.1.
1	3.2.2.3	Remote monitoring of hibernation behavior	2	ES	UNIV, CONS, states, NGO, USGS	260	-	120	140	-	-	
1	3.2.3	Model hibernacula conditions; monitor modified hibernacula	5	ES	UNIV, CONS, states, NGO, USGS	395	-	-	-	-	395	Contingent on completion of 3.2.2.1 and 3.2.2.2.
1	3.3.2	Assess habitat requirements for maternity colonies	5	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	4,425	-	-	-	-	4,425	
1	3.3.9	Determine land management practices that will increase or maintain suitability of habitat and the impacts of habitat perturbations on maternity colony persistence.	5	ES, Refuges, PFW	UNIV, CONS, states, NGO, USGS, DOD, USFS	2,250	450	450	450	450	450	
1	3.3.10	Estimate suitable summer habitat	3	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	495	-	-	-	-	495	Costs supplemented by expenditures in other tasks; contingent on completion of 3.3.2.

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
2	1.1.1.2.3	Develop HMPs for all P1B hibernacula (n=7).	2	ES	States, NPS, DOD	13	-	3	10	-	-	
2	1.1.1.2.4	Develop HMPs for at least 50% of P2 hibernacula (n=50% of 53=27).	4	ES	States, USFS, NPS, DOD, TNC, KARS,	48	-	10	10	10	18	
2	1.1.1.2.8	Implement HMPs and associated remedial measures at publicly owned P2 hibernacula (n=18) recognized as high need for alleviating disturbance.	4	ES	States, USFS, NPS, TNC, DOD, KARS	85	-	-	-	10	75	
2	1.1.1.2.9	Implement HMPs and associated remedial measures at privately owned P2 hibernacula (n=34) recognized as high priority for alleviating disturbance where landowner cooperation is obtained.	5	ES	PRIV	170	-	-	-	30	140	
2	1.1.3.1	Assess needs and develop a prioritized list of privately owned P1 (n=8) and P2 (n=34) hibernacula that indicates whether acquisition of the cave/mine entrance and adjacent areas from willing sellers is a high priority goal or whether the development of management agreements should be pursued	1	ES	States, KARS, UNIV, USGS, CONS, PRIV, NGO, DOD	10	-	10	-	-	-	
2	1.1.3.2	Purchase from willing sellers or implement long-term agreements at high-priority hibernacula, using information obtained from 1.1.3.1.	Continuous	ES	States, KARS, TNC, UNIV, PRIV, CONS, BCI, NGO	TBD	TBD	TBD	TBD	TBD	TBD	

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
2	1.1.4.1	Characterize land use and land-use trends surrounding all P1 and P2 hibernacula via a GIS-based analysis.	3	ES	DOD (CERL)	617.5	167.5	250	200	-	-	Initiated in 2005.
2	1.1.4.2	Identify and prioritize P1 and P2 hibernacula with inadequately managed surroundings/buffers.	2	ES	DOD, states, UNIV, USGS, NGO, CONS,	12	-	-	-	8	4	
2	1.1.4.3	Work with partners to complete remedial actions designed to conserve high-priority hibernacula identified on the list developed in 1.1.4.2.	10	ES	States, NGO, PRIV, UNIV, CONS	100	-	-	-	30	70	
2	1.1.4.4.1	Purchase from willing sellers or conserve through long-term agreements areas surrounding high-priority P1 hibernacula identified on the list developed in 1.1.4.2.	10	ES, PFW, Refuges	States, KARS, PRIV, TNC, CONS, NGO	2,500	-	-	-	-	2,500	
2	1.2.1	Research and develop cave/mine restoration guidance.	1	ES	States, BCI, OSM, KARS, UNIV, CONS, NGO, BCI	40	40	-	-	-	-	
2	1.2.2	Identify, assess, and prioritize hibernacula that warrant restoration actions in each Recovery Unit.	2	ES	States, NGO, CONS, UNIV, USGS, BCI, KARS	60	30	30	-	-	-	
2	1.2.3	Develop site-specific restoration plans for the highest priority sites identified in 1.2.2 and implement restoration work.	3	ES	States, NGO, UNIV, CONS, BCI, KARS	150	-	-	50	50	50	

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
2	1.3.1.2	Survey extant and uncertain populations in P3 (n=135) and P4 (n=167) hibernacula approximately every four years or as funding allows.	Ongoing	ES	States, BCI, USFS, NPS, DOD, NGO, TNC, KARS, UNIV, CONS	200	10	10	10	10	160	Surveyed on even or odd years.
2	1.3.2	Search for new winter populations and historically important Indiana bat winter roost sites.	Ongoing	ES	States, BCI, KARS, NSS, NGO, CONS	100	5	5	5	5	80	
2	1.3.4	Research, develop, and field test alternative methods of surveying Pilot Knob Mine in Missouri.	3	ES	UNIV, BCI, NGO, USGS, CONS	12	6	3	3	-	-	
2	1.3.5	Calculate and report rangewide population estimate based upon biennial winter surveys.	Ongoing	ES	States, UNIV, BCI, NGO, USGS, CONS	20	2	-	2	-	16	
2	1.4.1	Establish a comprehensive Indiana bat hibernacula database.	2	ES	States, UNIV, CONS, NGO	8	5	3	-	-	-	Initiated in 2005
2	1.4.2	Maintain the Indiana bat hibernacula database.	Ongoing	ES	States, UNIV, CONS, NGO	80	6	2	6	2	64	
2	2.5	Develop guidelines for protection of Indiana bats from pesticide or other chemical exposure.	1	ES	EPA, states	35	-	-	-	-	35	Research results are needed before developing these guidelines
2	2.6.1	Minimize adverse impacts to the Indiana bat and its habitat during review of Federal, state, county, municipal, and private activities with a Federal nexus under the ESA: Section 7 (a)(2)	Ongoing	ES	Federal agencies, states, counties, MUNI	30,800	1,540	1,540	1,540	1,540	24,640	

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
2	2.6.2	Minimize adverse impacts to the Indiana bat and its habitat by using conservation agreements with state, county, municipal, and private entities under the ESA: Section 10(a) for exception to take permits	Ongoing	ES	States, counties, MUNI, PRIV	11,200	560	560	560	560	8,960	
2	3.1.2.1	Develop new standardized winter bat survey techniques	1	ES	UNIV, BCI, NGO, USGS, CONS	390	135	85	85	85	-	
2	3.1.2.2	Field test new winter bat survey techniques during biennial survey of P1 and P2 hibernacula in winter 2006-2007.	1	ES	States, UNIV, BCI, NGO, USGS, CONS	30	30	-	-	-	-	
2	3.1.2.3	Revise the winter bat survey protocol to include newly developed survey techniques.	4 (every 5 yrs.)	ES	States, UNIV, BCI, NGO, USGS, CONS	30	-	15	-	-	15	Assumes minor revisions every 5 years.
2	3.1.3	Investigate marking methods for demographic studies	5	ES	UNIV, CONS, NGO, states, USGS, USFS, DOD	1,225	385	285	185	185	185	Costs supplemented by expenditures in 3.1.1.
2	3.1.5	Determine reproductive traits	10	ES	UNIV, CONS, NGO, states, USGS, USFS, DOD	900	-	-	-	-	900	Costs supplemented by expenditures in other tasks; contingent on completion of 3.1.3.
2	3.2.4	Predict and monitor responses to restoration and creation of hibernacula	5	ES	UNIV, CONS, states, NGO, USGS	TBD	-	-	-	-	TBD	
2	3.3.5	Develop means to estimate persistence of maternity colonies	TBD	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	TBD	-	-	-	-	TBD	Costs supplemented by expenditures in other tasks

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
2	3.4.1	Assess contaminants in bat tissues	5	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	475	-	95	95	95	190	
2	3.4.2	Determine geographic patterns in contaminant use	5	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	475	-	-	-	95	380	
3	1.1.1.2.5	Develop HMPs for P3 or P4 hibernacula as warranted.	5	ES	States, USFS, NPS, TNC, KARS, DOD, NGO	38	-	-	-	10	28*	$7/yr. in yrs. 5-8.
3	1.1.1.2.10	Implement HMPs and associated remedial measures at P3 and P4 hibernacula as warranted.	Continuous	ES	States, USFS, NPS, DOD, NGO, TNC, KARS	TBD	TBD	TBD	TBD	TBD	TBD	
3	1.1.1.3	Collate existing and/or develop new technical guidance for installing bat-friendly gates and other human barriers and deterrents (e.g., signs and alarm systems), including a pre- and post-gating monitoring protocol.	1	ES	OSM, BCI, NSS, states, USFS, NPS, NGO, CONS, USGS, ACCA, KARS, TNC	20	-	-	20	-	-	
3	1.1.1.4	Develop rangewide protocols for assessing general suitability of potential hibernacula and for conducting presence/probable absence surveys at potential hibernacula (e.g., pre-closure surveys of abandoned mines).	1	ES	UNIV, USGS, CONS, states, OSM, NGO, BCI	8	-	-	-	8	-	

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
3	1.1.1.5.1	Refine winter bat survey protocols to ensure that disturbance associated with surveys is minimized (see Recovery Action 1.3.4)	1	ES	States, USGS, CONS, NGO, UNIV, BCI, CONS,	-	-	-	-	-	-	Costs estimated in 1.3.4.
3	1.1.1.5.2	Evaluate and standardize all research conducted at hibernacula during the hibernation period through enhancement of survival permits under Section 10(a)(1)(A) of the ESA and Section 6 authorities granted to states.	1	ES	States, USGS, CONS, NGO, BCI, UNIV	4	-	-	4	-	-	
3	1.1.1.6	Provide guidance to local management authorities on procedures for alleviating human disturbance at hibernacula within their jurisdictions.	3	ES	States, NGO USFS, NPS, DOD, BCI, counties, MUNI, CONS, UNIV, TNC	12	-	-	4	4	4	
3	1.1.1.7	Coordinate with Federal, state, and local law enforcement authorities and jointly develop procedures to conserve hibernacula deemed at risk.	1	ES, LE	States, Counties, MUNI, NGO, CONS, KARS	6	-	-	-	6	-	
3	1.1.2.1	Develop evaluation procedures and criteria that will be used to designate hibernacula as ecological traps.	1	ES	States, CONS, USGS, NGO, UNIV, BCI	1	-	-	1	-	-	
3	1.1.2.2	Conduct an ecological benefit/risk analysis to determine the advisability of excluding Indiana bats from hibernacula identified as being ecological traps (n=3) in order to promote recovery.	1	ES	States, CONS, USGS, NGO, UNIV, BCI, KARS	10	-	-	-	10	-	

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
3	1.1.2.3	Design and implement site-specific actions to exclude bats from ecological traps where feasible and deemed beneficial to recovery.	2	ES	States, USGS, UNIV, NGO, CONS	20	-	-	-	-	20	
3	1.1.4.4.2	Purchase from willing sellers or conserve and manage through long-term agreements area surrounding high-priority P2 hibernacula identified on the list developed in 1.1.4.2.	5	ES, Refuges, PFW	States, NGO, PRIV, KARS, TNC, CONS	1,000	-	-	-	-	1,000	
3	1.1.4.5	Coordinate with private landowners and encourage voluntary enrollment into conservation incentive programs.	Ongoing	ES, PFW	States, USFS, NGO, NRCS, KARS	160	8	8	8	8	128	
3	1.1.4.6	Develop and distribute outreach materials containing BMPs for hibernacula owners/managers and adjacent land owners.	2	ES, PFW, External Affairs	States, USFS, NGO, NRCS, KARS	8	-	-	-	4	4	
3	1.1.5	Pursue Habitat Conservation Plans at or near private or state-owned hibernacula where unauthorized take is occurring or anticipated.	Ongoing	ES, PFW	States, PRIV, KARS, DOD,	100	5	5	5	5	80	
3	1.1.6	Pursue Safe Harbor Agreements at private or state-owned hibernacula if beneficial to the species and owners.	Ongoing	ES, PFW	States, PRIV, KARS, DOD	57	-	3	3	3	48	*Unimin Corp. is considering a Safe Harbor Agreement for silica mines in IL.
3	1.2.4	Investigate and pursue additional restoration work at Mammoth Cave, Kentucky.	1	ES	NPS, WKU, CONS, BCI, UNIV	10	-	10	-	-	-	
3	1.2.5	Investigate and pursue conservation and management at Rocky Hollow Cave, Virginia.	1	ES	USFS, VADGIF, TNC, BCI	5	-	-	5	-	-	

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
3	1.2.6	Identify and assess the potential of abandoned mines to serve as hibernacula and develop a prioritized list.	2	ES	States, OSM, UNIV, CONS, BCI	10	-	-	5	5	-	
3	1.2.7	Investigate and pursue enhancement of microclimate at Lewisburg Limestone Mine, Ohio.	1	ES	PRIV, ODNR, UNIV, CONS,	5	-	-	5	-	-	
3	1.3.1.3	Survey historically occupied hibernacula as warranted.	Ongoing	ES	States, USFS, NPS, DOD, BCI, KARS, TNC	-	-	-	-	-	-	Costs included in 1.3.1.1 and 1.3.1.2
3	1.3.3	Cooperate with BCI's Appalachian Saltpeter Caves Project in Kentucky to identify historically important hibernacula.	3	ES	BCI, UNIV, CONS	50	25	25	-	-	-	
3	1.3.6	Annually review and reassign hibernacula priority numbers based upon winter surveys.	Ongoing	ES	States, UNIV, CONS	8	0.4	0.4	0.4	0.4	6.4	
3	1.3.7	Update Indiana bat range map with generalized hibernacula locations and priority numbers every two years.	Ongoing	ES	-	10	-	1	-	1	8	
3	1.4.3	Coordinate with partners (n=20) and develop a hibernacula data-sharing policy.	1	ES	States, UNIV	10	-	10	-	-	-	
3	2.1.1.1	Develop habitat restoration and maintenance guidelines for Indiana bat on private lands throughout its range: Ozark-Central Recovery Unit	2	ES, PFW	States	70	-	-	35	35	-	

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
3	2.1.1.2	Develop habitat restoration and maintenance guidelines for Indiana bat on private lands throughout its range: Midwest Recovery Unit	2	ES, PFW	States	70	-	-	35	35	-	
3	2.1.1.3	Develop habitat restoration and maintenance guidelines for Indiana bat on private lands throughout its range: Appalachian Mountain Recovery Unit	2	ES, PFW	States	70	-	-	35	35	-	
3	2.1.1.4	Develop habitat restoration and maintenance guidelines for Indiana bat on private lands throughout its range: Northeast Recovery Unit	2	ES, PFW	States	70	-		35	35	-	
3	2.1.2	As necessary, develop agreements with landowners to conserve and manage maternity colonies and summer habitat on private lands.	Continuous	ES, PFW	States, NRCS, counties, NGO	7,700	385	385	385	385	6,160	
3	2.1.3	Minimize development and encourage activities that prevent degradation or destruction of summer habitat on private lands.	Continuous	ES, PFW	States, NRCS	176,000	8,800	8,800	8,800	8,800	140,800	
3	2.2.1.1	Develop guidelines for Indiana bat habitat management to be used on Federally owned lands throughout its range: Ozark-Central Recovery Unit	1	ES	USFS, DOD, NPS	44	-	44	-	-	-	
3	2.2.1.2	Develop guidelines for Indiana bat habitat management to be used on Federally owned lands throughout its range: Midwest Recovery Unit	1	ES	USFS, DOD, NPS	44	-	44	-	-	-	

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
3	2.2.1.3	Develop guidelines for Indiana bat habitat management to be used on Federally owned lands throughout its range: Appalachian Mountain Recovery Unit	1	ES	USFS, DOD, NPS	44	-	44	-	-	-	
3	2.2.1.4	Develop guidelines for Indiana bat habitat management to be used on Federally owned lands throughout its range: Northeast Recovery Unit	1	ES	USFS, DOD, NPS	44	-	44	-	-	-	
3	2.2.2	Develop and implement conservation programs on Federal lands for the recovery of Indiana bats pursuant to Sections 2(c)(1) and 7(a)(1) of the ESA	Continuous	ES	USFS, NPS, DOD	9,100	455	455	455	455	7,280	
3	2.3.1	Develop and implement guidelines for Indiana bat habitat management to be used on state, county, and municipal forest lands throughout its range: Ozark-Central Recovery Unit.	Continuous	ES	States, counties, MUNI	2,900	145	145	145	145	2,320	
3	2.3.2	Develop and implement guidelines for Indiana bat habitat management to be used on state, county, and municipal forest lands throughout its range: Midwest Recovery Unit.	Continuous	ES	States, counties, MUNI	6,300	315	315	315	315	5,040	
3	2.3.3	Develop guidelines and implement for Indiana bat habitat management to be used on state, county, and municipal forest lands throughout its range: Appalachian Mountain Recovery Unit.	Continuous	ES	States, counties, MUNI	4,900	245	245	245	245	3,920	

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
3	2.3.4	Develop and implement guidelines for Indiana bat habitat management to be used on state, county, and municipal lands throughout its range: Northeast Recovery Unit.	Continuous	ES	States, counties, MUNI	4,900	245	245	245	245	3,920	
3	2.4.1	Monitor maternity colonies through estimating numbers, survivorship, and demographic characteristics.	Continuous	ES	UNIV, NGO, States, USFS, DOD, USGS	11,200	560	560	560	560	8,960	Research results are needed before these guidelines can be developed, e.g., Recovery Action 3.1.
3	2.4.2	Identify foraging habitat, water, and travel corridor needs of maternity colonies.	5	ES	UNIV, NGO, States, USFS, DOD, USGS	TBD	TBD	TBD	TBD	TBD	TBD	
3	2.4.3	Identify existing and emerging threats, constraints, and limiting factors.	Ongoing	ES	UNIV, NGO, States, USFS, DOD, USGS	-	-	-	-	-	-	Costs covered by other tasks
3	2.7.1	Refine mist netting protocols.	1	ES	UNIV, CONS, NGO, states, USFS, DOD	17.5	17.5	-	-	-	-	
3	2.7.2.1	Develop standardized protocols for conducting telemetry on Indiana bats.	1	ES	UNIV, CONS, NGO, states, USFS, DOD	17.5	-	17.5	-	-	-	
3	2.7.2.2	Develop standardized protocols for conducting exit counts on Indiana bats.	1	ES	UNIV, CONS, NGO, states, USFS, DOD	17.5	17.5	-	-	-	-	
3	2.7.2.3	Develop standardized protocols for collection of summer habitat information.	1	ES	UNIV, CONS, NGO, states, USFS, DOD	17.5	-	-	-	-	17.5	Research results are needed before these protocols can be developed, e.g., Recovery Action 3.3.
3	2.7.2.4	Develop standardized protocols for banding and reporting band recoveries.	1	ES	UNIV, CONS, NGO, states, USFS, DOD	17.5	17.5	-	-	-	-	

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
3	2.7.2.5	Develop standardized protocols for artificial roosts (and monitoring of artificial roosts) for Indiana bats.	1	ES	UNIV, CONS, NGO, states, USFS, DOD	17.5	17.5	-	-	-	-	
3	2.7.2.6	Develop standardized protocols for use of bat detection systems to survey for Indiana bats	1	ES	UNIV, CONS, NGO, states, USFS, DOD	17.5	-	-	-	-	17.5	Protocol development is contingent on refinement of technology
3	3.1.7	Establish and maintain a central location for records of marked bats from life history and ecology studies	10	ES	UNIV, CONS, states, NGO, USGS, DOD	110	-	-	-	-	110	
3	3.3.1	Investigate use of site-occupancy models to assess summer habitat use	2	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	70	-	-	-	20	50	Costs supplemented by expenditures in 3.1.1.
3	3.3.3	Determine maternity colony spatial overlap, densities, distributions	5	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	500	-	-	-	-	500	Costs supplemented by expenditures in 3.3.2
3	3.3.4	Define the variability in colony characteristics	5	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	425	-	-	-	-	425	Costs supplemented by expenditures in 3.3.2
3	3.3.6	Assess diet and foraging requirements	4	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	320	-	-	-	-	320	Costs supplemented by expenditures in 3.3.2
3	3.3.7	Improve understanding of autumn swarming	5	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	956	-	-	-	-	956	

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
3	3.3.8	Maintain geographic records of occurrence of reproductive females and juvenile males	Continuous	ES	CONS, states, NGO, USFS, DOD	200	-	-	-	-	200	
3	3.4.3	Laboratory experiments on contaminant effects	5	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	900	-	-	-	-	900	
3	3.5.1	Prevalence of diseases	5	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	150	-	-	-	-	150	Costs supplemented by expenditures in other tasks
3	3.5.2	Determine genetic structuring at maternity colonies across the summer distribution	3	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	390	-	-	-	-	390	Costs supplemented by expenditures in 3.3.4 and other tasks
3	3.5.3	Conduct additional studies of Indiana bat population genetics based on sampling at hibernacula	3	ES	UNIV, CONS, states, NGO, USGS, DOD, USFS	TBD	-	-	-	-	TBD	
3	3.6	Develop a post-delisting monitoring plan	2	ES	UNIV, CONS, states, NGO, BCI	TBD					TBD	
3	4.1	Develop and implement outreach activities to enhance specific recovery tasks for Indiana bat.	Ongoing	ES, EA	States	TBD	TBD	TBD	TBD	TBD	TBD	Yearly cost estimates will depend on the timing of recovery-related activities.
3	4.2.1	Assemble an outreach planning and implementation team to conduct audience analysis, develop communications goals, develop needed products and coordinate implementation of recommended outreach strategies and actions.	Continuous	ES, EA	States, UNIV, NGO, CONS	120	60	60	TBD	TBD	TBD	Cost estimate assumes plan outreach plan would be completed in two years. Costs for remaining years will depend on the plan content.

Priority Number	Action Number	Action Description	Action Duration (Years)	Recovery Partners		Cost Estimates ($1000's)						Comments
				USFWS	Other	Total	Year 1	Year 2	Year 3	Year 4	Year 5-20	
3	4.2.2	Highlight the Indiana bat's association with unique environments–cave/karst–and their importance to the well-being of the human environment as well as for wildlife.	Continuous	ES, EA	States, UNIV, NGO, CONS	TBD	TBD	TBD	TBD	TBD	TBD	Yearly cost estimates will depend in part on opportunity and partner involvement.
3	4.2.3	Seek opportunities to raise awareness of the Indiana bat's special characteristics; foster a sense of appreciation for the bat, its habitat, and the unique life history of bats in general.	Continuous	ES, EA	States, UNIV, NGO, CONS	TBD	TBD	TBD	TBD	TBD	TBD	Yearly cost estimates will depend in part on opportunity and partner involvement
3	4.2.4	Organize, with partners, discussion opportunities with industry groups and transportation and energy agencies to provide information and to listen to concerns.	Continuous	ES, EA	States, UNIV, NGO, CONS	TBD	TBD	TBD	TBD	TBD	TBD	Yearly cost estimates will be partially issue and opportunity driven.
3	4.2.5	Use Service websites as a repository of information about the Indiana bat. This information should be organized so that it is easily located and accessible and specific to key audiences (i.e., educators, planners, industry representatives, consultants).	Continuous	ES, EA	States, UNIV, NGO, CONS	TBD	TBD	TBD	TBD	TBD	TBD	Yearly cost estimates will be partially issue driven and/or may be a part of other Service expenditures.

