FINAL REPORT

MINES AS BAT HIBERNACULA WITH EMPHASIS ON INDIANA BATS

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EXECUTIVE SUMMARY

About 12 species of bats occur in Illinois, most of which hibernate during the winter. Because of destruction of natural habitats, many cavernicolous bat species rely on abandoned mines for hibernacula. In Alexander County in southern Illinois, abandoned underground microcrystalline silica mines, owned by Unimin Specialty Minerals Corporation, provide winter hibernacula for five species of bats: the federally endangered Indiana bat (*Myotis sodalis*), big brown bat (*Eptesicus fuscus*), little brown bat (*M. lucifugus*), northern long-eared bat (*M. septentrionalis*), and eastern pipistrelle (*Perimyotis subflavus*). Within the last decade, the number of Indiana bats using these mines as hibernacula has risen dramatically. For example, Magazine mine now houses >36,000 hibernating Indiana bats. A total of 110 surveys of 45 abandoned mines was conducted between 2003 and 2007 in southern Illinois to determine predictive factors for the total number of bats as well as the number of each species using a mine. Factors measured included: size of the opening, number of openings, mean temperature during hibernation (November through March), temperature variability, distance to water, distance to nearest road, and evidence of disturbance. A total of 75,067 bats was observed hibernating in 43 mines. Three sets of data were analyzed. The first included data from all of the mines (N=45). The second set of analyses was limited to the 16 mines that contained temperature loggers. For this analysis, only loggers that were in place near hibernating bats were used. The third set of analyses used the 16 mines with dataloggers, using both loggers that were placed near hibernating bats, as well as those loggers placed where there were no bats hibernating. Univariate and multivariate

regression analyses were conducted using these datasets. Temperature was the primary variable significantly related to the number of hibernating bats. There is a negative relationship between temperature and the number of bats: as temperature decreases, the number of bats increases. We identified 5 mines in addition to Magazine Mine and Mine 30 that have recurring populations of hibernating *M. sodalis*. An additional 644 *M. sodalis* were counted in these mines (Barney Grace, Birk 2, Birk 3, Jason Mine, and Mine 26) during the winter of 2006. In addition to housing hibernating *M. sodalis*, all of these mines except Birk 3 have bachelor colonies of male *M. sodalis* that use the mines during the summer. Mines are a very important resource for bats, and specifically Indiana bats. Ongoing efforts are being made to protect these mines and determine their long-term stability as bat hibernacula.

INTRODUCTION

With the exception of the rodents, bats are the most speciose order of mammals in existence today. Nonetheless, bats have a bad reputation with the general public. As a result, it is not surprising that many bat populations are declining (Meier and Garcia 2000). Of the 45 species of bats in the United States, 6 are on the federal threatened or endangered list, and 20 were of special concern to the U.S. Fish and Wildlife Service (Harvey et al. 1999). Most other species are experiencing population declines (Meier and Garcia 2000)--in many cases as a direct result of human activities. Bats are often disturbed by humans during both hibernation and summer roosting periods. Many residential and commercial developers close surface entrances to natural caves, often for liability purposes, eliminating access for the bats. Mining activities also eliminate access when openings are closed by excavation and road building. Also, many natural cave openings along streams and rivers have been closed due to the creation of flood control reservoirs (Meier and Garcia 2000).

While humans have done much harm to natural bat habitat, we have also inadvertently created habitat. Researchers are becoming increasingly aware of the importance that abandoned mines play in bat conservation. Mines are used by 28 of the 45 species of bats (62%) in the United States, primarily as roosting areas (Altenbach and Pierson 1995). Like caves, mines are used both in summer and winter. During winter, most mines have areas that stay above freezing and have stable temperatures, which is very important to hibernating bats. Mines also provide some protection from predators. Bats throughout the United States are using mines for hibernation, day roosting, maternity shelter, feeding and watering (Meier and Garcia 2000). In Arizona, California, Colorado, and New Mexico, 6000 mines were surveyed for bat use. Of the mines surveyed, 30-70% showed signs of use. In addition, 10% of the mines contained important colonies (Meier and Garcia 2000). Up to 70% of the mines in the northern and eastern United States may be used by bats (Tuttle and Taylor 1994; Altenbach and Pierson 1995; Mesch and Lengas 1996). In Wyoming, 12 of the 16 species present use mines (Luce 1993). Species such as Townsend's big-eared bat (Corynorhinus townsendii) and the California leaf-nosed bat (Macrotus californicus) form the largest known colonies in man-made habitat (Luce 1993). In Michigan, the most important hibernation sites are mines (Kurta 1999). Scattered throughout 34 states, there are 367,000 open mines and shafts. A majority of these mines is located in the western 1/3 of the country, and provide hibernation sites for many species (Meier and Garcia 2000). As of 2000, the state of Illinois was reported to contain 83 mine openings, some of which are critical hibernation sites for endangered species. For example, in southern Illinois, >36,000 federally endangered Indiana bats (Myotis sodalis) were counted during a 2005 census of Magazine Mine. This is the largest known Indiana bat hibernaculum in Illinois (Kath 2005), housing 12.7% of the estimated population of 457,000 (USFWS 2006).