LITERATURE CITED

Adornato, T.G. 2005. Assessment of contamination in caves located at the Ozark Plateau National Wildlife Refuge, Oklahoma. Project ID:1261-2N46. U.S. Fish and Wildlife Service, Environmental Contaminants Program, Tulsa, Oklahoma. 67 pp.

Aguillar, A. 1984. Relationships of DDE/DDT in marine mammals to the chronology of DDT input into the ecosystem. Canadian Journal of Fisheries and Aquatic Sciences 21:840-844.

Aldridge, H.D. and R.M. Brigham. 1988. Load carrying and maneuverability in an insectivorous bat: a test of the 5% "rule" of radio-telemetry. Journal of Mammalogy 69:379-382.

American Consulting, Inc. 2002. Habitat Conservation Plan for Six Points Road Interchange and associated development. Project No. DEM-070-3(196)68. Des. No.:9500900. 56 pp. Available at: http://www.fws.gov/midwest/SixPointsNEPA/. (Accessed: March 10, 2006).

Anthony, E.L.P. 1988. Age determination. Pp. 47-57 *in* T.H. Kunz (ed.), Ecological and behavioral methods for the study of bats. Smithsonian Institution Press, Washington, D.C.

Apogee Environmental Consultants, LLC. 2004. A review of Indiana bat monitoring on Laxare (Permit No. SMA S-5012-00) and Black Castle Contour (Permit No. SMA S-5023-00) Permits, Boone County, West Virginia. Report prepared for Massey Energy, Inc., Richmond, VA. 5 pp.

Araujo, M.B. and P.H. Williams. 2001. The bias of complimentary hotspots toward marginal populations. Conservation Biology 15:1710-1720.

Aulerich, R.J., S.J. Bursian, W.J. Breslin, B.A. Olson, and R.K. Ringer. 1985. Toxicological manifestations of 2,4,5,2',4',5'-, 2,3,6,2',3',4'-, and 3,4,5,3',4',5'-hexachlorobiphenyl and Aroclor 1254 in mink. Journal of Toxicology and Environmental Health 15:63-79.

Aulerich, R.J. and R.K. Ringer. 1977. Current status of PCB toxicity to mink and effect on their reproduction. Archives of Environmental Contamination and Toxicology 6:279-292.

Bailey, V. 1933. Cave life of Kentucky. Mainly in the Mammoth Cave Region. American Midland Naturalist 14:440-458.

Bailey, R.G. 1997. Map: Ecoregions of North America (rev.). Washington, DC:USDA Forest Service in cooperation with The Nature Conservancy and the U.S. Geological Survey. Shapefile accessed via the internet (http://nationalatlas.gov/mld/ecoregp.html, raw data release dated March 2004).

Baker, G.B., L.F. Lumsden, E.B. Dettmann, N.K. Schedvin, M. Schulz, D. Watkins, and L. Jansen. 2001. The effect of forearm bands on insectivorous bats (Microchiroptera) in Australia. Wildlife Research 28:229-237.

Bakken, G.S. and T.H. Kunz. 1988. Microclimate methods. Pp. 303-332 *in* T.H. Kunz (ed.), Ecological and behavioral methods for the study of bats. Smithsonian Institution Press, Washington, D.C.

Barbour, R.W. and W.H. Davis. 1969. Bats of America. University Press of Kentucky, Lexington. 286 pp.

Barclay, R.M.R. and L.D. Harder. 2003. Life histories of bats: life in the slow lane. Pp. 209-253 *in* T.H. Kunz and M.B. Fenton (eds)., Bat ecology. University of Chicago Press; Chicago, IL.

Barclay, R.M.R., J. Ulmer, C.J.A. MacKenzie, M.S. Thompson, L. Olson, J. McCool, E. Cropley, and G. Poll. 2004. Variation in reproductive rate of bats. Canadian Journal of Zoology 82:688-693.

Barclay, R. M. R. and A. Kurta. In press. Ecology and behavior of bats roosting in tree cavities and under bark. *In* M.J. Lacki, J.P. Hayes, and A. Kurta (eds), Bats in forests: conservation and management. Johns Hopkins University Press, Baltimore, MD. (Scheduled for publication in December 2006).

Barr, T., Jr. and R. Norton. 1963. Predation on cave bats by the pilot black snake. Journal of Mammalogy 46:672.

Bat Conservation International. 2001. Indiana Myotis, *Myotis sodalis*. Pp. 68-72 *in* Bats in Eastern Woodlands. Bat Conservation International. Austin, TX. 307 pp.

Battle, B. 2003. Evaluation of landscape-level habitat attributes of Indiana bats (*Myotis sodalis*)] autumn home ranges in the Bankhead National Forest, Alabama. M.S. Thesis. Alabama Agricultural and Mechanical University, Normal, AL. 41 pp.

Batulevicius D., N. Pauziene, and D.H. Pauza. 2001. Dental incremental lines in some small species of the European vespertilionid bats. Acta Theriologica 46: 33-42.

Beckett, K., S. Millsap, A. Blankenship, M. Zwiernik, J. Geisy, and S. Bursian. 2005. Squamous epithelial lesion of the mandibles and maxillae of wild mink (*Mustela vison*) naturally exposed to polychlorinated biphenyls. Environmental Toxicology and Chemistry 24:674-677.

Belwood, J.J. 1979. Feeding ecology of an Indiana bat community with emphasis on the endangered Indiana bat, *Myotis sodalis*. M.S. Thesis, University of Florida, Gainesville, FL. 103 pp.

Belwood, J.J. 2002. Endangered bats in suburbia: observations and concerns for the future. Pp. 193-198 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

BHE Environmental, Inc. 2004. 2002 Annual report: implementation of reasonable and prudent measures & terms and conditions in the Biological Opinion for BRAC implementation at Fort Leonard Wood. Fort Leonard Wood, MO. 143 pp.

BHE Environmental, Inc. 2005. 2003 Annual report: implementation of reasonable and prudent measures & terms and conditions in the Biological Opinion for BRAC implementation at Fort Leonard Wood. Fort Leonard Wood, MO. 133 pp.

Blatchley, W.S. 1897. Indiana caves and their fauna. Indiana Department of Geological and Natural Resources Annual Report 21:121-212.

Bosveld, A. and M. Van den Berg. 1994. Effects of polychlorinated biphenyls, dibenzo-*p*-dioxins, dibenzofurans on fish-eating birds. Environmental Review 2:147-166.

Brack, V., Jr. 1983. The non-hibernating ecology of bats in Indiana with emphasis on the endangered Indiana bat, *Myotis sodalis*. Dissertation. Purdue University, West Lafayette, IN. 280 pp.

Brack V., Jr. 1988. The Indiana bat. Pp. 609-622 *in* Chandler W.J. (ed.), Audubon Wildlife Report 1988/1989. The National Audubon Society. Academic Press, New York, NY.

Brack, V., Jr. 2005. The biology and life history of the Indiana bat: hibernacula. Pp. 7-14 *in* K.C. Vories and A. Harrington (eds.), The Proceedings of the Indiana bat and coal mining: a technical interactive forum Office of Surface Mining, U.S. Department of the Interior, Alton, IL. Available at: http://www.mcrcc.osmre.gov/PDF/Forums/Bat%20Indiana/TOC.pdf. (Accessed October 17, 2006).

Brack, V. Jr. 2006. Autumn activities of *Myotis sodalis* (Indiana bat) in Bland County, Virginia. Northeastern Naturalist 13(3):421-434.

Brack, V., Jr. In press. Diet and foraging activity of the Indiana bat, *Myotis sodalis*, in Indiana. Northeastern Naturalist.

Brack, V., Jr. and K. Dunlap. 2003. A 2002-2003 winter survey for Indiana bats (*Myotis sodalis*) in hibernacula of Indiana. Report prepared for the Indiana Department of Natural Resources, Nongame and Endangered Wildlife Program. 92 pp.

Brack, V., Jr. and R.K. LaVal. 1985. Food habits of the Indiana bat in Missouri. Journal of Mammalogy 66:308-315.

Brack, V., Jr. and J.O. Whitaker, Jr. 2004. Bats of the Naval Surface Warfare Center at Crane, Indiana. Proceedings of the Indiana Academy of Science 113:66-75.

Brack, V., Jr., A.M. Wilkinson, and R.E. Mumford. 1984. Hibernacula of the endangered Indiana bat in Indiana. Proceedings of the Indiana Academy of Science 93:463-468.

Brack, V., Jr., S.A. Johnson, and R.K. Dunlap. 2003. Wintering populations of bats in Indiana, with emphasis on the endangered Indiana myotis, *Myotis sodalis*. Proceedings of the Indiana Academy of Science 112:61-74

Brack, V., Jr., S. Johnson, and C. Stihler. 2005a. Winter hibernacula temperatures used by Indiana bats in: (1) caves in Indiana; (2) a mine in Preble County, Ohio; (3) caves in West Virginia; and (4) caves in Bland County, Virginia. Report prepared for the Indiana Bat Risk Assessment Workshop, Shepherdstown, West Virginia. 37 pp.

Brack, V., Jr., J.O. Whitaker, Jr., and S.E. Pruitt. 2004. Bats of Hoosier National Forest. Proceedings of the Indiana Academy of Science 113:76-86.

Brack, V., Jr., A.M. Wilkinson, and R.E. Mumford. 1983. Hibernacula of the endangered Indiana bat in Indiana. Indiana Academy of Science 93:463-468.

Brack, V., Jr., C.W. Stihler, R.J. Reynolds, C.M. Butchkoski, and C.S. Hobson. 2002. Effect of climate and elevation on distribution and abundance in the mideastern United States. Pp. 21-28 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Brack, V., Jr., J.A. Duffey, R.K. Dunlap, and S.A. Johnson. 2005b. Flooding of hibernacula in Indiana: are some caves population sinks? Bat Research News 46:71-74.

Brack, V., Jr., R.J. Reynolds, W. Orndorff, J. Zokaites, and C. Zokaites. 2005c. Bats of Skydusky Hollow, Bland County, Virginia. Virginia Journal of Science 56:93-106.

Brenner, F.J. 1973. Influence of daily arousal on body composition of two species of *Myotis* (Mammalia: Chiroptera). Proceedings of the Pennsylvania Academy of Science 47:77-78.

Brigham, R.M. and M.B. Fenton. 1986. The influence of roost closure on the roosting and foraging behaviour of *Eptesicus fuscus* (Chiroptera: Vespertilionidae). Canadian Journal of Zoology 64:1128-1133.

Brigham, M.R., M.J. Vonhof, R.M.R. Barclay, and J.C. Gwilliam. 1997. Roosting behavior and roost-site preferences of forest-dwelling California bats (*Myotis californicus*). Journal of Mammalogy 78:1231-1239.

Britzke, E.R. 2003. Spring roosting ecology of female Indiana bats (*Myotis sodalis*) in the Northeastern United States. Report prepared for the U.S. Fish and Wildlife Service, Concord, NH. 24 pp.

Britzke, E.R., M.J. Harvey, and S.C. Loeb. 2003. Indiana bat, *Myotis sodalis*, maternity roosts in the southern United States. Southeastern Naturalist 2:235-242.

Britzke, E.R., A.C. Hicks, S.L. von Oettingen, and S.R. Darling. 2006. Description of spring roost trees used by female Indiana Bats (*Myotis sodalis*) in the Lake Champlain Valley of Vermont and New York. American Midland Naturalist 155:181-187.

Britzke, E.R., K.L. Murray, J.S. Heywood, and L.W. Robbins. 2002. Acoustic identification. Pp. 221-225 *in* Kurta, A. and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Brown, J.H. 1984. On the relationship between abundance and distribution of species. American Naturalist 124:255-279.

Brown, J.H., D.W. Mehlman, and G.C. Stevens. 1995. Spatial variation in abundance. Ecology 76:2028-2043.

Brown, R.J. and V. Brack, Jr. 2003. A summer mist net survey for the Federally endangered Indiana bat (*Myotis sodalis*) at the Newport Chemical Depot, Newport, Indiana. Report prepared for Newport Chemical Depot. 41 pp.

Brunstöm, B., B. Lund, A. Bergman, L. Asplund, I. Athanassiadis, M. Athanasiadou, S. Jensen, and J. Örberg. 2001. Reproductive toxicity in mink (*Mustela vison*) chronically exposed to environmentally relevant polychlorinated biphenyl concentrations. Environmental Toxicology and Chemistry 20:2318-2327.

Buckner, C.H. 1964. Metabolism, food capacity, and feeding behavior in four species of shrews. Canadian Journal of Zoology 42:259-279.

Burghardt, J.E. 2000. Bat-compatible closures of abandoned underground mines in National Park System units. Pp. 79-98 i*n* K.C. Vories and D. Throgmorton (eds.), Proceedings of Bat Conservation and Mining: a technical interactive forum. U.S. Office of Surface Mining and Coal Research Center, Southern Illinois University, IL.

Bursian, S., R. Aulerich, B. Yamini, and D. Tillitt. 2003. Dietary exposure of mink to fish from the Housatonic River: effects on reproduction and survival. Revised Final Report, June 10, 2003, submitted to Weston Solutions, Inc. Available from U.S. Environmental Protection Agency. Available at: http://www.epa.gov/ne/ge/thesite/restofriver-reports.html.

Butchkoski, C.M. 2003. Indiana bat (*Myotis sodalis*) investigations at Canoe Creek, Blair County Pennsylvania. Report to Pennsylvania Game Commission, Bureau of Wildlife Management. 13 pp.

Butchkoski, C.M. and J.D. Hassinger. 2002. Ecology of a maternity colony roosting in a building. Pp. 130-142 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Butchkoski, C.M. and G. Turner. 2005. Indiana bat (*Myotis sodalis*) investigations at Canoe Creek, Blair County, Pennsylvania. Project Annual Job Report. Pennsylvania Game Commission, Bureau of Wildlife Management, Research Division, Harrisburg, PA.

Butchkoski, C.M. and G. Turner. 2006. Indiana bat (*Myotis sodalis*) summer roost investigations. Project 06714 Annual Job Report. Pennsylvania Game Commission, Bureau of Wildlife Management, Research Division, Harrisburg, PA. 17 pp.

Byrne, J.J, J.P. Carbone, and E.A. Hanson. 1987. Hypothyroidism and abnormalities in the kinetics of thyroid hormone metabolism in rats treated chronically with polychlorinated biphenyl and polybrominated biphenyl. Endocrinology 121:520-527.

Callahan, E.V. 1993. Indiana bat summer habitat requirements. M.S. Thesis. University of Missouri, Columbia. 84 pp.

Callahan, E.V., R.D. Drobney, and R.L. Clawson. 1997. Selection of summer roosting sites by Indiana bats (*Myotis sodalis*) in Missouri. Journal of Mammalogy 78:818-825.

Carter, T.C. 2003. Summer habitat use of roost trees by the endangered Indiana bat (*Myotis sodalis*) in the Shawnee National Forest of southern Illinois. Dissertation. Southern Illinois University, Carbondale, IL. 82 pp.

Carter, T.C. 2005. Summer habitat assessment. Pp. 81-87 *in* K.C. Vories and A. Harrington (eds.), The Proceedings of the Indiana bat and coal mining: a technical interactive forum Office of Surface Mining, U.S. Department of the Interior, Alton, IL. Available at: http://www.mcrcc.osmre.gov/PDF/Forums/Bat%20Indiana/TOC.pdf. (Accessed October 17, 2006).

Carter, T.C., G. Feldhamer, and J. Kath. 2001. Notes on summer roosting of Indiana bats. Bat Research News 42:197-198.

Carter, T.C, S.K. Carroll, J.E. Hofmann, J.E. Gardner, and G.A. Feldhamer. 2002. Landscape analysis of roosting habitat in Illinois. Pp. 160-164 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Cary D.L, R.L. Clawson, and D. Grimes. 1981. An observation on snake predation on a bat. Transactions of the Kansas Academy of Science 84:223-224.

Channell, R. and M.V. Lomolino. 2000a. Dynamic biogeography and the conservation of endangered species. Nature 403:84-86.

Channell, R. and M.V. Lomolino. 2000b. Trajectories to extinction: spatial dynamics of the contraction of geographical ranges. Journal of Biogeography 27:169-179.

Chapman, J. 2005. Focused ecological risk assessment PCBs and mammalian and avian piscivores in Conard's Branch and Richland Creek; Neal's landfill site, Bloomington, Monroe County, Indiana. U.S. Environmental Protection Agency, Chicago, IL. 190 pp.

Chenger, J. 2003. Iowa Army Ammunition Plant 2003 Indiana bat investigations. Unpublished report. Iowa Army Ammunition Plant, Middletown, IA.

Clark, B.K. 1984. Summer status and possible factors limiting the northern range of the Indiana bat (*Myotis sodalis*) in Iowa. M.S. Thesis. Western Illinois University, Macomb, IL. 91 pp.

Clark, B.K., J.B. Bowles, and B.S. Clark. 1987. Summer status of the endangered Indiana bat in Iowa. American Midland Naturalist 118:32-39.

Clark, D.R., Jr. 1978. Uptake of dietary PCB by pregnant big brown bats (*Eptesicus fuscus*) and their fetuses. Bulletin of Environmental Contamination and Toxicology 19:707-714.

Clark, D.R., Jr. 1979. Lead concentrations: bats vs. terrestrial small mammals collected near a highway. Environmental Science and Technology 13:338-341.

Clark, D.R., Jr. 1986. Toxicity of methyl parathion to bats: mortality and coordination loss. Environmental Toxicology and Chemistry 5:191-195.

Clark, D.R., Jr. 1988. Environmental contaminants and the management of bat populations in the United States. Pp. 409-413 *in* R.C. Szaro, K.S. Severson, and D.R. Patton (eds.), Proceedings of the Symposium on Management of Amphibians and Reptiles and Small Mammals of North America, Flagstaff, AZ. USDA Forest Service, General Technical Report RM-166. 458 pp.

Clark, D. R., Jr. and A. Krynitsky. 1978. Organochlorine residues and reproduction in the little brown bat, Laurel, Maryland–June 1976. Pesticides Monitoring Journal 12:113-116.

Clark, D. R., Jr. and T.G. Lamont. 1976. Organochlorine residues and reproduction in the big brown bat. Journal of Wildlife Management 40:249-254.

Clark, D. R., Jr. and R. M. Prouty. 1976. Organochlorine residues in three bat species from four localities in Maryland and West Virginia, 1973. Pesticides Monitoring Journal 10:44-53.

Clark, D.R., Jr., and B.A. Rattner. 1987. Orthene® toxicity to little brown bats (*Myotis lucifugus*): acetylcholinesterase inhibition, coordination loss, and mortality. Environmental Toxicology and Chemistry 6:705-708.

Clark, D.R., Jr., R.L. Clawson, and C.J. Stafford. 1983. Gray bats killed by dieldrin at two additional Missouri caves: aquatic macroinvertebrates found dead. Bulletin of Environmental Contamination and Toxicology 30:214-218.

Clark, D.R., Jr., R.K. LaVal, and A.J. Krynitsky. 1980. Dieldrin and heptachlor residues in dead gray bats, Franklin County, Missouri–1976 versus 1977. Pesticides Monitoring Journal 13:137-140.

Clark, D.R., Jr., R.K. LaVal, and D.M. Swineford. 1978. Dieldrin-induced mortality in an endangered species, the gray bat (*Myotis grisescens*). Science 199:1357-1359.

Clark, D.R., Jr., C.O. Martin, and D.M. Swineford. 1975. Organochlorine insecticide residues in the free-tailed bat (*Tadarida brasiliensis*) at Bracken Cave, Texas. Journal of Mammalogy 56:429-443.

Clawson, R.L. 1986. An investigation of the summer distribution and status of Indiana bats in Missouri. Final report prepared for U.S. Fish and Wildlife Service Federal Aid project no. W-13-R-40. 17 pp.

Clawson, R.L. 2000. Implementation of a recovery plan for the Endangered Indiana bat. Pp. 239-248 *in* K.C. Vories and D. Throgmorton (eds.), Proceedings of bat conservation and mining: a technical interactive forum. U.S. Department of Interior, Office of Surface Mining and Coal Research Center, Southern Illinois University, IL.

Clawson, R.L. 2002. Trends in population size and current status. Pp. 2-8 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Clawson, R.L., R.K. LaVal, M.L. LaVal, and W. Caire. 1980. Clustering behavior of hibernating *Myotis sodalis* in Missouri. Journal of Mammalogy 61:245-253.

Colburn, T., D. Dumanoski, and J.P. Myers. 1996. Our stolen future. Penguin Books USA Inc., New York, NY. 316 pp.

Cope, J.B. and S.R. Humphrey. 1977. Spring and autumn swarming behavior in the Indiana bat, *Myotis sodalis*. Journal of Mammalogy 58:93-95.

Cope, J.B., A.R. Richter, and R.S. Mills. 1974. A summer concentration of the Indiana bat, *Myotis sodalis*, in Wayne County, Indiana. Proceedings of the Indiana Academy of Sciences 83:482-484.

Crampton, L.H. and R. Barclay. 1996. Habitat selection by bats in fragmented and unfragmented aspen mixedwood stands of different ages. Pp. 238-259 *in* R. Barclay and R. Brigham (eds.), Bats and Forests Symposium. Victoria, BC, Canada.

Cronin, J.T. 2003. Movement and spatial population structure of a prairie planthopper. Ecology 84:1179-1188.

Cryan, P.M., M.S. Bogan, and G.M. Yanega. 2001. Roosting habits of four species in the Black Hills of South Dakota. Acta Chiropterologica 3:43-52.

Currie, R.R. 2000. An overview of the response of bats to protection efforts. Pp. 173-186 *in* K.C. Vories and D. Throgmorton (eds.), Proceedings of bat conservation and mining: a technical interactive forum. U.S. Department of Interior, Office of Surface Mining and Coal Research Center, Southern Illinois University, IL.

Currie, R.R. 2002. Response to gates at hibernacula. Pp. 86-99 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Davies, W. E. 1970. Karstlands and cavern areas. The national atlas of the United States of America: United States Department of the Interior, Geological Survey.

Davis, W. 1964. Fall swarming of bats at Dixon Cave, Kentucky. National Speleological Society 26:82-3.

DeBlase, A.F., S.R. Humphrey, and K.S. Drury. 1965. Cave flooding and mortality in bats in Wind Cave, Kentucky. Journal of Mammalogy 46:96.

DeWitt, J., D.M. Millsap, R.L. Yeager, S.S. Heise, D.W. Sparks, and D.S. Henshel. 2006. External heart deformities in passerine birds exposed to environmental mixtures of PCBs during development. Environmental Toxicology and Chemistry.

Dijak, W.D. and F.R.Thompson, III. 2000. Landscape and edge effects on the distribution of mammalian predators in Missouri. Journal of Wildlife Management 64:209-216.

Drobney, R.D. and R.L. Clawson. 1995. Indiana bats. Pp. 97-98 *in* E.T.LaRoe, G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac (eds.), Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. U.S. Department of the Interior, National Biological Service, Washington, DC. 530 pp. Available at: http://biology.usgs.gov/s+t/noframe/c164.htm

Dunbar, M.B. and T.E. Tomasi. In press. Arousal patterns, metabolism, and a winter energy budget of eastern red bats (*Lasiurus borealis*). Journal of Mammalogy.

Easterla, D.A. and L.C. Watkins. 1969. Pregnant *Myotis sodalis* in northwestern Missouri. Journal of Mammalogy 50:372-373.

Eaton, R.D.P, D.C. Secord, and P. Hewitt. 1980. An experimental assessment of the toxic potential of mercury in ringed seal liver for adult laboratory cats. Toxicology and Applied Pharmacology 55:514-521.

Eisler, R. and A. Belise. 1996. Planar PCB hazards to fish, wildlife and invertebrates: a synoptic review. National Biological Service Biological Report 31. 75 pp.

Evans, D.E., W.A. Mitchell, and R.A. Fischer. 1998. Species profile: Indiana bat (*Myotis sodalis*) on military installations in the southeastern United States. U.S. Army Corps of Engineers Waterways Experiment Station Technical Report SERDP-98-3. 23 pp. Available at: http://el.erdc.usace.army.mil/tes/pdfs/serdp983.pdf. (Accessed October 27, 2006).

Farmer, A.H., B.S. Cade, and D.F. Staufer. 2002. Evaluation of a habitat suitability index model. Pp. 172-179 *in*. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Fenton, M.B. and G.K. Morris. 1976. Opportunistic feeding by desert bats (*Myotis* spp.). Canadian Journal of Zoology 54:526-530.

Fischer, L., R. Seegal, P. Ganey, I. Pessah, and P. Kodavanti. 1998. Toxicity of non-coplanar PCBs. Toxicological Sciences 41:49-61.

Fleming, T.H. and P. Eby. 2003. Ecology of bat migration. Pp. 156-208 *in* T. Kunz and M.B. Fenton (eds.), Bat ecology. The University of Chicago Press, Chicago, IL.

Foley, R.E., T. Marin, and G. Caputo. 1991. Mink and otter in New York State: contaminants and preliminary population studies. Pp. 12 *in* Proceeding from the expert consultation meeting–mink & otter. International Joint Commission. Windsor, ON. 30 pp.

Foster, R. and A. Kurta. 1999. Roosting ecology of the northern bat (*Myotis septentrionalis)* and comparisons with the endangered Indiana bat (*Myotis sodalis*). Journal of Mammalogy 80:659-672.

Fraser, D.F. 2000. Species at the edge: The case for listing "peripheral" species. Pp. 49-54 *in* L.M. Darling (ed.), Proceedings of the biology and management of species and habitats at risk. Kamloops, BC, Canada.

Furlow, F. B. and T. Armijo-Prewitt. 1995. Peripheral populations and range collapse. Conservation Biology 9:1345.

Gardner, J.E. and E.A. Cook. 2002. Seasonal and geographic distribution and quantification of potential summer habitat. Pp. 9-20 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Gardner, J. E., J. D. Garner, and J. E. Hofmann. 1989. A portable mist-netting system for capturing bats with emphasis on *Myotis sodalis* (Indiana bat). Bat Research News 30:1-8.

Gardner, J.E., J.D. Garner, and J.E. Hofmann. 1990. Combined progress reports: 1989 and 1990 investigations of *Myotis sodalis* (Indiana bat) distribution, habitat use, and status in

Illinois. Unpublished report to Region 3–U.S. Fish and Wildlife Service, Fort Snelling, MN and Illinois Department of Transportation, Springfield, IL. 19 pp.

Gardner, J.E., J.D. Garner, and J.E. Hofmann. 1991a. Summary of *Myotis sodalis* summer habitat studies in Illinois: with recommendations for impact assessment. Report prepared for Indiana/Gray bat Recovery Team Meeting, Columbia, MO 28 pp.

Gardner, J.E., J.D. Garner, and J.E. Hofmann. 1991b. Summer roost selection and roosting behavior of *Myotis sodalis* (Indiana bat) in Illinois. Unpublished report to Region-3 U.S. Fish and Wildlife Service, Fort Snelling, MN. 56 pp.

Gardner, J.E., J.E. Hofmann, and J. D. Garner. 1996. Summer distribution of the Federally endangered Indiana bat (*Myotis sodalis*) in Illinois. Transactions of the Illinois State Academy of Science 89:187-196.

Garner, J.D. and J.E. Gardner. 1992. Determination of summer distribution and habitat utilization of the Indiana bat (*Myotis sodalis)* in Illinois. Final Report: Project E-3. Endangered Species Act Section 6 Report, Illinois Department of Conservation.

Garner, T.W.J., S. Angelone, and P. Pearman. 2003. Genetic depletion in Swiss populations of *Rana latastei* (Boulenger): Conservation implications. Biological Conservation 114:371-376.

Gaston, K.J. 1990. Patterns in the geographical ranges of species. Biological Reviews 65:105-129.

Geiser, F. 2004. Metabolic rate and body temperature reduction during hibernation and daily torpor. Annual Reviews of Physiology 66:239-74.

Geiser, F. and R.L. Drury. 2003. Radiant heat affects thermoregulation and energy expenditure during rewarming from torpor. Journal of Comparative Physiology B 173:55-60.

Goodpaster, W. and D.F. Hoffmeister. 1950. Bats as prey for mink in Kentucky cave. Journal of Mammalogy 31:457.

Goyer, R.A. 1996. Toxic effects of metals, Pp. 691-736 *in* Klaassen, C.D. (ed.), Cassarett and Doull's Toxicology: the basic science of poisons, 5th Edition. McGraw-Hill, New York, NY.

Greenhall, A. 1973. Indiana bat: a cave-dweller in trouble. National Parks Conservation Magazine 47:14-17.

Griffin, D.R. 1940a. Migrations of New England bats. Bulletin: Museum of Comparative Zoology 86(6):217-246.

Griffin, D.R. 1940b. Notes on the life histories of New England cave bats. Journal of Mammalogy 21:181-187.

Grindal, D.R. 1996. Habitat use by bats in fragmented forests. Pp. 260-272 *in* R. Barclay and R. Brigham (eds.), Bats and forests symposiums. British Columbia Ministry of Forest, Victoria, BC, Canada. 292 pp.

Grindal, S.D., T.S. Collard, R.M. Brigham, and R.M.R. Barclay. 1992. The influence of precipitation on reproduction by *Myotis* bats in British Columbia. American Midland Naturalist 128:339-344.

Grue, C.E., P.L. Gibert, and M.E. Seeley. 1997. Neurophysiological and behavioral changes in non-target wildlife exposed to organophosphate and carbamate pesticides: thermoregulation, food consumption and reproduction. American Zoologist 37:369-388.

Grue, C.E., W.J. Fleming, D.C. Busby, and E.F. Hill. 1983. Assessing hazards of organophosphate pesticides to wildlife. Transactions of the North American Wildlife Natural Resource Conference 48:200-220.

Gumbert, M.W. 2001. Seasonal roost tree use by Indiana bats in the Somerset Ranger District of the Daniel Boone National Forest, Kentucky. M.S. Thesis. Eastern Kentucky University, Richmond, Kentucky. 136 pp.

Gumbert, M.W., J.M. O'Keefe, and J.R. MacGregor. 2002. Roost fidelity in Kentucky Pp. 143-152 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species Bat Conservation International, Austin, TX.

Guo, Q., M. Taper, M. Schoenberger, and J. Brandle. 2005. Spatial-temporal population dynamics across species range: from centre to margin. Oikos 108:47-57.

Gustafson, A.W. 1975. A study of the annual male reproductive cycle in a hibernating vespertilionid bat (*Myotis lucifugus*) with emphasis on the structure and function of the interstitial cells of Leydig. Ph.D. Dissertation. Cornell University, Ithaca, NY. 191 pp.

Guthrie, M.J. 1933. The reproductive cycles of some cave bats. Journal of Mammalogy 14:199-216.

Hall, E.R. 1981. The Mammals of North America. Vol. 2. 2nd ed.. The Ronald Press, New York, NY. 536 pp.

Hall, J.S. 1962. A life history and taxonomic study of the Indiana bat, *Myotis sodalis*. Reading Public Museum and Art Gallery, Scientific Publications 12:1-68.

Hanski, I. 1998. Metapopulation dynamics. Nature 396:41-49.

Hardin, J.W. and M. Hassell. 1970. Observation on waking periods and movements of *Myotis sodalis* during hibernation. Journal of Mammalogy 51:829-831

Harvey, M.J. 2002. Status and ecology in the southern United States. Pp. 29-34. *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, Texas.

Harvey, M.J., J.S. Altenbach, and T.L. Best. 1999. Bats of the United States. Arkansas Fish and Game Commission. 64 pp.

Hassell, M. 1963. A study of homing in the Indiana bat, *Myotis sodalis*. Transactions of the Kentucky Academy of Sciences 24:1-4.

Hassell, M.D. and M.J. Harvey. 1965. Differential homing in *Myotis sodalis*. American Midland Naturalist 74:501-503.

Hawkins, J.A. and V. Brack, Jr. 2004. Habitat Conservation Plan: 2003 telemetry study of autumn swarming behavior of the Indiana bat (*Myotis sodalis*). Report prepared for the Indiana Department of Natural Resources, Indianapolis, IN. 23 pp.

Hawkins, J.A., J. Jaskula, A. Mann, and V. Brack, Jr. 2005. Habitat Conservation Plan: 2004 telemetry study of autumn swarming behavior of the Indiana bat (*Myotis sodalis*). Report prepared for the Indiana Department of Natural Resources, Indianapolis, IN. 25 pp. plus appendices.

Hayes, J.P. 2003. Habitat ecology and conservation of bats in western coniferous forests. Pp. 81-119 *in* C.J. Zabel and R.G. Anthony (eds.), Mammal community dynamics in coniferous forests of western North America: management and conservation.

Heaton, S.N., S. Bursian, J. Giesy, D. Tillitt, J. Render, P. Jones, D. Verbrugge, T. Kubiak, and R. Aulerich. 1995. Dietary exposure of mink to carp from Saginaw Bay, Michigan. 1. Effects on reproduction and survival, and the potential risks to wild mink populations. Archives of Environmental Contamination and Toxicology 28:334-343.

Hengeveld, R. and J. Haeck. 1982. The distribution of abundance. I. Measurements. Journal of Biogeography 9:303-316.

Henshaw, R.E. 1965. Physiology of hibernation and acclimatization in two species of bats (*Myotis lucifugus* and *Myotis sodalis*). Ph.D. Dissertation. University of Iowa, Iowa City, IA. 143 pp.

Henshaw, R.E. 1970. Thermoregulation in bats. Pp. 188-232 *in* B.H. Slaughter and D.W. Walton (eds.), About bats: a chiropteran biology symposium. Southern Methodist University Press, Dallas, TX. 339 pp.

Henshel, D.S. 1998. Developmental and neurotoxic effects of dioxin and dioxin-like compounds on domestic and wild avian species. Environmental Toxicology and Chemistry 17:88-98.

Henshel, D.S., D.W. Sparks, T.P. Simon, and M.J. Tosick. 2006. Age structure and growth of creek chub (*Semotilus atromaculatus*) (Mitchill) in PCB-contaminated streams in Indiana. Journal of Fish Biology 68:44-62.

Herder, M. 2003. Pre- and post-gate biological monitoring. Bat Research News 44:105.

Herreid, C.F. 1964. Bat longevity and metabolic rate. Experimental Genetics 1:1-9.

Hicks, A. 2003. Indiana Bat (*Myotis sodalis*): Protection and management in New York State. endangered species investigations performance report. Prepared for project number W-166-E Segment 2002-2003, New York Department of Environmental Conservation. 27 pp.

Hicks, A. 2004. Indiana Bat (*Myotis sodalis*): Protection and management in New York State. endangered species investigations performance report. Prepared for project number W-166-E Segment 2003-2004, New York Department of Environmental Conservation. 15 pp.

Hicks, A. New York Department of Environmental Conservation. 2005. Memorandum to S. von Oettingen, U.S. Fish and Wildlife Service. 1p.

Hicks, A.C. and P.G. Novak. 2002. History, status, and behavior of hibernating populations in the northeast. Pp. 35-47 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Hicks, A.C., Herzog, and M. Clark. 2005. Indiana bat (*Myotis sodalis*) protection and management in New York State. Annual report on New York Department of Environmental Conservation Activities. 30 pp.

Hill, E.F. 1995. Organophosphorus and carbamate pesticides. Pp. 243-273 *in* D.J. Hoffman, B.A. Rattner, G.A. Burton, Jr., and J. Cairns, Jr. (eds.), Handbook of ecotoxicology. Lewis Publishers, CRC Press, Boca Raton, FL.

Hobson, C.S. and J.N. Holland. 1995. Post-hibernation movement and foraging habitat of a male Indiana bat, *Myotis sodalis* (Chiroptera: Vespertilionidae), in western Virginia. Brimleyana 23:95-101.

Hoffman, D.J. 2003. Wildlife toxicity testing. Pp. 75-110 *in* Hoffman, D.J., B.A. Rattner, G.A. Burton, Jr. and J. Cairns, Jr. (eds.), Handbook of Ecotoxicology. Lewis Publishers, Boca Raton, FL.

Hoffman, D., C. Rice, and T. Kubiak. 1996. PCBs and dioxins in birds. Pp. 165-207 *in* Beyer, W., G. Heinz and A. Redmon-Norwood (eds.), Environmental Contaminants in Wildlife, Interpreting Tissue Concentrations. Lewis Publishers, Boca Raton, FL.

Hornshaw, T.C., R.J. Aulerich, and H.E. Johnson. 1983. Feeding Great Lakes fish to mink: effects on mink and accumulation and elimination of PCBs by mink. Journal of Toxicology and Environmental Health 11:933-946.

Hovey, H.C. 1882. Celebrated American caverns. Robert Clarke and Co. Cincinnati, Ohio. 228 pp.

Hudgins, J.E. 1993. Pesticide residue and metals in guano of Virginia big-eared bats in West Virginia, 1991. U.S. Fish and Wildlife Service, Environmental Contaminants Program, West Virginia Field Office Special Report 93-2, Elkins, WV. 12 pp.

Humphrey, S.R. 1978. Status, winter habitat, and management of the endangered Indiana bat, *Myotis sodalis*. Florida Scientist 41:65-76.

Humphrey, S.R. 1992. Indiana bat *Myotis sodalis*, family Vespertilionidae, order Chiroptera. Pp. 54-62 *in* S. Humphrey (ed.), Rare and endangered biota of Florida; Volume 1: mammals. University Press of Florida, Tallahassee, FL.

Humphrey, S.R. and J.B. Cope. 1976. Population ecology of the little brown bat, *Myotis lucifugus*, in Indiana and north-central Kentucky. Special publications of the American Society of Mammalogists 4:1-81.

Humphrey, S.R. and J.B. Cope. 1977. Survival rates of the endangered Indiana bat, *Myotis sodalis*. Journal of Mammalogy 58:32-36.

Humphrey, S.R., A.R. Richter, and J.B. Cope. 1977. Summer habitat and ecology of the endangered Indiana bat, *Myotis sodalis*. Journal of Mammalogy 58:334-346.

Humphries, M.H., D.W. Thomas, and J.R. Speakman. 2002. Climate-mediated energetic constraints on the distribution of hibernating mammals. Nature 418: 313-316.

Hunt, G. and R.R. Stitt. 1975. Cave gating–a handbook. National Speological Society, Huntsville, Alabama. 43 pp.

Hunter, M.L., Jr. 1991. Coping with ignorance: the coarse-filter strategy for maintaining biodiversity. Pp. 266-281 *in* K. Kohm (ed.), Balancing on the brink of extinction: the Endangered Species Act and lessons for the future. Island Press, Washington, DC.

Jensen, S. 1972. The PCB story. Ambio 1:123-131.

Johnson, G. 2005. A review of bat mortality at wind-energy developments in the United States. Bat Research News 46:45-48.

Johnson, S.A., V. Brack, and R.K. Dunlap. 2002. Management of hibernacula in the State of Indiana. Pp. 100-109 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Jung, T.S., I.D. Thompson, R.D. Titman, and A.P. Applejohn. 1999. Habitat selection by forest bats in relation to mixed-wood stand types and structure in central Ontario. Journal of Wildlife Management 63:1306-1319.

Kath, J.A. 2000. A Midwestern case study to secure an underground mine for bat habitat: the Unimin Magazine Mine in Alexander County, Illinois. Pp. 169-172 *in* K.C.Vories and D. Throgmorton (eds.), Proceedings of bat conservation and mining: a technical interactive forum. U.S. Department of Interior, Office of Surface Mining and Coal Research Center, Southern Illinois University, IL.

Kath, J.A. 2002. An overview of hibernacula in Illinois, with emphasis on the Magazine Mine. Pp. 110-116 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Kennedy, J. 2005. Tracking saltpeter. Bats 24(4):6.

Kerth, G. and B. König. 1999. Fission, fusion, and nonrandom associations in female Bechstein's bats (*Myotis bechsteinii*). Behaviour 136:1187-1202.

Kerth, G., M. Wagner, and B. König. 2001. Roosting together, foraging apart: information transfer about food is unlikely to explain sociality in female Bechstein's bats (*Myotis bechsteinii*). Behavioral Ecology and Sociobiology 50:283-291.

Kessler, J.S., W.M. Turner, and L. Morgan. 1981. A survey for the Indiana bat *Myotis sodalis* on Knob Creek, Bullitt County, Kentucky. Transactions of the Kentucky Academy of Science 42:38-40.

King, A. 2006. Deep in the bat cave. Inside Region 3. U.S. Fish and Wildlife Service, Fort Snelling, MN. March 2006. Available at: http://www.fws.gov/midwest/InsideRegion3. (Accessed June 7, 2006).

King, R.A., R.J. Brown, A.B. Henry, R. Beck, R.C. Rommé, M.J. Bruening, and D. Swanson. 2001. Distribution, abundance and roost-site fidelity of hibernating bats in relation to ceiling temperature in an abandoned mine in southwestern Ohio. Bat Research News 42:32-33.

Kiser, J.D. and C.L. Elliott. 1996. Foraging habitat, food habits, and roost tree characteristics of the Indiana bat (*Myotis sodalis*) during autumn in Jackson County, Kentucky. Report prepared for Kentucky Department of Fish and Wildlife Resources, Nongame Program, Frankfort, KY. 65 pp.

Kiser, J. and J.R. MacGregor. 2005. Indiana bat (Myotis sodalist) mist net surveys for coal mining activities. Pp 45-62 *in* K.C. Vories and A. Harrington (eds.), The Proceedings of the Indiana bat and coal mining: a technical interactive forum. U.S. Department of the Interior, Office of Surface Mining, Alton, IL. 229 pp.

Kiser, J.D., J.R. MacGregor, H.D. Bryan, and A. Howard. 2002. Use of concrete bridges as nightroosts. Pp. 208-215 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Krusac, D.L. and S.R. Mighton. 2002. Conservation of the Indiana bat in national forests: where we have been and where we should be going. Pp. 55-65 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Kubiak, T.J. and D.A. Best. 1991. Wildlife risks associated with passage of contaminated, anadromous fish at Federal Energy Regulatory Commission licensed dams in Michigan. Contaminants Program, Division of Ecological Services, U.S. Fish and Wildlife Service, East Lansing, MI. 54 pp.

Kunz, T.H. and L.F. Lumsden. 2003. Ecology of cavity and foliage roosting bats. Pp. 3-89 *in* T. Kunz and M.B. Fenton (eds.), Bat Ecology. The University of Chicago Press, Chicago, IL.

Kunz, T.H., J.A. Wrazen, and C.D. Burnett. 1998. Changes in body mass and fat reserves in pre-hibernating little brown bats (*Myotis lucifugus*). Ecoscience 5:8-17.

Kurta, A. 1980. Status of the Indiana bat, *Myotis sodalis*, in Michigan. Michigan Academician 13:31-36.

Kurta, A. 1985. External insulation available to a non-nesting mammal, the little brown bat (*Myotis lucifugus*). Comparative Biochemistry and Physiology 82A:413-420.

Kurta, A. 2000. The bat community in northwestern Lower Michigan, with emphasis on the Indiana bat and eastern pipistrelle. Report submitted to United States Forest Service, Huron-Manistee National Forests, Cadillac, MI. 43 pp.

Kurta, A. 2005. Roosting ecology and behavior of Indiana bats (*Myotis sodalis*) in summer. Pp. 29-42 *in* K.C. Vories and A. Harrington (eds.), Proceedings of the Indiana bat and coal mining: a technical interactive forum. Office of Surface Mining, U.S. Department of the Interior, Alton, IL. Available at: http://www.mcrcc.osmre.gov/PDF/Forums/Bat%20Indiana/TOC.pdf. (Accessed October 17, 2006).

Kurta, A. and R. Foster. 1995. The brown creeper (Aves: Certhiidae): a competitor of tree-roosting bats? Bat Research News 36:6-7.

Kurta, A. and J. Kennedy (eds.). 2002. The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, Texas. 253 pp.

Kurta, A. and S.W. Murray. 2002. Philopatry and migration of banded Indiana bats (*Myotis sodalis*) and effects of radio transmitters. Journal of Mammalogy 83:585-589.

Kurta, A. and H. Rice. 2002. Ecology and management of the Indiana bat in Michigan. Michigan Academician 33:361-376.

Kurta, A. and J.A. Teramino. 1994. A novel hibernaculum and noteworthy records of the Indiana bat and eastern pipistrelle (Chiroptera: Vespertilionidae). American Midland Naturalist 132:410-413.

Kurta, A. and J.O. Whitaker, Jr. 1998. Diet of the endangered Indiana bat (*Myotis sodalis*) on the northern edge of its range. American Midland Naturalist 140:280-286.

Kurta, A., J. Caryl, and T. Lipps. 1997. Bats and Tippy Dam: species composition, seasonal use, and environmental parameters. Michigan Academician 24:473-490.

Kurta, A., T.H. Kunz, and K.A. Nagy. 1990. Energetics and water flux of free-ranging big brown bats (*Eptesicus fuscus*) during pregnancy and lactation. Journal of Mammalogy 71:59-65.