Unfortunately, humans are also destroying these artificial habitats. Most of the mines that are being used by bats are no longer used by mining operations. These mines are being closed in large numbers. From1978 to 1994, a total of 12,557 vertical openings and portals was closed. Most of these closings were for a single reason, to keep people out for public safety and liability reasons. Again, most of the mines are located in the western portion of the US. However, Illinois is no exception. As of 2000, a total of 1,282 mine openings were closed. To close a mine, companies or government agencies would seal the entrance with solid fill or construct a solid door. Historically, there was very little concern for bats and surveys were not conducted to see if there were bats roosting inside. In addition, closings were done throughout the year (Meier and Garcia 2000). A mine in Pennsylvania's Canoe Creek State Park was closed on a hibernating colony of bats. Also, New Jersey's largest known population of hibernating bats was trapped when Hibernia mine was closed. In both of these cases, biologists convinced authorities to reopen the mines in time to save the bats (Meier and Garcia 2000). Tragically, these cases are the exception. Again, Illinois follows this trend. Of the 1,282 mines that have been closed in the state, only 22 were closed to the public, but remained accessible to bats. It has only been recently that government agencies and mining operations have taken the needs of bats into account before mine closures. Today, mines are routinely surveyed for the presence of bats before they are closed. In some cases these surveys show that a small population of non-threatened species is using a mine. In these cases, the agency will simple wait until the bats leave, and then seal the mine. In other cases, the mine may serve as a hibernaculum for an endangered or threatened species, or house a large population of bats, and other measures must be taken.

A large colony or an endangered or threatened species using a mine does not eliminate the public safety or liability risk. These mines must be closed to humans, but still accessible to bats. Government agencies and mining companies use "bat-friendly closures", or "bat gates" (Tuttle and Taylor 1998) to accomplish this. There are several criteria in the design of bat-friendly closures. First, the closure must not change airflow or water drainage patterns into the mine, as this could change the temperature and moisture regime of the hibernaculum. Second, the number of vertical support members must be minimized while the number of horizontal fly through spaces is maximized. Third, the design should be simple and safe to construct, as well as safe for the general public. Finally, the closure materials should be durable, vandal resistant, and easily maintained and repaired. It has been shown by Martin et al. (2006) that properly built bat-friendly closures have no impact on ambient and substrate temperatures in the summer, and non-biologically significant impact on winter ambient and substrate temperatures.

In addition to keeping the public out of mines, bat-friendly closures also protect the bats. Bats are extremely sensitive to human disturbance, even non-tactile disturbance such as sound or light. The mere presence of observers can often lead to arousal of bats, even if they are neither touched nor had a light shined on them (Fenton 1983; Hill and Smith 1984; Thomas 1995). According to Thomas et al. (1990), arousals are thought to be the main cause of the depletion of fat reserves during winter. The arousal process occurs in three stages. First is the warming stage where heat is generated by the muscles, liver, and brown adipose tissue, which elevates the temperature from near ambient to around 37°C (Foster and Frydman 1978; Hayward and Ball 1966). In little brown bats (*Myotis lucifugus*), this takes 44.1 ± 2.2 min. and requires 14.5 mg of body fat (Thomas et al. 1990). This elevated temperature is maintained in the homeothermic phase, during which the bat remains active for a variable amount of time (French 1985). If this stage lasts 3 hours, the total metabolic cost would be 83.7 mg of body fat for *M. lucifigus*. The final or cooling stage, is characterized by the animal reducing body temperature to near ambient temperature and reentering hibernation, and requires 9.7 mg of body fat (Thomas et al. 1990). It has been shown that bats spontaneously arouse periodically during the hibernation period (Avery 1985; Brack and Twente 1985; Hardin and Hassel 1970;