Kurta, A., S.W. Murray, and D.H. Miller. 2002. Roost selection and movements across the summer landscape. Pp. 118-129 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Kurta, A., K.J. Williams, and R. Mies. 1996. Ecological, behavioural, and thermal observations of a peripheral population of Indiana bats (*Myotis sodalis*). Pp. 102-117 *in* R.M.R. Barclay and R. M. Brigham (eds.), Bats and Forests Symposium. Research Branch, British Columbia Ministry of Forests, Victoria, BC, Canada.

Kurta, A., G.P. Bell, K.A. Nagy, and T.H. Kunz. 1989. Water balance of free-ranging little brown bats (*Myotis lucifugus*) during pregnancy and lactation. Canadian Journal of Zoology 67:2468-2472.

Kurta, A., D. King, J.A. Teramino, J.M. Stribley, and K.J. Williams. 1993a. Summer roosts of the endangered Indiana bat (*Myotis sodalis*) on the northern edge of its range. American Midland Naturalist 129:132-138.

Kurta, A., J. Kath, E.L. Smith, R. Foster, M.W. Orick, and R. Ross. 1993b. A maternity roost of the endangered Indiana bat (*Myotis sodalis*) in an unshaded, hollow, sycamore tree (*Platanus occidentalis*). American Midland Naturalist 130:405-407.

Lacki, M. J., S. K. Amelon, and M. D. Baker. 2006. Foraging ecology of bats in forests. *In* M.J. Lacki, J.P. Hayes, and A. Kurta (eds), Bats in forests: conservation and management. Johns Hopkins University Press, Baltimore, MD. (Scheduled for publication in December 2006).

Larkin, R.P. 2006. Migrating bats interacting with wind turbines: what birds can tell us. Bat Research News 47:23-32.

LaVal, R.K. and M.L. LaVal. 1980. Ecological studies and management of Missouri bats, with emphasis on cave-dwelling species. Missouri Department of Conservation, Terrestrial Series 8:1-52.

LaVal, R., R. Clawson, M. LaVal, W. Caire. 1977. Foraging behavior and nocturnal activity patterns of Missouri bats, with emphasis on the endangered species *Myotis grisescens* and *Myotis sodalis*. Journal of Mammalogy 58:592-9.

LaVal, R. K., R. L. Clawson, W. Caire, L. R. Wingate, and M. L. LaVal. 1976. An evaluation of the status of myotine bats in the proposed Meramec Park Lake and Union Lake project areas, Missouri. Unpublished report. U.S. Army Corps of Engineers, St. Louis, MO.

Lee, Y.F. 1993. Feeding ecology of the Indiana bat, *Myotis sodalis*, and resource partitioning with *Myotis keenii* and *Myotis lucifugus*. M.S. thesis. University of Tennessee, Knoxville, TN. 140 pp.

Leonards, P., T. de Vries, W. Minnaard, S. Stuijfzand, P. de Voogt, W. Cofino, N. van Straalen, and B. van Hattum. 1995. Assessment of experimental data on PCB-induced reproduction inhibition in mink, based on an isomer- and congener specific approach using 2,3,7,8-tetrachlorodibenzo-*p*-dioxin toxic equivalency. Environmental Toxicology and Chemistry 14:639-652.

Lesica, P. and F.W. Allendorf. 1995. When are peripheral populations valuable for conservation? Conservation Biology 9:753-760.

Lewis, S.E. 1993. Effect of climatic variation on reproduction by pallid bats (*Antrozous pallidus*). Canadian Journal of Zoology 71:1429-1433.

Linzey, A. 1987. Effects of chronic polychlorinated biphenyls exposure on reproductive success of white-footed mice (*Peromyscus leucopus*). Archives of Environmental Contamination and Toxicology 16:455-460.

Linzey, A. 1988. Effects of chronic polychlorinated biphenyls exposure on growth and reproduction of second generation white-footed mice (*Peromyscus leucopus*). Archives of Environmental Contamination and Toxicology 17:39-45.

Livengood, K. 2003. The Anabat bat detector's zone of reception and the factors that affect detection volume. Masters Thesis. University of Missouri, Columbia, MO. 134 pp.

Loeb, S. 2003. Range of endangered bat wider than previously thought. Society of American Foresters, The Forestry Source [online]. Available at: http://www.SAFnet.org.

Lomolino, M.V. and R. Channell. 1995. Splendid isolation: patterns of range collapse in endangered mammals. Journal of Mammalogy 76:335-347.

Lomolino, M.V. and R. Channell. 1997. Range collapse, re-introductions, and biogeographic guidelines for conservation. Conservation Biology 12:481-484.

MacCarthy, K. A., T.C. Carter, B.J. Steffen, and G. A. Feldhamer. 2006. Efficacy of the Mist-net Protocol for Indiana Bats: A Video Analysis. Northeastern Naturalist 13:25-28.

MacGregor, J. 1993. Responses of winter populations of the Federal endangered Indiana bat (*Myotis sodalis*) to cave gating in Kentucky. Pp. 364-370 *in* 1991 National Cave Management Symposium Proceedings. Bowling Green, KY.

MacGregor J., J. Kiser, M. Gumbert, and T. Reed. 1999. Autumn roosting habitat of male Indiana bats (*Myotis sodalis*) in a managed forest setting in Kentucky. Pp. 169-170 *in* J. Stringer and D. Loftis (eds), Proceedings 12th central hardwood forest conference, 1999 February 28-March 1-2, Lexington, KY. General Technical Report SRS-24. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC.

Martin R. 1973. The current status of bat protection in the United States of America. Periodicum Biologorum 75:153-4.

Martin, D.B. 1992. Contaminant studies on endangered bats in northeastern Oklahoma. U.S. Fish and Wildlife Service, Environmental Contaminants Program, Tulsa, OK. 12 pp.

Martin K.W., W.L. Puckette, S.L. Hensley, and D.M. Leslie, Jr. 2000. Internal cave gating as a means of protecting cave-dwelling bat populations in eastern Oklahoma. Proceedings of the Oklahoma Academy of Science 80:133-7.

Martin K.W., R.F. Lance, and C.H. Bucciantini. 2005. Collisions with aircraft and use of culverts under runways by bats at U.S. Naval Air Station Meridian, Meridian, Mississippi. Bat Research News 46:51-54.

Maul, J.D. and J.L Farris. 2005. Monitoring exposure of northern cardinals, *Cardinalis cardinalis*, to cholinesterase-inhibiting pesticides: enzyme activity, reactivations, and indicators of environmental stress. Environmental Toxicology and Chemistry 24:1721-1730.

McCoy, G., M. Finlay, A. Rhone, K. James and G. Cobb. 1995. Chronic polychlorinated biphenyls exposure on three generations of oldfield mice (*Peromyscus polionotus*): effects on reproduction, growth, and body residues. Archives of Environmental Contamination and Toxicology 28:431-435.

McFarland, C.A. 1998. Potential agricultural insecticide exposure of Indiana bats (*Myotis sodalis*) in Missouri. M.S. Thesis. University of Missouri, Columbia, MO. 241 pp.

Menzel, M.A., J.M. Menzel, T.C. Carter, W.M. Ford, and J.W. Edwards. 2001. Review of the forest habitat relationships of the Indiana bat (*Myotis sodalis*). USDA, Forest Service, Northeastern Research Station, General Technical Report NE-284:1-21.

Menzel, J.A., W.M. Ford, M.A. Menzel, T.C. Carter, J.E Gardner, J.D. Garner, and J.E. Hofmann. 2005. Summer habitat use and home-range analysis of the endangered Indiana bat. Journal of Wildlife Management 69:430-436.

Messenger, S.L., C.E. Rupprecht, and J.S. Smith. 2003. Bats, emerging virus infections, and the rabies paradigm. Pp. 622-679 *in* T. Kunz and M.B. Fenton (eds.), Bat Ecology. The University of Chicago Press, Chicago, IL.

Miller, G.S., Jr. and G.M. Allen. 1928. The American bats of the genus *Myotis* and *Pizonyx*. Bulletin of the United States National Museum 114:1-218.

Miller, N.E. 1996. Indiana bat summer habitat patterns in northern Missouri. M.S. Thesis. University of Missouri, Columbia, MO. 60 pp.

Miller, N.E., R.D. Drobney, R.L. Clawson, and E.V. Callahan. 2002. Summer habitat in northern Missouri. Pp. 165-171 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Miyamoto, J. 1976. Degradation, metabolism and toxicity of synthetic pyrethroids. Environmental Health Perspectives 14:15-28.

Mohr, C.E. 1952. A survey of bat banding in North America. 1932-1951. Bulletin of the National Speleological Society 14:3-13.

Mohr, C.E. 1953. Possible causes of an apparent decline in wintering populations of cave bats. National Speleological Society News Nov:4-5.

Mohr, C.E. 1972. The status of threatened species of cave-dwelling bats. Bulletin of the National Speleological Society 34:33-37.

Mumford, R.E. and J.B. Cope. 1958. Summer records of *Myotis sodalis* in Indiana. Journal of Mammalogy 39:586-587.

Mumford, R.E. and L.L. Calvert. 1960. *Myotis sodalis* evidently breeding in Indiana. Journal of Mammalogy 41:512.

Mumford, R.E. and J.O. Whitaker, Jr. 1982. Mammals of Indiana. Indiana University Press, Bloomington, IN. 537 pp.

Munson, P. J. and J. H. Keith. 1984. Prehistoric raccoon predation on hibernating *Myotis*, Wyandotte Cave, Indiana. Journal of Mammalogy 65:152-155.

Murphy, M. 1987. Vandals destroy hibernating Indiana bats. Bats Magazine 5(2):5-8.

Murray, F., F. Smith, K. Nitschke, C. Humiston, R. Kociba, and B. Schwetz. 1979. Three-generation reproduction study of rats given 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) in the diet. Toxicology and Applied Pharmacology 50:241-252.

Murray, S.W. 1999. Diet and nocturnal activity patterns of the endangered Indiana bat, *Myotis sodalis*. M.S. Thesis. Eastern Michigan University, Ypsilanti, MI. 77 pp.

Murray, S.W. and A. Kurta. 2002. Spatial and temporal variation in diet. Pp. 182-192 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Murray, S.W. and A. Kurta. 2004. Nocturnal activity of the endangered Indiana bat (*Myotis sodalis).* Journal of Zoology 262:197-206.

Myers, R.F. 1964. Ecology of three species of myotine bats in the Ozark Plateau. Ph.D. Dissertation. University of Missouri, Columbia, MO. 210 pp.

Nason, E.S. 1948. Morphology of hair of eastern North American bats. The American Midland Naturalist 39:345-361.

National Marine Fisheries Service. 2004. Interim endangered and threatened species recovery planning guidance. National Marine Fisheries Service, Silver Spring, MD. 124 pp. Available at: http://www.nmfs.noaa.gov/pr/readingrm/Recoverplans/rpg_%20nmfs04.pdf

Neubaum, D.J., M.A. Neubaum, L.E. Ellison, and T.J. O'Shea. 2005. Survival and condition of big brown bats (*Eptesicus fuscus*) after radiotagging. Journal of Mammalogy 86:95-98.

New York State Department of Environmental Conservation, United States Department of Interior, and National Oceanic and Atmospheric Administration. 2004. Hudson River NRDA Floodplain Data Summary. 57 pp. Available at: http://www.darrp.noaa.gov/northeast/hudson/pdf/floodplain_2004.pdf (Accessed December 5, 2006).

O'Brien, R.D. 1967. Insecticides: action and metabolism. Academic Press, New York, NY. 322+ pp.

O'Donnell, C. 2000. Cryptic local populations in a temperate rainforest bat *Chalinolobus tuberculatus* in New Zealand. Animal Conservation 3:287-297.

Olson, R. 1996. This old cave: the ecological restoration of the historic entrance ecotone of Mammoth Cave, and mitigation of visitor impact. Pp. 87-95 *in* Proceedings of Mammoth Cave National Park's Fifth Science Conference. U.S. National Park Service, Mammoth Cave National Park, Mammoth Cave, KY.

Ormsbee, P.C., J. Kiser, and S.I. Perlmeter. In press. The importance of night roosts to the ecology of forest bats. *In* M.J. Lacki, J.P. Hayes, and A. Kurta (eds), Bats in forests: conservation and management. Johns Hopkins University Press, Baltimore, MD. (Scheduled for publication in December 2006).

Osgood, F.L., Jr. 1938. The mammals of Vermont. Journal of Mammalogy 19:435-441.

O'Shea, T.J. and D.R. Clark, Jr. 2002. An overview of contaminants in bats, with special reference to insecticides and the Indiana bat. Pp. 237-253 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Palm, J. 2003. Indiana bat (*Myotis sodalis*) summer roost tree selection and habitat use in the Champlain Valley of Vermont. M.S. Thesis. Antioch University, Keene, NH. 44 pp.

Parker, G.R. and C. M. Ruffner. 2004. Current and historical forest conditions and disturbance regimes in the Hoosier-Shawnee Ecological Assessment area. Pp. 23-58 *in* F.R. Thompson III (ed.), The Hoosier-Shawnee Ecological Assessment. General Technical Report NC-244. U.S. Forest Service, North Central Research Station, St. Paul, MN. 267 pp.

Parsons, K.N., G. Jones, and F. Greenaway. 2003. Swarming activity of temperate zone microchiropteran bats: effects of season, time of night and weather conditions. Journal of Zoology(London) 261:257-264.

Patterson, B.D., M.R. Willig, and R.D. Stevens. 2003. Trophic strategies, niche partitioning, and patterns of ecological organization. Pp. 536-579 *in* T. Kunz and M.B. Fenton (eds.), Bat Ecology. The University of Chicago Press, Chicago, IL.

Pearson, E.W. and T.R.B. Barr. 1962. Absence of rabies in some bats and shrews from southern Illinois. Transactions of the Illinois State Academy of Sciences 55:35-37.

Peurach, S. 2004. History and current status of the Bat Banding Office, National Museum of Natural History. Bat Research News 45:35-41.

Platonow, N. and L. Karstad. 1973. Dietary effects of polychlorinated biphenyls on mink. Canadian Journal of Comparative Medicine 37:391-400.

Posluszny, E.T and C.M. Butchkoski. 2000. Pennsylvania case studies to secure underground mine workings for bat habitat. Pp. 159-168 *in* K.C. Vories and D. Throgmorton (eds.), Proceedings of Bat Conservation and Mining: a technical interactive forum. U.S. Department of Interior, Office of Surface Mining and Coal Research Center, Southern Illinois University, IL.

Powers, R. D. 1993. Design improvements for gating bat caves. Pp. 356-358 *in* D. L.Foster, D. G. Foster, M. M. Snow, and R. K. Snow (eds.), 1991 National Cave Management Symposium Proceedings. American Cave Conservation Association, Horse Cave, KY.

Pruitt. L. 1995. Summary of Jefferson Proving Ground bat surveys: 1993-1995. U.S. Fish and Wildlife Service, Bloomington Field Office, Bloomington, IN. 5 pp.

Pulliam, H. R. 1988. Sources, sinks, and population regulation. American Naturalist 132:652-661.

Quisand, G.B., L.U. Staiger, G.C. Jamieson, and D.A. Schooley. 1982. Metabolism of fluvalinate by a lactating cow. Journal of Agricultural and Food Science 30:895-901.

Racey, P.A. 1982. Ecology of bat reproduction. Pp. 57-104 *in* T.H. Kunz (ed.), Ecology of bats. Plenum Press, New York, NY. 425 pp.

Racey, P.A. and A.C. Entwistle. 2000. Life history and reproductive strategies of bats. Pp. 363-414 *in* E.G. Chrichton and P.H. Krutzsch (eds.), Reproductive Biology of Bats. Academic Press, New York., NY.

Racey, P.A. and A.C. Entwistle. 2003. Conservation ecology of bats: reproduction. Pp. 680-743 *in* T.H. Kunz and M.B. Fenton (eds.), Ecology of bats. University of Chicago Press, Chicago, IL.

Remington, C.L. 1968. The population genetics of insect introduction. Annual Review of Entomology 13:415-450.

Restum, J., S. Bursian, J. Giesy, J. Render, W. Helferich, E. Shipp, D. Verbrugge, and R. Aulerich. 1998. Multigenerational study of the effects of consumption of PCB-contaminated carp from Saginaw Bay, Lake Huron, on mink: 1. Effects on mink reproduction, kit growth, and survival, and selected biological parameters. Journal of Toxicology and Environmental Health Part A 54:343-375.

Rice, C.P., P. O'Keefe, and T. Kubiak. 2003. Sources, pathways, and effects of PCBs, dioxins, and dibenzofurans. Pp. 501-576 *in* D.J. Hoffman, B.A. Rattner, G.A. Burton, Jr., and J. Cairns, Jr. (eds.), Handbook of Ecotoxicology. Boca Raton, FL.

Richardson, J.J., Jr. 2003. Local land use regulation of karst in the United States. Pp. 492-501 *in* B.F. Beck (ed.), Sinkholes and the Engineering and Environmental Impacts of Karst. Proceedings of the Ninth Multidisciplinary Conference, The Geo-Institute of the American Society of Civil Engineers, The National Ground Water Association, P.E. LaMoreaux & Associates, Inc.

Richter, A.R., S.R. Humphrey, J.B. Cope, and V.W. Brack, Jr. 1993. Modified cave entrances: thermal effect on body mass and resulting decline of endangered Indiana bats (*Myotis sodalis*). Conservation Biology 7:407-415.

Ringer, R.K. 1983. Toxicology of PCBs in mink and ferrets. Pp. 227-240 *in* F.M. D'Itri and M.A. Kamrin (eds.), PCBs: human and environmental hazards. Butterworth Publishers, Woburn, MA.

Ritzi, C.M., B.L. Everson, and J.O. Whitaker, Jr. 2005. Use of bat boxes by a maternity colony of Indiana myotis (*Myotis sodalis*). Northeastern Naturalist 12:217-220.

Ritzi, C.M., T.A. Wethington, and J.O. Whitaker, Jr. 2002. A summary of ectoparasites, including new host records. Pp. 216-220 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Rodrigue, J.L. 2004. Biological Asssement: Fernow Experimental Forest. Final Report, USDA Forest Service Northeastern Research Station, Parsons, WV. 105 pp. Available at: http://www.fs.fed.us/ne/parsons/Environmental_Impact_Statement/index.htm.

Rodriguez, J.P. 2002. Range contraction in declining North American bird populations. Ecological Applications 12:238-248.

Rommé, R.C., K. Tyrell, and V. Brack, Jr. 1995. Literature summary and habitat suitability index model: components of summer habitat for the Indiana bat, *Myotis sodalis*. Report submitted to the Nongame Program, Indiana Department of Natural Resources, Bloomington, IN. 43 pp.

Rommé, R.C., A.B. Henry, R.A. King, T. Glueck, and K. Tyrell. 2002. Home range near hibernacula in spring and autumn. Pp. 153-158 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species Bat Conservation International, Austin, TX.

Rubinoff, J., S. Sekscienski, S. Belfit, and T. Wills. 2006. Installation summaries from the 2005 survey of threatened and endangered species on Army lands. Technical Report (TR) 2006002, U.S. Army Environmental Center, Aberdeen Proving Ground, Maryland. 21+ pp. Available at: http://aec.army.mil/usaec/natural/tes-fy05.pdf. (Accessed October 27, 2006).

Russell, A.L., C. Butchkoski, A. Tibbels, and G.F. McCracken. 2002. Bats, road-kill, and the FBI (flat bat investigation). Bat Research News 43:180.

Ryan, J.M., D.A. Stilwell, and N.J. Morse. 1992. An evaluation of contaminant exposure of three endangered bat species in Virginia. U.S. Fish and Wildlife Service, Environmental Contaminants Program, White Marsh, VA. 20 pp.

Sagarin R.D. and S.D. Gaines. 2002. The "abundant centre" distribution: to what extent is it a biogeographical rule? Ecology Letters 5:137-147.

Sanders, C., J. Chenger, and B. Denlinger. 2001. Williams Lake telemetry study: New York Indiana bat spring migration tracking study. Report for Bat Conservation and Management. 21 pp. Available at: www.batmanagement.com.

Scherer, A. 2000. A survey for the Federally listed endangered Indiana bat (*Myotis sodalis*), Picatinny Arsenal, Morris County, New Jersey. Report prepared for U.S. Army Tank, Automotive and Armaments Command, Armament Research Development and Engineering Center, Picatinny Arsenal, Morris County, NJ. 27+ pp.

Schmitt, C.J., J.L. Zajicek, T.W. May, and D.F. Cowman. 1999. Organochlorine residues and elemental contaminants in U.S. freshwater fish, 1976-1986: National Contaminants Biomonitoring Program. Reviews of Environmental Contamination and Toxicology 162:43-104.

Schultes, K.L. 2002. Characteristics of roost trees used by Indiana bats (*Myotis sodalis*) and northern bats (*M. septentrionalis*) on the Wayne National Forest, Ohio. M.S. Thesis. Eastern Kentucky University, Richmond, KY. 147 pp.

Schultes, K.L. and C. Elliot. 2002. Roost tree selection by Indiana bats and northern bats on the Wayne National Forest, Ohio. Final report prepared for the U.S. Fish and Wildlife Service, Ecological Services Field Office, Reynoldsburg, OH. 107 pp.

Schowalter, D.B., J.R. Gunson, and L.D.Harder. 1979. Life history characteristics of little brown bats (*Myotis lucifugus*) in Alberta. Canadian Field Naturalist 93:243-251.

Schwartz, C.C., R. B. Harris, and M. A. Haroldson. 2006. Impacts of spatial and environmental heterogeneity on grizzly bear demographics in the Greater Yellowstone Ecosystem: A source-sink dynamic with management consequences. Wildlife Monographs 161:57-67.

Scudder, G.G.E. 1989. The adaptive significance of marginal populations: a general perspective. Pp. 180-185 *in* C.D. Levings, L.D. Holtby, and M.A. Henderson (eds.), Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. Canadian Special Publication of Fisheries and Aquatic Sciences 105:180-185.

Shaffer, M.L. and B.A. Stein. 2000. Safeguarding our precious heritage. Pp. 301-321 *in* B.A. Stein, L.S. Kutner, and J.S. Adams (eds.), Precious Heritage: The Status of Biodiversity in the United States. Oxford University Press, New York, NY

Shore, R.F., D.G. Myhill, M.C. French, D.V. Leach, and R.E. Stebbings. 1991. Toxicity and tissue distribution of pentachlorophenol and permethrin in pipistrelle bats experimental exposed to treated timber. Environmental Pollution 73:101-118.

Silliman, B.S., Jr., J.D. Dana, and W. Gibbs. 1851. On the Mammoth Cave of Kentucky. American Journal of Science and Arts (Second Series) 11:332-339.

Smith, G.J. 1987. Pesticide use and toxicology in relation to wildlife: organophosphorous and carbamate compounds. U.S. Department of the Interior, U.S. Fish and Wildlife Service Resource Publication 170. 171 pp.

Smith, W.B., P.D. Miles, J.S. Vissage, and S.A. Pugh. 2003. Forest resources of the United States, 2002. U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN. General Technical Report NC-241. 137 pp.

Spanjer, G.R. and M.B. Fenton. 2005. Behavioral responses of bats to gates at caves and mines. Wildlife Society Bulletin 33:1101-1112.

Sparks, D.W. 2003. How does urbanization impact bats? Ph.D. Dissertation. Indiana State University, Terre Haute, IN. 121 pp.

Sparks D.W., M.T. Simmons, C.L. Gummer, and J.E. Duchamp. 2003. Disturbance of roosting bats by woodpeckers and raccoons. Northeastern Naturalist 10:105-8.

Sparks, D.W., C.M. Ritzi, J.E. Duchamp, and J.O. Whitaker, Jr. 2005a. Foraging habitat of the Indiana bat, (*Myotis sodalis*) at an urban-rural interface. Journal of Mammalogy 86:713-718.

Sparks, D.W., J.O. Whitaker, Jr., and C.M. Ritzi. 2005b. Foraging ecology of the endangered Indiana bat. Pp. 15-27 *in* K.C. Vories and A. Harrington (eds.), The Proceedings of the Indiana bat and coal mining: a technical interactive forum Office of Surface Mining, U.S. Department of the Interior, Alton, IL. Available at: http://www.mcrcc.osmre.gov/PDF/Forums/Bat%20Indiana/TOC.pdf. (Accessed October 17, 2006).

Sparks, D.W., T.P. Simon, M.J. Tosick, D.S. Millsap, and D.S. Henshel. 2005c. Creek chub (*Semotilus atromaculatus* Mitchill) reproduction in PCB-contaminated streams in Indiana. Pp. 201-202 in Abstracts of the 26th Annual Meeting Society of Environmental Toxicology and Chemistry, Baltimore, MD, November 13-17, 2005.

Sparks, D.W. 2006. Organophosphate insecticide residues in bats from Indiana. U.S. Fish and Wildlife Service, Environmental Contaminants Program, Bloomington, IN. 12 pp.

Speakman, J.R. and P.A. Racey. 1989. Hibernal ecology of the pipistrelle bat: energy expenditure, water requirements and mass loss, implications for survival and the function of winter emergence flights. Journal of Animal Ecology 58:797-813.

Speakman, J.R. and D.W. Thomas. 2003. Physiological ecology and energetics of Bats. Pp. 430-490 *in* T. H. Kunz and M.B. Fenton (eds.), Bat Ecology. University of Chicago Press, Chicago, IL.

Speakman, J.R., P.I. Webb, and P.A. Racey. 1991. Effects of disturbance on the energy expenditure of hibernating bats. Journal of Applied Ecology 28:1087-1104.

Stansley, W.D., E. Roscoe, E. Hawthorne, and R. Mayer. 2001. Food chain aspects of chlordane poisoning in birds and bats. Archives of Environmental Contamination and Toxicology 40:285-291.

Stihler, C. 2005. Hellhole Cave, Pendleton County, West Virginia: results of the winter bat survey conducted on 26 February 2005. Unpublished report. West Virginia Division of Natural Resources, Wildlife Resources Section, Wildlife Diversity Program. 29 pp.

Suzuki, T. 1979. Dose-effect and dose-response relationships of mercury and its derivatives. Pp. 399-431 *in* Nriagu, J.O. (ed.), The biogeochemistry of mercury in the environment. Elsevier / North-Holland Biomedical Press, New York, NY.

Thomas, D.W. 1995. The physiological ecology of hibernation in vespertilionid bats. Symposia of the Zoological Society of London 67:233-244.

Thomas, D.W. and D. Cloutier. 1992. Evaporative water loss by hibernating little brown bats, *Myotis lucifugus*. Physiological Zoology 65:443-456.

Thomas, D.W. and F. Geiser. 1997. Periodic arousals in hibernating mammals: is evaporative water loss involved? Functional Ecology 11:585-591.

Thomas, D.W., M. Dorais, and J.M. Bergeron. 1990. Winter energy budgets and cost of arousals for hibernating little brown bats, *Myotis lucifugus*. Journal of Mammalogy 71:475-479.

Thomson, C.E. 1982. *Myotis sodalis*. Mammalian Species. The American Society of Mammalogists 163:1-5.

Tillitt, D.E., G.T. Ankley, J.P. Giesy, J.P. Ludwig, H. Kurita-Matsuba, D.V. Weseloh, P.S. Ross, C.A. Bishop, L. Sileo, K.L. Stomborg, J. Larson, and T.J. Kubiak. 1992. Polychlorinated biphenyl residues and egg mortality in double-crested cormorants from the Great Lakes. Environmental Toxicology and Chemistry 11:1281-1288.

Timpone, J.D. 2004. Roost-site selection of bats in Northeast Missouri with emphasis on the endangered Indiana bat (*Myotis sodalis*). M.S. Thesis. Southwest Missouri State University, Springfield, MO. 63 pp.

Toomey, R.S., III, M.L. Colburn, and R.A. Olson. 2002. Paleontological evaluation of use of caves: a tool for restoration of roosts. Pp. 79-85 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Tuttle, M.D. 1975. Population ecology of the gray bat (*Myotis grisescens*): Factors influencing early growth and development. Occasional Papers of the Museum of Natural History and Department of Systematics and Ecology, The University of Kansas, Lawrence, KS 36:1-24.

Tuttle, M.D. 1977. Gating as a means of protecting cave-dwelling bats. Pp. 77-82 *in* T. Aley and D. Rhodes (eds.), National Cave Management Symposium Proceedings. Mountain View, AR.

Tuttle, M.D. 1996. Wisconsin gains key bat sanctuary. Bats 14(4):3-7.

Tuttle, M.D. 1997. A mammoth discovery. Bats 15:3-5.

Tuttle, M.D. 1999. Former home of more than a million endangered Indiana bats protected. Bats 17(3):8-9.

Tuttle, M.D. and A.R. Taylor. 1998. Bats and mines. Bat Conservation International. Resource Publication No. 3. Austin, TX. 41 pp. Available at: http://www.batcon.org/news2/mines/batsmines_34-37.pdf. (Accessed August 14, 2006).

Tuttle, M.D. and J. Kennedy. 2002. Thermal requirements during hibernation. Pp. 68-78 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Tuttle, M.D. and D.E. Stevenson. 1977. An analysis of migration as a mortality factor in the gray bat based on public recoveries of banded bats. American Midland Naturalist 97:235-240.

Tuttle, M.D. and D. Stevenson. 1978. Variation in the cave environment and its biological implications. Pp. 108-121 *in* R. Zuber, J. Chester, S. Gilbert, and D. Rhodes (eds.), 1977 National Cave Management Symposium Proceedings. Adobe Press, Albuquerque, NM. 140 pp.

Tuttle, M.D. and D. Stevenson. 1982. Growth and survival of bats. Pp. 105-150, *in* T.H. Kunz (ed.), Ecology of bats. Plenum Press, New York, NY. 425 pp.

U.S. Environmental Protection Agency. Undated. US EPA dichlorvos: preliminary environmental effects assessment. 62 pp. Available at: http://www.epa.gov/oppsrrd1/op/ddvp/efedrisk.pdf

U.S. Fish and Wildlife Service (USFWS). 1976. Determination of critical habitat for American crocodile, California condor, Indiana bat, and Florida manatee. Final rule. 41 FR:41914-41916, September 24, 1976.

U.S. Fish and Wildlife Service (USFWS). 1983. Recovery plan for the Indiana bat. U.S. Fish and Wildlife Service, Washington, DC. 80 pp.

U.S. Fish and Wildlife Service (USFWS). 2003. Biological opinion on the issuance of Section 404 permit to the Monon Ditch Joint Drainage Board for a drainage improvement project on Big Monon Ditch in Pulaski, Starke and White Counties, Indiana. USFWSEcological Services Field Office, Bloomington, IN. 23 pp.

U.S. Fish and Wildlife Service (USFWS). 2004a. Biological opinion on the impacts of the Laxare East and Black Castle contour coal mining projects on the Indiana bat. USFWS Ecological Services Field Office, Elkins, WV. 144 pp.

U.S. Fish and Wildlife Service (USFWS). 2004b. Final biological opinion in implementation of the revised Land and Resource Management Plan and its effects on the Indiana bat, Daniel Boone National Forest, KY. USFWS Ecological Services Field Office, Frankfort, KY. 54 pp.

U.S. Fish and Wildlife Service (USFWS). 2006. Proceedings of the Indiana Bat Workshop: An Exercise in Risk Assessment and Risk Management. U.S. Department of Interior, U.S. Fish and Wildlife Service, National Conservation Training Center, Shepherdstown, WV. 49 pp + 13 appendices.

U.S. Forest Service. 2005. A snapshot of the northeastern forests, NA-IN-01-06. U.S. Department of Agriculture, Forest Service, Northeastern Area, State and Private Forestry. Newton Square, PA. 23 pp.

U.S. Forest Service. 2006. NCRS–the changing Midwest assessment. U.S. Department of Agriculture, Forest Service, North Central Research Station. Available at: http://www.ncrs.fs.fed.us/4153/deltawest/landcover. (Accessed: January 25, 2006).

Verboom, B. and H. Huitema. 1997. The importance of linear landscape elements for the pipistrelle *Pipistrellus pipistrellus* and the serotine bat *Eptesicus serotinus*. Landscape Ecology 12:117-125.

Viele, D.P., A. Kurta, and J. Kath. 2002. Timing of nightly emergence. Pp. 199-207 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Vories, K.C. and A. Harrington. 2005. Proceedings of the Indiana bat and coal mining: a technical interactive forum. U.S. Department of the Interior, Office of Surface Mining, Alton, IL. 229 pp. Available at: Available at: http://www.mcrcc.osmre.gov/PDF/Forums/Bat%20Indiana/TOC.pdf. (Accessed October 27, 2006).

Vories K.C. and D. Throgmorton. 2000. Proceedings of bat conservation and mining: a technical interactive forum. U.S. Department of Interior, Office of Surface Mining and Coal Research Center, Southern Illinois University, Carbondale, IL. 378p. Available at: http://www.mcrcc.osmre.gov/PDF/Forums/Bat%20Conservation/TOC.pdf. (Accessed October 27, 2006).

Vories, K.C., and D. Throgmorton. 2002. Proceedings of Bat Gate Design: A Technical Interactive Forum. U.S. Department of the Interior, Office of Surface Mining, Alton, IL and Coal Research Center, Southern Illinois University, Carbondale, IL. 434 pp.

Available at: http://www.mcrcc.osmre.gov/PDF/Forums/Bat%20Gate%20Design/TOC.pdf. (Accessed October 27, 2006).

Vucetich, J.A. and T.A. Waite. 2003. Spatial patterns of demography and genetic processes across the species' range: Null hypotheses for landscape conservation genetics. Conservation Genetics 4:639-645.

Watrous, K.S., T.M. Donovan, R.M. Mickey, S.R. Darling, A.C. Hicks, and S.L. von Oettingen. In press. Predicting minimum habitat characteristics for the Indiana bat in the Champlain Valley. Journal of Wildlife Management.

Wear, D.N. and J.G. Greis (eds.). 2002. Southern forest resource assessment. General Technical Report SRS-53. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC. 635 pp.

Whitaker, J.O., Jr. 2004. Prey selection in a temperate zone insectivorous bat community. Journal of Mammalogy 85:460-469.

Whitaker, J.O., Jr. and V. Brack, Jr. 2002. Distribution and summer ecology in Indiana. Pp. 48-54 *in* A. Kurta and J. Kennedy (eds.), The Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, TX.

Whitaker, J.O., Jr. and L.R. Douglas. In press. Bat rabies in Indiana, 1966-2003. Journal of Wildlife Management.

Whitaker, J.O., Jr. and C.L. Gummer. 2002. Bats of Camp Atterbury, with emphasis on roosting of Indiana Myotis and evening bats 2002. Report for the Military Department of Indiana. 51 pp plus appendices.

Whitaker, J.O., Jr. and D.W. Sparks. 2003. 2002 Monitoring program for the Indiana myotis (*Myotis sodalis*) near the site of the future Six Points interchange in Hendricks and Marion Counties, Indiana as required under the Six Points Interchange Habitat Conservation Plan. 46 pp.

Whitaker, J.O., Jr., J.B. Cope, and V. Brack, Jr. 2003. Bats of Wyandotte Cave. Proceedings of the Indiana Academy of Science 112:75-84.

Whitaker, J.O., Jr., J. Deunff, and J.J. Belwood. 2000. Ectoparasites of neonate Indiana bats, *Myotis sodalis* (Chiroptera: Vespertilionidae), with description of male of Paraspinturnix globosa (Acari: Spinturnicidae). Journal of Medical Entomology 37:446-453.

Whitaker, J.O., Jr., D.W. Sparks, and V. Brack, Jr. 2004. Bats of the Indianapolis International Airport Area, 1991-2001. Proceedings of the Indiana Academy of Science 113:151-161.

Whitaker, J.O., Jr., D.W. Sparks, C.M. Ritzi, and B.L. Everson. 2005a. 2004 Monitoring program for the Indiana myotis (*Myotis sodalis*) near the site of the future Six Points interchange in Hendricks and Marion Counties, Indiana as required under the Six Points Interchange Habitat Conservation Plan. 60 pp. plus appendices.

Whitaker, J.O., Jr., D. Sparks, J. Boyles, D. Judy, J. Burskey, and C. Ritzi. 2005b. 2005 Monitoring program for the Indiana myotis (*Myotis sodalis*) near the site of the future Six Points interchange in Hendricks and Marion Counties, Indiana as required under the Six Points Interchange Habitat Conservation Plan. 82 pp. plus appendices.

Wilhide, J.D., M.J. Harvey, V.R. MacDaniel, and V.E. Hoffman. 1998. Highland pond utilization by bats in the Ozark National Forest, Arkansas. Journal of the Arkansas Academy of Science 52:110-112.

Willis, C.K.R. and R.M. Brigham. 2004. Roost Switching, roost sharing and social cohesion: forest-dwelling big brown bats, *Eptesicus fuscus*, conform to the fission-fusion model. Animal Behaviour 68: 495-505.

Willis, C.K.R., J.E. Lane, E.T. Likness, D.L. Swanson, and R.M. Brigham. 2005. Thermal energetics of female big brown bats (*Eptesicus fuscus*). Canadian Journal of Zoology 83:871-879.

Williams, B.K., J.D. Nichols, M.J. Conroy. 2002. Analysis and management of animal populations. Academic Press, San Diego, CA 817 pp.

Winhold, L. and A. Kurta. 2006. Aspects of Migration by the Endangered Indiana Bat, *Myotis sodalis*. Bat Research News 47:1-11.

Winhold, L., E. Hough, and A. Kurta. 2005. Long-term fidelity by tree-roosting bats to a home area. Bat Research News 46:9-10.

APPENDIX 1: Summary of Comments on the 1999 Agency Draft Indiana Bat (*Myotis sodalis*) Revised Recovery Plan

The U.S. Fish and Wildlife Service released an agency draft Indiana Bat revised recovery plan for public comment in April 1999 (64 FR 17406, April 9, 1999). That draft was never completed. Substantial new information regarding the Indiana bat has been collected since the 1999 draft was prepared. Therefore, the Service chose to prepare a new revised draft. Individuals who commented on the previous draft are encouraged to review and comment on the current draft.

The Service reviewed the 218 comment letters received on the 1999 draft in preparing the current draft. We provide following summary of major issues raised on the 1999 draft, and a brief explanation of how those comments were addressed in the current revised draft.

1. Seventeen letters included comments and/or specific data regarding distribution of the Indiana bat (i.e., additions or corrections to distribution data presented in the 1999 draft revision). All of these letters were reviewed and appropriate changes to text, tables, and maps on distribution data have been made.

2. Many commenters were concerned that the Service did not address the need for protection of summer habitat, and particularly the protection of maternity colonies. The Service concurs that the need for protection of summer habitat and maternity colonies needs to be explicitly addressed, and the current draft reflects this need:
a) The section of the plan that addresses Indiana bat conservation efforts has been expanded compared to the previous draft, and includes a discussion that highlights efforts which have been made to identify and protect maternity colonies of Indiana bats (see Conservation Efforts: Location and Protection of Maternity Colonies section).
b) The requirement of 10-years of positive population growth in each Recovery Unit before reclassification and delisting (Reclassification Criterion 3 and Delisting Criterion 3) indirectly ensures that summer habitat protection is addressed because without adequate summer habitat the populations will not increase.
c) Recovery actions have been developed specifically to address the need to protect maternity colonies. This information is in the Recovery Narrative section under the heading 2.4 Monitor and manage known maternity colonies.

3. Many comments were received regarding the characterization of summer habitat in the 1999 draft. Generally, commenters felt that the discussion of summer habitat was not sufficient, and there was criticism of specific aspects of the characterization of summer habitat. Extensive information published (as well as unpublished reports) since the 1999 draft have been incorporated into the current draft revision. Note that approximately 45 percent of the citations in the Literature Cited section were published in 1999 or later. Many of these citations address summer habitat and the discussion of summer habitat is greatly expanded and more comprehensive. In addition, specific issues raised in the comments on the 1999 draft have been clarified in the text of the current draft.

4. Many commenters wanted more prescriptive guidance for land managers, particularly with reference to summer habitat. The Service acknowledges the need for guidance of this nature and has addressed this need in the revised plan to the extent feasible, while also developing Recovery Actions to address information gaps that have hindered the development of guidance. Specific issues addressed include:
a) To the extent feasible, more specific information on habitat parameters (both for hibernation and summer habitat) have been incorporated into the current draft. For example, the current draft contains an expanded discussion of the species and size of trees used as roosts by Indiana bats. However, we also highlight gaps in our knowledge regarding this species which make it difficult to provide management prescriptions. For example, the Hibernacula Microclimate section reflects that questions remain regarding the optimal temperature range for Indiana bat hibernation.
b) Recovery Actions have been developed specifically to address the development of guidance for management of summer habitat. This information is in the Recovery Narrative section under the headings 2.1, 2.2, and 2.3.
c) Recovery Actions have been developed specifically to address the development of guidance for management of hibernacula and winter populations. This information is in the Recovery Narrative under the heading 1.1 Conserve and manage hibernacula and their winter populations, and more specifically under the subheading 1.1.1.2 Develop site-specific, Hibernacula Management Plans for important hibernacula.
d) Research designed to fill information gaps, the results of which will be used to further refine management guidance, is identified in the Recovery Narrative section under the heading 3.0 Plan and conduct research essential for the recovery of Indiana bats.

5. The reclassification and delisting criteria in the 1999 draft was:

> "The Criteria for reclassification will be based upon the status of the Indiana bat throughout its range, as determined through a 12 year, two-stage process. The species will be evaluated for reclassification from endangered to threatened following documentation of stable or increasing populations for three consecutive census periods (six years) and permanent protection (i.e., public ownership or long-term easement/lease, and gate/fence [where necessary and feasible]) at all Priority One hibernacula. To delist, the above criteria must be met, in addition to protection and documentation of stable or increasing populations for three consecutive census periods at 50% of the Priority Two hibernacula in each state, and the overall population level must be restored at least to that of 1980. This level is believed to be sufficient to maintain enough genetic diversity to enable the species to persist over a large geographic area and avoid extinction."

There was widespread criticism of the delisting criteria, particularly with regard to the requirement that "the overall population level must be restored at least to that of 1980." Many commenters did not consider this population level sufficient for delisting because it represented a much lower population than occurred at the time of listing.

The reclassification and delisting criteria are more comprehensive in the current draft:
a) The current draft includes Reclassification Criterion 2 (repeated as Delisting Criterion 2): "A minimum overall population estimate equal to the 2005 population estimate of 457,000." The 2005 population estimate is lower than the 1980 level specified in the 1999 plan. However, as

noted in the justification for the criterion: "Because of lack of information on the species demographic parameters, it is not possible to calculate a minimum viable population number for this species or to justify biologically an overall numerical population goal. Furthermore, a low population number was not one of the reasons that the bat was originally listed as endangered; the species was listed because of vulnerability to human and environmental disturbance and subsequent large-scale declines (Barbour and Davis 1969, Mohr 1972, Greenhall 1973, L. Pruitt, pers. comm., 2006). Species experts consider the 2005 population estimate of 457,374 to be an adequate number for recovery as long as the threats to the species have been alleviated, the population growth rate has been positive, and there is a rangewide distribution that incorporates the need for redundancy, resiliency, and representation."
b) Other criteria address the need to alleviate threats. Specifically, see Reclassification Criterion 1 (Permanent protection at 80% of all Priority 1 hibernacula in each Recovery Unit) and Delisting Criterion 1 (Protection of a minimum of 50% of Priority 2 hibernacula).
c) Criteria have also been developed to ensure that Indiana bat reclassification and delisting will be dependent on a rangewide distribution that reflects the need for redundancy, resiliency, and representation. Specifically, see Reclassification Criterion 3 (Documentation using statistically reliable information that shows a positive annual population growth rate over a 10-year period of time in each Recovery Unit).

6. Commenters provided input on issues that need to be addressed through further research. Three research areas stressed in comment letters were the need to evaluate reproductive success of maternity colonies, temperature (and humidity) requirements of hibernating bats, and swarming ecology of the Indiana bat. Another point made by several commenters was the need for more specificity in research recommendations, and better prioritization of research needs (i.e., too many research needs were identified as Priority 1). All of these comments were considered in preparing the current draft. Research needs are addressed in the Recovery Narrative section under the heading 3.0 Plan and conduct research essential for the recovery of Indiana bats. Specifically, several actions are identified under 3.1 (Conduct research on the population biology of Indiana bats) that address the need to evaluate demographic parameters, including the reproductive success of maternity colonies. Recovery Actions identified in 3.2 (Conduct research on the physiological and ecological requirements of Indiana bats in relation to hibernation, and characterize the most important features of key hibernacula) address the need to characterize microclimate needs of hibernating bats. The need to conduct research on swarming ecology of the Indiana bat is addressed in 3.3.7 (Improve understanding of the importance of autumn swarming).

APPENDIX 2: Rangewide distribution records for *Myotis sodalis*

Background

In 1995, the Indiana Bat Recovery Team requested distributional data in a letter sent to consultants, researchers, and authorities on endangered species in 28 states (Gardner and Cook 2002). From the responses received from this data request and other published and unpublished records, Gardner and Cook (2002) developed a rangewide database of county distributional records for the Indiana bat and used GIS software (ArcInfo® and ArcView®) to examine the bat's geographic distribution and to produce seasonal distribution maps. In June 2005, the Service's Bloomington Field Office (BFO) e-mailed an Indiana bat hibernacula data request to over 75 individuals including Service biologists, Recovery Team members, bat researchers, state and Federal agency biologists, consultants, and other bat conservation partners in 27 states, who in turn forwarded the request to other colleagues. Hibernacula data were received from all 27 states. BFO biologists used the combined responses from the 1995 and 2005 data requests, existing Recovery Team records, and other published and unpublished records, to develop a GIS-based hibernacula database containing detailed information for all known (i.e., current and historic) hibernacula with one or more Indiana bat winter occurrence records (A. King, pers. comm., 2005). BFO also requested Recovery Team members and Service biologists from across the species' range to provide updates to Gardner and Cook's (2002) summer and winter distribution maps during an Indiana Bat Risk Assessment Workshop in March 2005 and subsequent e-mails sent after the close of the 2005 summer reproductive season. Additional maternity colony data was obtained in response to a data request e-mailed to Service Field Offices throughout the species' range in February 2006. All distribution records/maps have been updated through at least October 2006.

Definitions

For consistency, evidence of a maternity colony at a particular locality was considered to be a juvenile and/or a pregnant, lactating, or post-lactating adult female captured from May 15 to August 15. Occasionally, bats that were collected outside this period were considered to be a record of reproduction, but only if the investigator had valid reasons to suspect a record reflected local reproduction. In this appendix, the "No. of Extant Maternity Colonies" column includes the same records as those in Table 4, but also includes records of any secondary counties (shown in parentheses) that are being used by colonies that primarily occupy habitat in another adjacent county.

Most of the "Other Summer Records" are adult males and/or nonreproductive adult females caught between May 15 and August 15. Records of maternity colonies that for various reasons are no longer considered extant have also been included in this column to insure these summer distribution records are documented for the county (e.g., a maternity colony in Graham County, North Carolina that could not be found during a subsequent survey was included under this column heading).

The majority of winter records in this appendix are of bats that were observed in hibernacula during biennial winter surveys conducted between December 1 and March 15. A P1 hibernaculum is a site with a current or historic population of more than 10,000 hibernating Indiana bats. P2, P3, and P4 hibernacula are those that at one point in time contained a maximum of 1000-9999, 50-999, and <50, respectively. Under the "Current Winter Pop. Status" heading, extant = presence of 1 or more Indiana bats between 1995 and 2006; historic = surveys have been conducted since 1995 but no Indiana bats found; uncertain = no surveys have been conducted/reported to the Service since 1995. The "Max. All-time Pop.Estimate" is the largest population estimate made by a biologist conducting a traditional bat survey (i.e., most maximum estimates were based on direct observations made within the cave/mine since 1960. We have not included other estimates derived from paleontological evidence or other indirect means). The "Max. Estimate Since 2000" is the largest recorded number of Indiana bats in this hibernaculum since the year 2000.

NOTE: Please send any comments/missing data/corrections to the BFO (e-mail to: indiana_bat@fws.gov).

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
ALABAMA	Blount			Crump	cave		uncertain	4	1	0
	Colbert		X							
	De Kalb		X							
	Jackson		X	Fern	cave	Federally owned	historic	3	200	0
				Nitre	cave	Federally owned	uncertain	4	1	0
				Sauta	cave	Federally owned	extant	3	307	281
	Lauderdale		X	Saltpetre	cave	Federally owned	uncertain	4	1	0
	Lawrence		X	Armstrong	cave	Federally owned	extant	4	21	21
				Backward Confusion	cave	Federally owned	extant	4	6	6
	Limestone		X							
	Marshall		X	Cathedral Caverns	cave	State-owned	extant	4	3	3
				King's School	cave	State-owned	extant	4	1	0
	Morgan		X	Hughes	cave	Private Individuals(s)	uncertain	4	11	0
	Shelby		X							
ARKANSAS	Baxter			Twigly	cave	Private Individuals(s)	uncertain	4	1	0
	Benton		X	Cave Springs	cave	Private & Public	historic	4	1	0
				Logan	cave	Federally owned	historic	4	1	0
				War Eagle Cavern	cave	Private Individuals(s)	historic	3	150	0
	Clay	1	X							
	Craighead		X							
	Franklin			Rosson Hollow Crevices	cave	Federally owned	extant	3	125	105
	Independence		X	Cushman	cave	Private Individuals(s)	historic	4	1	0
				Dodd	cave	Private Individuals(s)	historic	4	?	0
				Hankins	cave	Private Individuals(s)	historic	3	240	0
	Madison		X	Horsethief	cave	Private Individuals(s)	historic	2	1,000	0
				Mitchell	cave	Private Individuals(s)	uncertain	4	2	0
	Marion		X	Bat	cave	Federally owned	historic	4	4	0
				Elm	cave	Private Individuals(s)	uncertain	4	5	0
				Marble Falls	cave	State-owned	historic	4	1	0
				Reed	cave	State-owned	historic	4	2	0
				Summer	cave	Federally owned	uncertain	4	4	0
	Newton		X	Cave Mountain	cave	Federally owned	extant	2	1,200	300
				Corkscrew	cave	Federally owned	extant	3	60	0

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
AR (continued)	Newton			Edgeman	cave	Private Individuals(s)	extant	2	5,000	1,107
				Fitton	cave	Federally owned	extant	3	300	300
				Flea	cave	Federally owned	historic	4	1	0
				Horseshoe	cave	Federally owned	extant	2	1,600	1,600
				Wolf Creek	cave	Federally owned	extant	3	132	67
	Searcy		X	Bear Creek	cave		uncertain	4	1	0
				Hurricane River	cave	Private Individuals(s)	historic	4	1	0
	Stone		X	Amphitheatre	cave	Federally owned	extant	3	630	360
				Barkshed Saltpetre	cave	Federally owned	extant	3	100	0
				Biology	cave	Federally owned	historic	3	130	0
				Blanchard Springs	cave	Federally owned	extant	4	3	3
				Gustafson	cave	Federally owned	extant	3	600	525
				Hidden Springs	cave	Federally owned	extant	3	135	7
				Joe Bright	cave	Private Individuals(s)	historic	4	1	0
				Rowland	cave	Federally owned	extant	3	400	400
	Washington		X	Devils Den State Park	cave	State-owned	extant	4	49	49
				Nichols	cave	Private Individuals(s)	uncertain	4	6	0
CONNECTICUT	Litchfield			Roxbury Iron Mine	mine	Private Organization	historic	3	224	0
	New Haven			Guelph Aqueduct	other	Private Organization	extant	4	1	0
FLORIDA	Jackson			Old Indian	cave	State-owned	historic	4	1	0
GEORGIA	Catoosa		X							
	Dade		X	Case	cave	State-owned	uncertain	4	2	0
				Sitton's	cave	State-owned	uncertain	4	10	0
	Murray		X							
	Whitfield		X							
ILLINOIS	Adams	2	X	Burton	cave	State-owned	historic	N/A	?	0
	Alexander	1	X	Birk 2	mine	Private Organization	extant	4	1	1
				Birk 3	mine	Private Organization	extant	4	27	27
				Mine 26	mine	Federally owned	extant	3	400	400
				Rhymer	mine	Unknown	extant	4	1	1
				Unimin - Magazine Mine	mine	Private Organization	extant	1	33,500	33,500
				Unimin - Mine 30	mine	Private Organization	extant	2	3,700	3,700
	Bond	1	X							

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
IL (continued)	Cass	1	X							
	Christian		X							
	Clay		X							
	Cook		X							
	Edwards		X							
	Ford	1	X							
	Hardin		X	Cave Spring	cave	Private Organization	historic	3	80	0
				Griffith	cave	Private Individuals(s)	extant	2	1,500	1,500
				Gutherie	cave	Private Individuals(s)	extant	2	1,000	1,000
	Henderson	1								
	Jackson	3	X	Toothless	cave	Private Individuals(s)	extant	2	3,200	740
	Jersey	1	X	Brainerd	cave	State-owned	extant	3	450	450
	Jo Daviess			a lead mine	mine	Unknown	uncertain	4	3	0
	Johnson	(1)	X							
	LaSalle		X	Blackball Mine	mine	State-owned	extant	2	1,804	1,804
	Lawrence		X							
	Macoupin	1								
	Madison		X							
	McDonough		X							
	Monroe	4	X	Fogelpole	cave	State-owned	extant	3	403	171
				Ilinois Caverns	cave	State-owned	uncertain	N/A	?	0
	Morgan		X							
	Perry		X							
	Pike	2	X	Slick Crawl	cave	Private Individuals(s)	uncertain	N/A	?	0
	Pope		X	Brasher	cave	Federally owned	extant	3	500	0
				Ellis	cave	Private Individuals(s)	extant	2	1,557	1,557
	Pulaski	1								
	Randolf	1								
	Saline	1								
	Sangamon		X							
	Schuyler	1								
	St. Clair	1								
	Scott	1								

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
IL (continued)	Union	1	X	Barney Grace Mine	mine	Federally owned	extant	3	519	519
				Guthrie	cave	Unknown	uncertain	4	1	0
				Jason Mine	mine	Federally owned	extant	3	87	87
	Vermilion	1	X							
	Wabash		X							
	Washington	2								
INDIANA	Bartholomew	3	X							
	Blackford	(1)								
	Boone	(1)								
	Brown		X							
	Clark		X							
	Clay		X							
	Clinton	2								
	Crawford	1	X	Batwing	cave	State-owned	extant	1	5,0000	9,350
				Bentz	cave	Unknown	historic	4	8	0
				Robinson Ladder	cave	Private Organization	extant	3	388	366
				Saltpeter-Crawford	cave	State-owned	extant	3	907	907
				Wildcat	cave	State-owned	extant	3	61	35
				Wyandotte	cave	State-owned	extant	1	54,913	54,913
	Daviess	2 (1)	X							
	Dearborn	1								
	Delaware		X							
	Fountain		X							
	Fulton		X							
	Gibson	2 (1)								
	Greene	3	X	Ashcraft	cave	State-owned	extant	4	28	0
				Clyfty	cave	Private Individuals(s)	extant	4 (ET)	575	575
				Ozzy's Hole	cave	Private Individuals(s)	extant	4	1	1
				Ray's	cave	Private Individuals(s)	extant	1	62,464	54,325
				Sexton Spring	cave	Private Individuals(s)	extant	3	117	113
	Hancock	(1)								
	Harrison		X	Binkley	cave	Private Individuals(s)	extant	3	84	9
				Jug Hole	cave	Private Individuals(s)	extant	1	29,430	29,430

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
IN (continued)	Harrison			Parker's Pit	cave	Private Individuals(s)	extant	2	1803	989
				Swinney	cave	Unknown	extant	3	200	200
				Twin Domes	cave	State-owned	extant	1	100,000	50,325
				Wallier	cave	Private Individuals(s)	extant	3	917	917
	Hendricks	2	X							
	Henry	1	X							
	Howard	1								
	Huntington	1								
	Jackson	3	X							
	Jasper	1								
	Jay	1								
	Jefferson	2								
	Jennings	2 (1)	X							
	Johnson	3	X							
	Knox	1 (1)								
	Kosciusko	1	X							
	La Porte	2								
	Lagrange		X							
	Lake	(1)								
	Lawrence		X	Bronson's	cave	State-owned	uncertain	4	4	0
				Donaldson	cave	State-owned	uncertain	4	1	0
				Mitchell Cr. Stone Quarry	cave	Private Organization	extant	4	38	38
				Storm's Pit	cave	Private Individuals(s)	extant	4	28	28
				Sullivan's	cave	Private Organization	extant	4	25	25
	Marion	1 (1)	X							
	Martin	1	X	Bluff House	cave	Federally owned	extant	4	1	1
				Gypsy Bill Allen	cave	Federally owned	extant	3	250	250
	Monroe	2	X	Buckner	cave	Private Individuals(s)	extant	3	500	40
				Coon	cave	Private Individuals(s)	extant	1	10,675	10,675
				Grotto	cave	Private Individuals(s)	extant	1	10,338	10,338
				King Blair/Brinegar	cave	Private Organization	extant	3	663	263
				Leonard Spring	cave	Private Individuals(s)	extant	3	138	138
				Primitive Baptist Spring	cave	Private Individuals(s)	extant	4	1	1

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
IN (continued)	Monroe			Reeves	cave	Private Individuals(s)	extant	4	34	34
				Salamander	cave	Private Individuals(s)	extant	3	74	0
				Saltpeter	cave	Private Individuals(s)	extant	3	245	96
	Montgomery	3	X							
	Morgan	4 (3)	X							
	Newton	1								
	Orange			Nichols	cave	Private Individuals(s)	extant	4	39	39
	Parke	2	X							
	Perry	2	X							
	Pike	2 (2)	X							
	Porter		X							
	Posey	1								
	Pulaski	2								
	Putnam	2	X							
	Randolph	3	X							
	Ripley	2 (1)	X							
	Rush	1	X							
	Scott		X							
	Shelby	2								
	Spencer	1								
	St. Joseph	1								
	Starke		X							
	Steuben	1								
	Sullivan		X							
	Tippecanoe	4	X							
	Vermillion	1	X							
	Vigo	1	X							
	Wabash	2								
	Warren	2								
	Warrick	2	X							
	Washington		X	Endless	cave	Private Individuals(s)	extant	3	957	957
				Panther/Neyman	cave	Private Individuals(s)	extant	3	349	349
				River	cave	Private Individuals(s)	extant	3	104	2

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
IN (continued)	Wayne	1	X							
	Wells	1	X							
IOWA	Appanoose	2								
	Davis	1								
	Decatur	2								
	Des Moines	2								
	Dubuque			Becker's Quarry	cave	Unknown	uncertain	4	3	0
				Yew Ridge	cave		uncertain	4	2	0
	Iowa	1								
	Jasper	1	X							
	Keokuk	1	X							
	Louisa		X							
	Lucas	2								
	Madison	2								
	Marion	7								
	Monroe	1								
	Poweshiek		X							
	Ringgold	1								
	Van Buren	1								
	Wapello	1								
	Washington	2								
KENTUCKY	Adair			Jones	cave	State-owned	historic	4	1	0
	Allen		X							
	Ballard	2								
	Barren			Indian	cave	Private Individuals(s)	historic	3	100	0
	Bath	3								
	Breathitt		X							
	Breckinridge	1		B&O	cave	Private Individuals(s)	extant	2	1,763	1,763
				Big Bat	cave	Private Individuals(s)	extant	3	104	26
				Buzzard	cave	Private Individuals(s)	extant	3	351	242
				Norton Valley	cave	Private Individuals(s)	extant	2	2,000	241
				Penitentiary	cave	Private Individuals(s)	extant	3	81	8
				Thornhill	cave	Private Individuals(s)	extant	2	3,680	0

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
KY (continued)	Bullitt	4								
	Calloway		X							
	Carlisle	(1)								
	Carter		X	Bat (Carter Caves SRP)	cave	State-owned	extant	1	100,000	29,500
				Carter City Caves	cave	Private Individuals(s)	uncertain	3	150	0
				Cascade	cave	State-owned	extant	3	75	75
				Cow	cave	Private Individuals(s)	extant	4	12	12
				Laurel	cave	State-owned	extant	2	2,550	2,550
				Saltpeter	cave	State-owned	extant	2	6,100	6,100
	Christian			Bob Overton	cave	Private Individuals(s)	extant	3	770	0
				Monroe Overton	cave	Federally owned	extant	4	1	?
	Daviess	1								
	Edmonson	3	X	Bat	cave	Federally owned	extant	3	200	37
				Beckner's Saltpeter	cave	Private Individuals(s)	extant	3	68	0
				Coach	cave	Private Individuals(s)	extant	1	100,000	101
				Colossal	cave	Federally owned	extant	2	6,000	760
				Dixon	cave	Federally owned	extant	1	16,550	3,670
				Jesse James	cave	Private Individuals(s)	extant	2	1,293	0
				Long	cave	Federally owned	extant	1	50,000	1,153
				Mammoth	cave	Federally owned	uncertain	3	126	0
	Elliott			Tar Kiln	cave	Private Individuals(s)	uncertain	4	3	0
	Estill		X	Morton	cave	Private Individuals(s)	extant	2	1,924	1,924
				Morton #2	cave	Private Individuals(s)	extant	4	1	1
				Peter	cave	Unknown	uncertain	4	7	0
				Pilot No. 2	cave	Private Individuals(s)	uncertain	4	2	0
				Prairie Hall	cave	Private Individuals(s)	extant	3	153	153
				Townsend	cave	Unknown	uncertain	4	3	0
	Fayette		X							
	Floyd	1								
	Franklin		X							
	Grayson		X							
	Hardin			Belt	cave	Private Individuals(s)	uncertain	4	2	0
				Dripping Springs	cave	Federally owned	uncertain	4	1	0

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
KY (continued)	Harlan	3	X							
	Hart		X	Frenchman's Knob Pit	cave	Private Individuals(s)	uncertain	3	161	161
				Riders Mill	cave	Private Individuals(s)	uncertain	4	26	0
				Wilson	cave	Federally owned	extant	3	83	83
	Henderson	2 (1)								
	Hickman	2								
	Jackson		X	1813	cave	Federally owned	historic	4	26	0
				Bowman Saltpeter	cave	Private Individuals(s)	extant	3	100	40
				Cedar Post	cave	Federally owned	extant	3	184	77
				Fox	cave	Private Individuals(s)	extant	4	10	10
				Furlough	cave	Federally owned	extant	4	1	0
				Howling Dog	cave	Private Individuals(s)	uncertain	4	5	0
				John Coffee	cave	Private Individuals(s)	extant	4	20	17
				John Griffin	cave	Private Individuals(s)	extant	4	32	15
				John Henry	cave	Unknown	extant	3	112	95
				John Rogers	cave	Private Individuals(s)	extant	4	2	2
				Lainhart No. 2	cave	Private Individuals(s)	historic	4	5	1
				Lakes	cave	Private Individuals(s)	uncertain	4	8	0
				Misty	cave	Private Individuals(s)	extant	3	109	109
				Morning Hole	cave	Unknown	uncertain	4	3	0
				Neotoma's Nemesis	cave	Private Individuals(s)	uncertain	4	1	0
				Resurgence	cave	Federally owned	extant	4	1	1
				Sinks and Rises	cave	Private Individuals(s)	extant	4	48	0
				String	cave	Federally owned	extant	3	135	72
				War Fork	cave	Federally owned	extant	3	993	647
	Jackson			Wind	cave	Private Individuals(s)	extant	2	3,000	660
	Jefferson	3								
	Jessamine		X							
	Lee		X	Armine Branch	cave	Private Individuals(s)	extant	3	281	205
				Ash	cave	Federally owned	extant	3	132	74
				Bus Stop	cave	Private Individuals(s)	extant	3	300	0
				Cave Hollow	cave	Federally owned	extant	2	5,066	5,066
				Cave Hollow Pit	cave	Federally owned	extant	4	17	0

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
KY (continued)	Lee			Logue Hollow	cave	Private Individuals(s)	extant	4	32	0
				Sparkle	cave	Federally owned	extant	3	448	304
				Stillhouse	cave	Federally owned	extant	2	2,400	519
	Letcher	(1)	X	Buckeye	cave	State-owned	extant	4	1	0
				Crystal	cave	Private Individuals(s)	extant	3	824	824
				Green	cave	Private Individuals(s)	extant	2	2,694	2,522
				Line Fork	cave	State-owned	extant	1	10,000	1,844
	Livingston			Shaw Hill Bat	cave	Other	extant	3	235	0
				Sweet Potato	cave	Private Individuals(s)	historic	4	34	0
	Logan	1								
	Magoffin		X							
	McCracken	2								
	McCreary		X							
	Meade			Grahamton	cave	Federally owned	extant	4	1	1
	Menifee		X	Bicycle Sandstone	cave	Federally owned	historic	4	2	0
				Big Amos	cave	Federally owned	historic	4	8	0
				Cave Branch	cave	Federally owned	extant	3	809	739
				Hale Branch	cave	Federally owned	uncertain	4	1	0
				Hall Sink	cave	Private Individuals(s)	historic	3	133	0
				Little Amos	cave	Federally owned	extant	2	1,972	335
				Murder Branch	cave	Federally owned	historic	4	2	0
				Well	cave	Federally owned	extant	3	808	425
	Morgan			Spaws Creek Sodalis	cave	Federally owned	uncertain	4	1	0
	Nelson		X							
	Powell		X	Betsey	cave	Private Individuals(s)	uncertain	4	1	0
	Pulaski	1	X	Baker	cave	Private Individuals(s)	extant	4	1	1
				Blowing	cave	Other	uncertain	4	1	0
				Dykes Bridge	cave	Private Individuals(s)	extant	4	1	0
				Hail	cave	Private Individuals(s)	extant	4	35	35
				Minton Hollow	cave	Federally owned	extant	3	300	78
				North Firestone	cave	Unknown	uncertain	4	1	0
				North Goldson	cave	Private Individuals(s)	uncertain	4	2	0
				South Goldson	cave	Private Individuals(s)	extant	3	375	200

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
KY (continued)	Pulaski			Wells	cave	Private Organization	extant	4	11	11
	Rockcastle		X	Climax	cave	Private Individuals(s)	uncertain	3	100	0
				Crooked Creek Ice	cave	Private Individuals(s)	uncertain	4	38	0
				Goochland	cave	Federally owned	extant	3	435	395
				Great Saltpeter	cave	Federally owned	uncertain	4	10	0
				Humongous Canyon	cave	Federally owned	extant	3	406	362
				Indian Bone Pit	cave	Unknown	uncertain	4	1	0
				Miller's	cave	Unknown	uncertain	4	3	0
				Sinks of Roundstone	cave	Private Individuals(s)	extant	3	50	26
				Smokehole	cave	Private Individuals(s)	extant	2	4,000	1,314
				Teamer's	cave	Unknown	uncertain	4	2	0
				Twin Springs	cave	Federally owned	extant	3	90	89
				Waterfall	cave	Federally owned	extant	2	1,138	768
	Rowan	1	X							
	Spencer	1								
	Taylor			Boones	cave	Private Individuals(s)	historic	4	1	0
	Trigg			Big Sulphur	cave	Private Individuals(s)	extant	3	200	12
				Cool Springs	cave	Private Individuals(s)	extant	3	400	208
	Union	1 (1)								
	Warren			Crump	cave	Private Individuals(s)	historic	4	1	0
				Pruett Saltpeter	cave	Private Individuals(s)	extant	4	43	43
	Wayne			Barefoot Pit	cave	Private Individuals(s)	extant	3	630	630
	Whitley			Limestone	cave	Private Individuals(s)	extant	3	500	0
MARYLAND	Allegany			Greises	cave	Private Organization	historic	4	?	0
	Carroll	2								
	Garrett			John Friend	cave	Private Organization	uncertain	4	5	0
	Garrett		X							
	Washington		X	Round Top Mine No. 4	mine	State-owned	uncertain	4	1	0
MASSACHUSETTS	Hampden			Chester Emery Mine	mine		uncertain	3	60	0
MICHIGAN	Barry		X							
	Branch		X							
	Calhoun	1	X							
	Cass	1								

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
MI (continued)	Eaton	1								
	Hillsdale	1	X							
	Ingham		X							
	Jackson	1								
	Lenawee	2								
	Livingston	1	X							
	Manistee			Tippy Dam	dam	Private Organization	extant	4	20	20
	St. Joseph	2	X							
	Van Buren	1								
	Washtenaw	(1)								
	Wayne		X							
MISSISSIPPI	Tishomingo		X							
MISSOURI	Barry			Chimney Rock	cave	Private Individuals(s)	uncertain	2	3,000	0
	Boone		X	Devil's Icebox	cave	State-owned	extant	3	550	550
				Rocheport	cave	State-owned	extant	3	350	230
	Camden		X	Carroll	cave	Private Individuals(s)	uncertain	3	600	0
				River	cave	State-owned	extant	3	85	75
				Toby	cave	Private Individuals(s)	extant	3	150	53
	Carter			Panther Spring	cave	Federally owned	extant	3	60	60
	Carter			Secesh	cave	Private Individuals(s)	uncertain	4	33	0
	Chariton	1								
	Christian		X							
	Clinton		X							
	Crawford		X	Bat	cave	State-owned	extant	3	800	7
				Dobkin Spring	cave	Private Individuals(s)	uncertain	4	15	0
				Hedley	cave	Private Individuals(s)	uncertain	4	11	0
				Hidden Ledge	cave	Private Individuals(s)	uncertain	4	2	0
				Jagged Canyon	cave	Private Individuals(s)	uncertain	4	14	0
				Mud Cave No. 2	cave	Private Individuals(s)	uncertain	4	1	0
				Mud River	cave	Private Individuals(s)	uncertain	4	1	0
				Nameless	cave	Private Individuals(s)	uncertain	4	1	0
				Onyx	cave	State-owned	extant	1	12,850	180
				Saloon	cave	State-owned	extant	3	150	0

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
MO (continued)	Crawford			Temple of Wisdom	cave	Private Individuals(s)	uncertain	4	1	0
	Daviess		X							
	Dent	(1)		Bat	cave	Private Individuals(s)	uncertain	4	1	0
				Onyx	cave	Private Individuals(s)	uncertain	4	38	0
				Watson	cave	Private Individuals(s)	uncertain	3	86	0
	Franklin		X	Bat Cave No. 1	cave	Private Individuals(s)	uncertain	4	4	0
				Bear	cave	State-owned	extant	2	3,250	105
				Copper Hollow Sink	cave	State-owned	extant	1	21,000	250
				Fisher	cave	State-owned	uncertain	4	1	0
				Lone Hill Onyx	cave	State-owned	uncertain	4	3	0
				Mushroom	cave	State-owned	uncertain	3	450	0
				Twin Springs	cave	Private Individuals(s)	uncertain	4	2	0
				Wildcat	cave	State-owned	extant	4	24	12
	Gasconade	1								
	Hickory		X							
	Iron	1	X	Cave Hollow	cave	Federally owned	extant	3	175	150
				Pilot Knob Mine	mine	Federally owned	extant	1	139,000	50,550
	Jefferson	1								
	Knox	2	X							
	Laclede		X	Coffin	cave	State-owned	uncertain	3	450	0
				Mary Lawson	cave	State-owned	extant	3	700	280
				Meents	cave	Private Individuals(s)	uncertain	4	36	0
				Slaven	cave	Private Individuals(s)	extant	3	975	440
	Lewis	1 (1)	X							
	Linn	1								
	Macon	1								
	Madison	1								
	Marion	1	X	White Bear Quarry	mine	Private Individuals(s)	extant	4	15	0
	McDonald		X							
	Mercer	1								
	Miller		X							
	Monroe	1								
	Nodaway	1								

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
MO (continued)	Oregon			White's Creek	cave	Federally owned	extant	4	39	33
	Phelps		X	Marcellus	cave	Private Individuals(s)	uncertain	4	4	0
	Pike		X	Frankford	cave	Private Individuals(s)	extant	4	7	0
	Pulaski	1	X	Brooks	cave	Federally owned	extant	1	19,461	235
				Bruce	cave	Private Individuals(s)	extant	3	500	52
				Davis Cave No. 2	cave	Federally owned	extant	3	95	26
				Great Spirit	cave	State-owned	extant	2	4,015	285
				Joy	cave	Federally owned	extant	3	135	4
				Knife	cave	Federally owned	extant	3	70	70
				Onyx	cave	Private Individuals(s)	uncertain	3	600	0
				Piquet	cave	Private Individuals(s)	extant	3	575	55
				Ryden	cave	State-owned	extant	1	10,550	13
				Tunnel	cave	Private Individuals(s)	historic	2	4,000	0
				Wolf Den	cave	Federally owned	extant	4	29	1
	Scotland	1								
	Shannon		X	Bat	cave	Private Organization	extant	ET	123,800	1,020
				Cookstove	cave	Private Individuals(s)	extant	2	1,050	1,050
				Holmes Hollow	cave	Private Organization	extant	4	24	24
	Shannon			Martin # 1	cave	Private Individuals(s)	extant	2	8,100	2,460
				Marvel	cave	Federally owned	extant	3	200	45
				Mose Prater	cave	Federally owned	uncertain	2	3,000	0
				Powder Mill	cave	State-owned	extant	2	2,175	2,175
				Round Spring	cave	Federally owned	extant	4	2	0
	St. Francois	1								
	St. Louis			Tyson Quarry	mine	Private Organization	extant	3	170	85
	Ste. Genevieve	1 (1)								
	Sullivan	1								
	Taney			Tumbling Creek	cave	Private Organization	extant	4	33	33
	Texas			Dunvin	cave	Private Individuals(s)	extant	3	500	17
	Washington		X	Great Scott	cave	State-owned	extant	1	85,700	8,250
				Hamilton	cave	State-owned	extant	2	1,000	1,000
				Scotia Hollow	cave	Private Organization	extant	2	6,225	450
				Susan	cave	Private Organization	uncertain	4	25	0

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
MO (continued)	Wayne	1								
	Wright			Smittle	cave	State-owned	historic	3	550	0
NEW JERSEY	Morris	5		Hibernia Mine	mine	State-owned	extant	3	115	115
				Leonard Mine	mine	Private Organization	uncertain	4	?	0
				Taylor Mine	mine	Private Organization	extant	3	537	537
	Somerset	1								
	Sussex	1								
NEW YORK	Albany		X	Haile's	cave	State-owned	extant	4 (ET)	749	710
	Cayuga	1								
	Columbia			Indian Oven	cave	Unknown	uncertain	4	5	0
	Dutchess	5								
	Essex	1		Barton Hill Mine	mine	Private Organization	extant	2	6,818	6,818
				Cheever Mine	mine	Private Organization	uncertain	4	3	0
	Jefferson	9		Glen Park Commercial	cave	Private Organization	extant	4	4	0
				Glen Park	cave	Private Organization	extant	2	3,129	2,264
	Onondaga	4		Jamesville Quarry	cave	Private Individuals(s)	extant	2	4,138	4,138
	Orange	8								
	Oswego	3								
	Schoharie			Schoharie Caverns	cave	Private Organization	uncertain	4	1	0
	Seneca		X							
	Ulster		X	Lawrenceville Mine	mine	Unknown	extant	3	57	57
				Walter Wlms. Pres. Mine	mine	State-owned	extant	1	11,394	11,394
				Williams Hotel Mine	mine	Private Individuals(s)	extant	1	15,438	15,438
				Williams Lake Mine	mine	Private Individuals(s)	extant	2	1,028	1,028
				Williams Mine #4b	mine	Private Individuals(s)	extant	4	1	1
	Warren			Bennet Hill - Hitchcock	mine	Private Organization	extant	3	60	7
				Main Graphite Mine	mine	Private Organization	extant	3	135	104
NORTH CAROLINA	Graham		X							
	Jackson			Kitchen	cave	Private Individuals(s)	historic	4	5	0
	Mitchell		X							
	Rutherford			Bat Cave Preserve	cave	Private Organization	extant	4	4	0
	Swain	(1)	X	Hewitt Station	mine	Federally owned	uncertain	4	1	0

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
OHIO	Adams			Black Run	cave		uncertain	N/A	?	0
	Ashland		X							
	Ashtabula	1								
	Athens		X							
	Brown			?	cave		uncertain	4	?	0
	Butler	1								
	Clermont	1								
	Cuyahoga	1								
	Greene	1	X							
	Hamilton	(1)								
	Highland		X	Dry Cave (Goodehope)	cave		uncertain	4	2	0
	Hocking	1		Clear Creek #1	cave		uncertain	4	?	0
				Clear Creek #2	cave		uncertain	4	?	0
	Lawrence	1		Ironton Mine	mine	Federally owned	extant	3	333	333
	Miami		X							
	Paulding	1								
	Pickaway	1								
	Preble		X	Lewisburg Mine	mine	Private Individuals(s)	extant	2	9,638	9,638
	Richland		X							
	Summit	1								
	Warren	(1)								
	Wayne	1								
OKLAHOMA	Adair		X	Adair Bat	cave	Private Organization	historic	4	2	0
	Delaware		X							
	Le Flore			Bear Den	cave	Federally owned	extant	4	9	5
	Pushmataha		X	Bower's Trail	cave	Private Individuals(s)	extant	4	3	0
	Sequoyah		X							
PENNSYLVANIA	Armstrong			Long Run Mine	mine	Private Individuals(s)	extant	3	67	67
				U.S. Steel No 2	mine	State-owned	extant	4	15	15
	Beaver			Steifel Park Mine	mine	City-owned	extant	4	1	1
	Bedford			Hipple	cave	Private Individuals(s)	historic	3	300	0
	Berks	1								
	Blair	1	X	Canoe Creek Mine	mine	State-owned	extant	2	1,000	765

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
PA (continued)	Blair			Ganister Cave No 3	cave	State-owned	extant	4	1	1
	Centre			Penns	cave	Private Individuals(s)	uncertain	2	2,000	0
				Sharer	cave	Private Individuals(s)	historic	3	150	0
				Stover	cave	Private Individuals(s)	historic	4	3	0
				Woodward	cave	Private Individuals(s)	historic	4	1	0
	Elk		X							
	Fayette			Laurel Caverns	cave	Private Individuals(s)	historic	4	4	0
				Layton Fire Clay Mine	mine	Private Individuals(s)	extant	4	11	11
	Franklin			S Penn RR - East & West Kittatinny Mtn.	tunnel	State-owned	historic	4	4	0
				S Penn RR – E. Blue Mtn.	tunnel	State-owned	historic	4	12	0
	Fulton			S Penn RR – Sideling Hill	tunnel	State-owned	historic	4	3	0
	Huntingdon			Indian Caverns	cave	Private Individuals(s)	uncertain	4	4	0
				S Penn RR - W. Tuscarora	tunnel	State-owned	historic	4	1	0
	Lawrence			CS&M Mine No 1	mine	Private Individuals(s)	extant	4	21	21
	Luzerne			Glen Lyon Sinkhole/ Anthracite Mine	mine	Private Individuals(s)	historic	4	?	0
				Shickshinny Portal #3	mine	State-owned	historic	4	?	0
	Mifflin			Aitkin	cave	Private Organization	extant	3	500	14
				Seawra	cave	Private Individuals(s)	extant	4	3	3
	Somerset			S Penn RR - Allegheny Mtn.	tunnel	State-owned	extant	3	52	52
				Salisbury Mine	mine	Private Individuals(s)	extant	4	3	3
	Westmoreland			Bear	cave	Private Individuals(s)	historic	4	5	0
TENNESSEE	Bedford			Ward	cave	Unknown	uncertain	4	2	0
	Blount	2	X	Bull	cave	Federally owned	extant	3	553	553
				Kelley Ridge	cave	Private Individuals(s)	extant	3	360	360
				Scott Gap	cave	Federally owned	extant	3	102	102
				White Oak Blowhole	cave	Federally owned	extant	1	12,500	7,861
	Campbell			Meredith	cave	Private Individuals(s)	historic	4	?	0
				New Mammoth	cave	Private Individual(s)	extant	2	4,000	310
				Norris Dam	cave	Federally owned	historic	4	?	0
				Unnamed	cave	Unknown	uncertain	4	?	0
	Claiborne		X							

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
TN (continued)	Fentress			Cobb Cr. Saltpetre	cave	Unknown	extant	3	74	0
				Cornstarch	cave	Unknown	extant	3	230	230
				Dragon's Breath	cave	Unknown	uncertain	3	235	0
				East Fork Saltpeter	cave	Unknown	extant	3	415	415
				Little Jack Creek	cave	Unknown	extant	4	5	5
				Redbud	cave	Unknown	extant	4	25	25
				Wolf River	cave	Private Organization	extant	2	2,550	2,415
				Xanadu	cave	Private Organization	uncertain	4	35	0
				Ygdrasils	cave	Private Organization	extant	3	325	325
				Zarathustra	cave	Unknown	extant	3	607	197
	Franklin		X							
	Grainger			Indian	cave	Unknown	historic	3	900	0
	Hawkins			Pearson	cave	Private Individual(s)	historic	2	5,000	0
	Hickman		X							
	Lincoln		X							
	Marion			Nickajack	cave	Federally owned	extant	2	1,500	0
	Maury		X							
	Monroe	1 (1)								
	Montgomery			Bellamy	cave	Private Individual(s)	historic	2	1,200	0
				Blue Spring	cave	Unknown	extant	3	80	0
				Coleman	cave	Unknown	extant	3	63	0
				Cooper Creek	cave	Unknown	uncertain	4	3	0
	Perry			Alexander	cave	Unknown	uncertain	3	74	0
	Sevier		X							
	Shelby		X							
	Stewart		X	Tobaccoport	cave	Private Individual(s)	extant	3	310	310
	Van Buren			Cagle Saltpeter	cave	State-owned	extant	4	26	26
				Camps Gulf	cave	State-owned	extant	3	140	33
				Rice	cave	State-owned	extant	3	87	87
	Warren			Hubbards	cave	Private Organization	historic	2	3,500	0
	White			Lost Creek	cave	Private Individual(s)	extant	4	46	430
				Upper	cave	Unknown	uncertain	4	1	0
VERMONT	Addison	6								

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
VT (continued)	Bennington			Aeolus Bat	cave	Private Organization	extant	3	237	16
				Skinner Hollow	cave	Private Individuals(s)	extant	3	297	297
	Crittenden	1								
	Orange			Ely Copper Mine	mine	Private Individuals(s)	historic	4	13	0
	Rutland		X	Brandon Silver Mine	mine	Private Organization	extant	3	159	159
				Nickwackett	cave	Private Individuals(s)	historic	3	246	0
	Windsor			Plymouth	cave	Private Organization	historic	3	81	0
VIRGINIA	Bath		X	Clark's	cave	Private Individuals(s)	extant	3	52	50
				Starr Chapel Saltpeter	cave	Federally owned	extant	3	600	67
	Bland			Hamilton	cave	Private Individuals(s)	uncertain	4	1	0
	Bland			Newberry -Bane	cave	Private Individuals(s)	extant	3	237	237
	Craig			Rufe Caldwell	cave	Private Individuals(s)	extant	4	3	0
				Shires Saltpeter	cave	Federally owned	extant	4	36	36
	Dickenson									
	Giles			Tawney's	cave	Private Individuals(s)	uncertain	4	14	0
	Highland			Hupman's Saltpeter	cave	Private Individuals(s)	extant	3	300	20
				Mountain Grove Saltpeter	cave	Federally owned	extant	4	5	2
	Lee	1		Cumberland Gap Saltpeter	cave	Federally owned	extant	2	1,094	313
				Grassy Springs	cave	Federally owned	extant	3	255	180
	Montgomery			Nellies Hole	cave	Private Individuals(s)	uncertain	4	1	0
	Shenandoah			Maddens	cave	Private Individuals(s)	uncertain	4	1	0
	Tazewell			Higgenbotham No. 1	cave	Private Individuals(s)	extant	2	4,000	0
	Wise		X	Kelly	cave	Federally owned	extant	4	18	9
				Rocky Hollow	cave	Unknown	extant	2	1,200	325
WEST VIRGINIA	Boone	2								
	Clay		X							
	Greenbrier			Bob Gee	cave	Private Individuals(s)	uncertain	4	9	0
				General Davis	cave	Private Organization	extant	4	10	6
				Higginbothams	cave	Private Individuals(s)	uncertain	4	?	0
				McFerrin	cave	Private Individuals(s)	uncertain	4	39	0
				Organ	cave	Private Individuals(s)	extant	4	14	14
				Piercys	cave	Private Organization	extant	3	54	54
	Hardy			Dyers	cave	Private Individuals(s)	uncertain	N/A	0	0

State	County	No. of Extant Maternity Colonies	Other Summer Records	Hibernaculum Name	Hib. Type	Hibernaculum Ownership	Current Winter Pop. Status	Priority Number	Max. All-time Pop. Estimate	Max. Pop. Estimate Since 2000
WV (continued)	Mercer			Honacker	cave	Private Individuals(s)	extant	4	31	31
	Monroe			Argobrites	cave	Private Individuals(s)	uncertain	N/A	?	0
				Greenville Saltpeter	cave	Private Organization	extant	3	300	6
				Patton	cave	Private Individuals(s)	extant	4	17	10
	Nicholas		X							
	Pendleton		X	Cave Mountain	cave	Federally owned	extant	4	1	1
				Hellhole	cave	Private Individuals(s)	extant	1	11,890	11,890
				Minor Rexrode	cave	Private Individuals(s)	extant	3	600	67
				Saltpeter	cave	Private Individuals(s)	extant	4	1	1
				Schoolhouse	cave	Private Individuals(s)	extant	4	2	0
	Pendleton			Smokehole	cave	Private Individuals(s)	uncertain	4	20	0
				Trout	cave	Private Organization	extant	2	1,000	95
	Pocahontas			Cass	cave	Private Individuals(s)	uncertain	4	4	0
	Pocahontas			Dreen	cave	State-owned	uncertain	4	4	0
				Lobelia Saltpeter	cave	Private Individuals(s)	extant	4	4	0
				Marthas	cave	Private Individuals(s)	extant	3	285	196
				Snedegars	cave	Private Individuals(s)	extant	3	193	193
				Tubb	cave	Private Individuals(s)	extant	4	20	20
				Upper Marthas	cave	Private Individuals(s)	historic	4	1	0
	Preston			Cornwell	cave	Private Organization	extant	3	148	148
	Raleigh		X							
	Randolph		X	Bear Heaven	cave	Federally owned	extant	4	12	0
				Falling Springs	cave	Private Organization	extant	4	49	49
				Fortlick	cave	Private Individuals(s)	extant	3	109	109
				Gooseberry	cave	Private Individuals(s)	extant	4	15	0
				Izaak Walton	cave	Private Individuals(s)	extant	3	97	97
				Simmons-Mingo	cave	Private Individuals(s)	uncertain	4	17	0
				Stewart Run	cave	Private Organization	extant	3	83	40
				Two Lick Run	cave	Federally owned	extant	4	12	7
	Tucker	1	X	Arbogast/Cave Hollow	cave	Private & Public	extant	3	234	234
				Big Springs	cave	Federally owned	extant	3	254	243
				Coal Run	cave	Federally owned	extant	4	1	0
WISCONSIN	Grant			Atkinson's Diggings	mine	Unknown	historic	4	1	0

This page intentionally left blank.

APPENDIX 3: Data matrix of P1 and P2 hibernacula depicting the actual occurrence and chronology of winter population surveys from 1950-2006

Tally	State	County	Hibernaculum Name	P#	Sub.	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1	IL	Alexander	Unimin - Magazine Mine	1	A																				
2	IN	Crawford	Batwing	1	A																				
3	IN	Crawford	Wyandotte	1	A				●		●					●					●				
4	IN	Greene	Ray's	1	A			●			●					●				●	●				●
5	IN	Harrison	Jug Hole	1	A																				
6	IN	Harrison	Twin Domes	1	A																				
7	IN	Monroe	Coon	1	A				●							●									
8	IN	Monroe	Grotto	1	A											●									●
9	KY	Carter	Bat (Carter Caves SRP)	1	A								●			●		●							
10	KY	Edmonson	Dixon	1	A										●	●									●
11	MO	Iron	Pilot Knob Mine	1	A											●									
12	MO	Washington	Great Scott	1	A																				
13	NY	Ulster	Walter Williams Pres. Mine	1	A																				
14	NY	Ulster	Williams Hotel Mine	1	A																				
15	TN	Blount	White Oak Blowhole	1	A																				
16	WV	Pendleton	Hellhole	1	A														●						
17	KY	Edmonson	Coach	1	B											●									
18	KY	Edmonson	Long	1	B				●				●	●	●	●		●							●
19	KY	Letcher	Line Fork	1	B															●					
20	MO	Crawford	Onyx	1	B																				
21	MO	Franklin	Copper Hollow Sink	1	B																				
22	MO	Pulaski	Brooks	1	B																				
23	MO	Pulaski	Ryden	1	B																				
1	AR	Madison	Horsethief	2				●	●	●	●	●	●		●										
2	AR	Newton	Cave Mountain	2										●	●										
3	AR	Newton	Edgeman	2																					
4	AR	Newton	Horseshoe	2																					
5	IL	Alexander	Unimin - Mine 30	2																					
6	IL	Hardin	Griffith	2																					
7	IL	Hardin	Gutherie	2																					
8	IL	Jackson	Toothless	2																					
9	IL	LaSalle	Blackball Mine	2					●				●	●	●	●									
10	IL	Pope	Ellis	2																					
11	IN	Harrison	Parker's Pit	2																					
12	KY	Breckinridge	B&O	2																					
13	KY	Breckinridge	Norton Valley	2																●					
14	KY	Breckinridge	Thornhill	2																●					
15	KY	Carter	Laurel	2																					
16	KY	Carter	Saltpeter	2																					
17	KY	Edmonson	Colossal	2					●							●									
18	KY	Edmonson	Jesse James	2												●									
19	KY	Estill	Morton	2																					
20	KY	Hart	Frenchman's Knob Pit	2																					
21	KY	Jackson	Wind	2												●									
22	KY	Lee	Cave Hollow	2																					
23	KY	Lee	Stillhouse	2																					
24	KY	Letcher	Green	2																					
25	KY	Menifee	Little Amos	2																					
26	KY	Rockcastle	Smokehole	2																					
27	KY	Rockcastle	Waterfall	2																					
28	MO	Franklin	Bear	2																					
29	MO	Pulaski	Great Spirit	2																					
30	MO	Pulaski	Tunnel	2											●										
31	MO	Shannon	Cookstove	2																					
32	MO	Shannon	Martin # 1	2																					
33	MO	Shannon	Mose Prater	2																		●		●	●
34	MO	Shannon	Powder Mill	2																					
35	MO	Washington	Hamilton	2																					
36	MO	Washington	Scotia Hollow	2																					
37	NY	Essex	Barton Hill Mine	2																					
38	NY	Jefferson	Glen Park Cave	2																					
39	NY	Onondaga	Jamesville Quarry Cave	2																					
40	NY	Ulster	Williams Lake Mine	2																					
41	OH	Preble	Lewisburg Limestone Mine	2																					
42	PA	Blair	Canoe Creek Mine	2																	●				
43	PA	Centre	Penns Cave	2																					
44	TN	Campbell	New Mammoth Cave	2														●							
45	TN	Fentress	Wolf River Cave	2																					
46	TN	Hawkins	Pearson Cave	2																					
47	TN	Montgomery	Bellamy	2																					
48	VA	Lee	Cumberland Gap Saltpeter	2																					
49	VA	Tazewell	Higgenbotham No 1	2																					
50	VA	Wise	Rocky Hollow Cave	2																					
51	WV	Pendleton	Trout	2			●				●		●			●		●							

1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
																													●		●		●		●	
							●				●		●		●		●		●		●		●		●		●		●		●		●		●	
●				●							●		●		●		●		●		●		●		●		●		●		●		●		●	
●					●						●	●	●		●		●		●		●		●		●		●		●		●		●		●	
																	●		●		●		●		●		●		●		●		●		●	
						●					●		●		●		●		●		●		●		●		●		●		●		●		●	
				●	●						●	●			●		●		●		●		●		●		●		●		●		●		●	
				●	●						●	●			●		●		●		●		●		●		●		●		●		●		●	
				●	●						●		●		●		●		●		●		●		●		●		●		●		●		●	
					●							●	●		●		●		●		●		●		●		●		●		●		●		●	
								●			●		●		●		●		●		●		●		●		●		●		●		●		●	
					●	●	●	●	●	●	●		●		●		●		●		●		●		●		●		●		●		●		●	
								●						●	●	●	●	●	●	●	●				●		●		●		●		●		●	
																													●		●		●		●	
									●		●												●				●		●		●		●		●	
												●		●		●			●		●		●		●		●		●		●				●	
					●					●		●	●		●		●	●	●		●		●		●		●		●		●		●		●	
					●			●				●			●		●	●	●		●		●		●		●		●		●		●		●	
												●						●			●	●			●		●		●		●		●		●	
						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●		●		●	
					●	●	●	●	●	●	●		●		●		●		●	●	●	●	●		●		●		●		●		●		●	
							●		●		●		●		●		●		●		●		●		●	●	●		●		●		●		●	
								●	●		●		●		●		●		●		●		●		●		●		●		●		●		●	
					●											●															●			●	
									●	●	●	●	●		●		●		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
											●	●	●		●		●		●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	
														●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●		
																													●	●	●		●		●	
				●																											●		●		●	
																													●		●		●		●	
				●																					●					●			●		●	
																	●		●		●		●		●		●		●		●		●		●	
																														●	●	●	●	●		
													●				●		●		●		●		●		●		●		●		●		●	
																												●		●		●		●		
																●								●		●		●		●						
																●	●							●				●								
																													●		●		●		●	
													●				●											●	●		●		●		●	
					●							●			●		●		●		●		●		●		●		●		●		●		●	
					●					●			●		●		●	●	●		●		●		●				●		●		●			
																															●		●		●	
									●																											
											●		●				●		●	●		●		●		●		●		●		●		●		
									●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●		●		●		●	
									●	●		●	●		●		●		●		●		●	●	●		●		●		●		●		●	
																							●	●			●		●		●		●		●	
												●	●			●		●	●		●		●		●		●		●	●	●	●	●		●	
		●				●					●		●				●		●	●		●		●		●		●		●		●		●		
						●					●		●							●	●	●		●		●		●		●		●		●		
						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●		●		●	
										●	●		●		●		●		●		●		●		●		●		●		●		●		●	
																	●																	●	●	
																														●			●		●	
									●	●	●		●		●		●		●		●		●		●		●		●		●		●		●	
●	●	●	●			●					●		●		●				●																	
						●		●									●										●		●		●		●		●	
						●	●		●									●					●			●	●		●			●	●		●	
						●	●	●	●	●	●		●		●		●		●		●		●		●		●	●	●		●		●		●	
															●	●	●	●	●	●	●		●		●		●		●		●		●		●	
								●		●	●	●	●	●	●	●	●	●	●	●	●	●		●	●		●		●		●		●		●	
												●	●	●	●	●	●	●	●	●	●	●		●	●		●		●		●		●		●	
										●		●		●																●	●		●		●	
																										●		●		●		●		●		●
																	●		●		●		●		●		●		●		●		●		●	
																	●																			
					●			●				●									●								●		●		●		●	
																●													●		●		●		●	
																●																●				
																●															●	●				
							●	●									●						●				●		●		●		●		●	
														●	●		●			●			●		●	●			●							
●								●						●	●		●				●		●								●		●		●	
												●	●		●		●		●		●		●		●		●		●		●		●		●	

APPENDIX 4: Indiana Bat Hibernacula Survey Guidelines

***NOTE**: The following guidelines were largely adapted from those that originally appeared in the 1983 Recovery Plan (USFWS 1983). These guidelines currently are in the process of being revised to improve the accuracy of bat survey estimates. Additional changes are anticipated pending the outcome of field tests of new survey techniques scheduled to begin in January 2007.*

Winter surveys should be conducted between January 15 and February 15 and should not be repeated more often than once every other year in any given hibernaculum. Surveys should be conducted by well-trained individuals. A demonstrated ability to identify the Indiana bat, as well as other bat species that are likely to be encountered, is required. The survey team must be composed of at least the lead surveyor and one assistant. The minimum number of people needed to safely and effectively conduct the survey should participate. After the initial survey of any given hibernaculum, each subsequent team of surveyors for that hibernaculum should include at least one member who participated in the original or most recent survey.

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). Researchers should also coordinate with the state wildlife agency in the state in which they plan to conduct surveys to determine what additional authorization may be required.

To the extent practical, Indiana bat hibernacula should be mapped by a qualified cave-mapping team during the bats' summer absence. Assistance from local cavers may be especially valuable in completing cave mapping. During the next winter survey, all Indiana bat roosting areas should be described and numbered with reference to the map, such that future surveyors can easily locate and determine the boundaries of each numbered roosting area. Cave (or mine) maps clearly indicating the general locations of Indiana bat concentration areas and the extent of the winter survey within the hibernaculum should be included in all survey reports.

Where few bats are found they may be counted individually, but where there are many clustered bats, photography is the preferred technique where possible; a written description of current photographic techniques is in preparation. Where photography is not possible, two approaches may be useful: (1) estimating the surface area covered by the cluster, and the average density of bats, or (2) determining the area covered by a set number of bats and estimating the number of such areas in the entire cluster. To determine area, a steel tape, folding engineers rule, or laser calipers (for high ceilings) may prove useful. For method (1), area and average density should be recorded and number of bats calculated after exiting the hibernaculum; for method (2), numbers of bats can be recorded directly.

Where photography is possible for a subset of clusters, density can be estimated from the photographed clusters if some distance measure can be included in the photograph, or if the dimensions of the photographed cluster are measured in the field and recorded. Because the bat cluster density is likely to vary from cave to cave, and cluster to cluster, and with temperature, the surveyor should attempt to estimate a unique density for all large clusters within each hibernaculum at the time of the survey or at least for each distinct roosting area within larger hibernacula. To improve the overall accuracy and reduce surveyor error, the Service requests that surveyors incorporate some level of digital photography into their standard survey methodology. For reference, the average number of Indiana bats per square foot generally ranges from 300 to 484 bats per square foot (Clawson et al. 1980, LaVal and LaVal 1980, Hicks and Novak 2002).

Since disturbance is a major cause of Indiana bat decline, it is imperative that disturbance during surveys be minimized. Limiting each survey team to two or three individuals, prior exploration and mapping, use of numbered sites, calculations based on square feet covered by clusters, and digital photography all serve to accomplish this end. Additionally, bright headlights, spotlights, and flash photography should not be shined directly on the bats or used more than necessary, and all sounds should be kept to a minimum. Banded bats that are easily accessible should only be handled long enough to read their band numbers and only then if this can be done in a timely manner that does not necessitate disturbing a large number of additional bats. Nonessential data taking, such as determining sex ratios, and other handling of bats should be eliminated. Surveyors should spend the least amount of time possible in the hibernacula.

If available, non-contact, infrared thermometers should be used to record cave surface temperatures adjacent to bat clusters in the most important roost areas. Location and height above the floor must be recorded, and the thermometer must be calibrated before each survey trip if such readings are to be useful and comparable over time. Also, care must be taken to record the temperature soon after arrival at a given cluster and well away from the potential influence of human body heat.

Any bat mortality or serious injury must be reported to the Service within 5 calendar days. Dead or moribund bats should be collected, placed in a well-sealed plastic bag, and kept chilled (frozen if practical) for necropsy or contaminant analysis. The Service should be promptly contacted for further shipping/transfer instructions.

Each survey report should include date of survey, time of hibernacula entry and exit, names and affiliations of all participants, number of Indiana bats present at each numbered roost, all calculations used to determine final estimates (including cluster sizes, estimated densities, areas of clusters, and any other intermediate calculations), representative photographs, and a copy of the cave map (if available) with description of numbered roosts. Notes on the numbers of other species observed, conditions of gates and evidence of human or other disturbance, and any evidence of predation should be included when possible. Survey reports should be sent within 90 days of the completion of the survey to the Bloomington Field Office of the U.S. Fish and Wildlife Service:

U.S. Fish and Wildlife Service
Bloomington Field Office
620 South Walker Street
Bloomington, IN 47403
Attn: Indiana bat

Alternatively, reports can be sent via e-mail to: indiana_bat@fws.gov.

APPENDIX 5: Indiana Bat Mist-Netting Guidelines

RATIONALE

A typical mist-net survey is an attempt to determine presence or probable absence of the species; it does not provide sufficient data to determine population size or structure. Following these guidelines will standardize procedures for mist netting. It will help maximize the potential for capture of Indiana bats at a minimum acceptable level of effort. Although capture of bats confirms their presence, failure to catch bats does not absolutely confirm their absence. Netting effort as extensive as outlined below usually is sufficient to capture Indiana bats if they are present. However, there have been instances in which additional effort yielded detection when the standard effort did not.

Some mist-netting projects will require modification (or clarification) of these guidelines; these situations must be resolved through coordination with the Service Field Office responsible for the state in which your project occurs. Consultation with the Field Office is always recommended, particularly for large-scale netting efforts.

The Service accepts the results of these surveys to determine presence for the purposes of Section 7 consultation. Survey results are valid for at least two years.

NETTING SEASON: May 15 - August 15

May 15-August 15 are acceptable limits for documenting the presence of summer populations of Indiana bats, especially maternity colonies. (However, see Kiser and MacGregor 2005 for precautions regarding early-season surveys between May 15 and June 1, as well as late-season surveys between August 1 and August 15). Capture of reproductive adult females (i.e., pregnant, lactating, or post-lactating) and/or young of the year during May 15-August 15 indicates that a nursery colony is active in the area. Outside these dates, data cannot be used to document the presence or probable absence of summer populations.

EQUIPMENT

Mist nets to be used for Indiana bat surveys should be the finest, lowest visibility mesh commercially available: 1) In the past, this was 1 ply, 40 denier monofilament–denoted 40/1; 2) Currently, monofilament is not available, and the finest on the market is 2 ply, 50 denier nylon denoted 50/2; 3). The finest mesh size available is approximately 38 mm (~1 1/2 in).

No specific hardware is required. There are many suitable systems of ropes and/or poles to hold nets. The system of Gardner et al. (1989) has been widely used. See NET PLACEMENT below for minimum net heights, habitats, and other netting requirements that affect the choice of hardware.

NET PLACEMENT

Potential travel corridors such as streams or logging trails typically are the most effective places to net. Place nets approximately perpendicular across the corridor. Nets should fill the corridor from side to side and from stream (or ground) level up to the overhanging canopy. A typical set is 7 m high consisting of three or more nets stacked on top one another and up to 20 m wide. (Nets of different width may be used as the situation dictates).

Occasionally it may be desirable to net where there is no good corridor. Take caution to get nets up into the canopy. The typical equipment described in the section above may be inadequate for these situations, requiring innovation on the part of the researchers.

Exercise safety precautions when placing nets. Poles and nets must be clear of overhead wires.

See Kiser and MacGregor (2005) for additional discussion of net placement.

RECOMMENDED NET SITE SPACING

Stream and other linear corridors – one net site per km (0.6 mi) of stream or corridor.
Non-corridor study areas – two net sites per square km of habitat (equivalent to one net site per 123 acres).

The Service Field Office responsible for the state in which your project occurs should be consulted during survey design to resolve issues related to net site spacing for specific projects.

MINIMUM LEVEL OF EFFORT

Netting at each site should include at least four net nights, consisting of: 1) a minimum of two net locations at each site (at least 30 m apart, especially in linear habitat such as a stream corridor); and 2) a minimum of two nights of netting (i.e., two net locations for two nights = four net nights per site). A "net night" is defined as one net set up for one night. The sample period should begin at sunset and continue for at least 5 hours (longer sample periods may improve success). For purposes of determining presence or probable absence of Indiana bats, four net nights at a site are not required if Indiana bats are caught sooner (i.e., if Indiana bats are caught on the first night of netting, a second night is not required for purposes of documenting presence).

CHECKING NETS

Each net should be checked approximately every 10 minutes. Some researchers prefer continuous monitoring (with or without an electronic bat detector); care must be taken to avoid noise and movement near the nets if this technique is used. When monitoring the site continuously with a bat detector, bats can be detected immediately when they are captured in the net. Prompt removal from the net decreases stress on the bat and potential for the bat to escape (MacCarthy et al. 2006). Monitoring the net with a bat detector also allows the researcher to assess the effectiveness of their net placement (i.e., if bats are active near the nets but avoiding capture); this may allow for adjustments that will increase netting success on subsequent nights. There should be no disturbance near the nets, other than to check nets and remove bats.

WEATHER AND LIGHT CONDITIONS

Severe weather adversely affects capture of bats. If Indiana bats are caught during weather extremes, it is probably because they are at the site and active despite inclement weather. On the other hand, if bats are not caught, it may be that bats are at the site but inactive due to the weather. Negative results combined with any of the following weather conditions throughout all or most of a sampling period are likely to require additional netting: 1) precipitation; 2) temperatures below 10^{o}C; and/or 3) strong winds (use good judgment-- moving nets are more likely to be detected by bats). Further, consider human safety when netting during adverse weather.

It is typically best to set nets under the canopy where they are out of moonlight, particularly when the moon is ½-full or greater. Areas illuminated by artificial light sources should also be avoided.

DOCUMENTATION OF *MYOTIS SODALIS* CAPTURES

Photo documentation of *M. sodalis* captured during mist netting is not required, but is encouraged. Photos taken of a bat's head, calcar, tragus, toe hairs, etc. using a macro lens or a digital camera's macro-mode are often diagnostic and aid in validating the record.

If a bat from the genus *Myotis* is captured during mist netting that cannot be readily identified to the species level, species can be verified through fecal DNA analysis. Collect one or more fecal pellets (i.e., guano) from the bat in question by placing it temporarily in a holding bag (15 minutes is usually sufficient, no more than 30 minutes is recommended). The pellet (or pellets) collected should be placed in a 1.5 ml vial with silica gel desiccant; pellets from each individual bat should be stored in separate vials. Samples should be stored out of direct light. Samples should be shipped to Dr. Jan Zinck, Department of Biology, Portland State University, 630 SW Mill St., Portland, Oregon, 97201 for subsequent fecal DNA analysis to assign or confirm the specimens' identification to the species level. The current cost for sequencing is approximately $50 per individual pellet of guano. Contact Dr. Zinck (e-mail: zinckj@pdx.edu) prior to shipping samples. To our knowledge, this is the only lab that currently provides this service. Any additional information (or additional sources) on this technique will be made available on the Indiana bat webpage on the Service's Region 3 website (www.fws.gov/midwest).

REFERENCES TO CONSULT REGARDING MIST NETTING

Gardner, J. E., J. D. Garner, and J. E. Hofmann. 1989. A portable mist-netting system for capturing bats with emphasis on *Myotis sodalis* (Indiana bat). Bat Research News 30:1-8.

Kiser, J.D. and J.R. MacGregor. 2005. Indiana bat (*Myotis sodalis*) mist net surveys for coal mining activities. Pp. 169-172 *in* K.C. Vories and A. Harrington (eds.), The Proceedings of the Indiana bat and coal mining: a technical interactive forum Office of Surface Mining, U.S.

Department of the Interior, Alton, IL. Available at: http://www.mcrcc.osmre.gov/PDF/Forums/Bat%20Indiana/2-1.pdf. (Accessed October 27, 2006).

MacCarthy, K.A., T.C. Carter, B.J. Steffen, and G.A. Feldhamer. 2006. Efficacy of the mist-net protocol for Indiana bats: A video analysis. Northeastern Naturalist 13:25-28.

Murray K., E. Britzke, B. Hadley, and L. Robbins. 1999. Surveying bat communities: a comparison between mist nets and the Anabat II bat detector system. Acta Chiropterologica 1(1):105-12.

Murray, K.L., J.G. Boyle, J.C. Timpone, M.N. Miller, and L.W. Robbins. 2003. A test of the sampling protocol for Indiana bats. Bat Research News 44(1):25.

Robbins, L.W., K.L. Murray, J.G. Boyles, J.C. Timpone, M.N. Miller, and S.A. Kelly. 2003. Capture and detection of five species using Indiana bat protocol. Abstracts of papers presented at the 33rd annual North American symposium on bat research held 8-11 October 2003 in Lincoln, NE. Bat Research News 44(4):165.

APPENDIX 6: Glossary

alternate roost tree - a tree roost used by single bats or small groups of bats within a maternity colony

bat detector - a device used to detect the ultrasonic echolocation calls emitted by bats

calcar - the cartilaginous structure that extends from the ankle of a bat towards the tail; it helps support the tail membrane; the presence of a keel on the calcar is one of the identifying characteristics of the Indiana bat

canopy closure - the percent of open space occupied by the collective tree crowns in a forest stand

clearcut - an area in which all the trees above a defined size are harvested; clearcutting is used to regenerate tree species that are intolerant of shade

confidence interval - range of statistical values within which a result is expected to fall with a specific probability

congener - a species that belongs to the same genus as another species; closely related

critical habitat - (i) the specific areas within the geographical area occupied by a species, at the time it is listed in accordance with the provisions of the ESA, on which are found those physical or biological features (I) essential to the conservation of the species and (II) which may require special management considerations or protection; and (ii) specific areas outside the geographical area occupied by the species at the time it is listed in accordance with the ESA, upon a determination by the Secretary that such areas are essential for the conservation of the species

emigration - the movement of individuals out of a population

endangered species - as defined by the ESA, any species which is in danger of extinction throughout all or a significant portion of its range

exfoliating bark - Tree bark that peels away from a trunk or a branch of a tree; when a tree dies, plates of bark spring away from the bole of the tree. Some living trees, such as shagbark hickory and white oak, have bark that peels back from the living cambium.

forest fragmentation - the process by which large, unbroken tracts of forest are split into separate, smaller parcels of forest

hibernaculum (plural **hibernacula)** - a site, usually a cave or mine, where bats hibernate during the winter

hibernaculum complex - a group of hibernacula that are geographically clumped with documented or presumed exchanges of bats

immigration - the movement of individuals into a population

karst - land type characterized by solution features such as caves and sinkholes, usually developed in limestone

maternity colony - a group of reproductively active female Indiana bats and their young that occupy the same summer habitat and interact to varying degrees

maternity roost - a summer roost, usually a tree, used by reproductively active female Indiana bats and their young

metapopulation - a set of geographically distinct local populations occupying discrete habitat patches

mtDNA - mitochondrial deoxyribonucleic acid; the DNA contained within a mitochondrion and maternally inherited since only the egg cell contributes significant numbers of mitochondria to the zygote

neonatal - pertaining to a newborn infant

net night - A unit of mist netting effort defined as one mist net, set at a net site, and operated one night for at least 5 hours after dark. Individual nets may be stacked to create a large net that fills a travel corridor; a stacked set of nets is equivalent to one net (and thus, one net night), even though it consists of 2 or 3 tiered mist nets.

parturition - the process of giving birth

philopatry - the propensity of a bat to return to the same summer colony area or hibernaculum year after year

population - a group of bats occupying a specific geographic area

postnatal - subsequent to birth

prenatal - prior to birth

primary roost tree - a tree roost used by most or many of the bats within a maternity colony; it is used consistently throughout the summer

radiotag - a transmitting device attached to a bat that emits a radio signal that can be remotely detected by a receiver

radiotelemetry - studying the movement of animals by sending signals from a transmitting device attached to the animal over some distance to a receiver; usually, radiotelemetry is used for gathering information about the physiology, behavior, or location of the organism

recruitment - the number of young-of-the-year bats entering a population each year; the process by which juvenile bats enter the population

reproductively active female - a pregnant, lactating, or post-lactating adult female bat

roost tree - any tree in which bats roost

sagittal crest - a ridge of bone on the skull

shelterwood cut - A forest harvest technique designed to regenerate a forest stand under the protection of remnants of the old stand. In such a cut, some of the trees in the original stand are retained to provide shade, cover, or a seed source for the new tree stand.

snag - a standing dead (or mostly dead) tree, generally with <10% living canopy

staging - the departure of bats from hibernacula in the spring, including processes and behaviors that lead up to departure

survey - a method of sampling, such as mist netting, that provides data concerning the presence/absence of bats at a site; also, the act of enumerating the bats hibernating in a cave or mine

swarming - A phenomenon in which, during late summer and autumn, numerous bats are observed entering and exiting entrances to caves and mines, but few, if any, of the bats may roost within the site during the day. Swarming probably is related to fall breeding activities and locating potential hibernation sites.

take – "Take" of listed species, as defined by the ESA, is harassing, harming, pursuing, hunting, shooting, wounding, killing, trapping, capturing, or collecting a or attempting to engage in any such conduct. "Harm" is further defined to include significant habitat modification or degradation that results in death or injury to a listed species by significantly impairing behavioral patterns such as breeding, feeding, or sheltering.

thermoregulation - the processes by which bats actively maintain their body temperature within a specified range in order to stabilize or optimize temperature-sensitive physiological processes

torpor – controlled reduction in body temperature; the condition in bats when body temperature drops in a parallel relation to ambient environmental temperatures

tragus - the prominence in front of the opening of the external ear of a bat

vespertilionid - a bat in the family Vespertilionidae; a large and wide ranging family of bats characterized by a long tail; almost all members are insect-eating

volant - able to fly

Region 3
U. S. Fish and Wildlife Service
Bishop Henry Whipple Federal Building
1 Federal Drive
Fort Snelling, MN 55111-4056

April 2007