Lyman et al. 1982). The mean duration between spontaneous arousals for *M. lucifugus* is 13 days (Brack and Twente 1985). If the hibernation period is 143 days, an individual would arouse 11 times. Before hibernating, bats acquire large fat reserves that will last through the hibernation period and allow for some periodic arousal. If human disturbances occur more often than these built-in periodic arousals, an individual may use up its fat reserves before the end of the hibernation period, especially in more northerly portions of the geographic range.

The reasons for installing bat-friendly closures are straightforward; the problem lies in which caverns to place them in. Most researchers agree that temperature is the most important factor that determines whether bats will use a cavern as a hibernaculum. While hibernating, energy costs of metabolism are low. Many temperate species rely on stored body fat as an energy source (Webb et al. 1996). Although there is variability between species, they all have a particular temperature that is optimal for hibernation. Hibernating Indiana bats prefer temperatures between 3-6°C in mid winter (Henshaw and Folk 1966). The metabolic rate for hibernating bats is lowest at just above 0°C. If the ambient temperature falls below this, the bat must produce metabolic heat to survive (Tuttle and Kennedy 2002). In addition to disturbance, bats also arouse due to abrupt changes in ambient temperature (Henshaw and Folk 1966). Because of this, stability of temperature becomes as important, if not more so, than the optimal mean temperature for hibernation. Thus, the more stable the temperature of a hibernaculum, the lower the energy requirements needed to survive the hibernation period (Thomas et al. 1990). While the actual temperature of a hibernaculum depends on the ambient temperature outside, the stability of temperature depends on the characteristics of the hibernaculum itself, be it a cave or an abandoned mine.

OBJECTIVES:

The overall objective of this study was to determine how the characteristics of a mine effect its selection as a hibernaculum by Indiana bats, eastern pipistrelles, little brown bats, northern long-eared bats, and big brown bats. Additionally this study addressed two specific questions pertaining to *M. sodalis*.

1. Are there more abandoned mines in the area that are being used as hibernacula by bats, specifically Indiana bats?

2. What characteristics of these mines make them suitable as Indiana bat hibernacula?

MATERIALS AND METHODS

STUDY AREA

The mines surveyed in this study are located within the Shawnee Hills Natural Division of Illinois, which extends across the southern tip if the state. This division is characterized by rugged topography, loess soils, and distinctive plant communities. The Shawnee Hills Natural Division is divided into two sections, the east-west escarpments of sandstone cliffs that make up the Greater Shawnee Hills Section, and lower hills underlain with sandstone and limestone that make up the Lesser Shawnee Hills Section (Schwegman 1974). The Greater Shawnee Hills Section forms a band along the northern edge of the division that averages 16 km wide and is bordered on the south by the Lesser Shawnee Hills Section. On average, the Lesser Shawnee Hills are 60 m lower in elevation that the Greater Shawnee Hills Section. Also, the Lesser Shawnee Hills Section is characterized by sinkhole topography.

Portions of Union and Alexander Counties within the Shawnee Hills Natural Division are home to unique microcrystalline silica mineral deposits about 4.6 km wide by 9.6 km long. The mineral deposits are patchy within the formation. This mineral was deposited in the Devonian period, and has been mined in the area for >100 years.

MINING HISTORY AND UNIMIN SPECIALTY MINERALS

Currently, southern Illinois is the only location in the world where microcrystalline silica is commercially mined. Historically, the deposit was mined by hand, using picks and wheelbarrows. During this early period, mines were no more than tunnels 1-2 m high and 1 m wide. With the advent of modern mining machinery and practices, the mines became much larger, both in area as well as volume. At one time, there were 7 companies mining microcrystalline silica in the region. By the 1980s, only two companies, Tammsco and Illinois Minerals Company remained active. These companies were later purchased by Unimin Specialty Minerals in 1986 and 1989, respectively (R. Fox, Unimin Specialty Minerals, personal comm.).

Although machinery and techniques were modern, finding a large deposit was not an exact science. Once a potential site was located, a test hole was dug. Using heavy equipment, miners tunnel into the hillside anywhere from 20 to 100 meters, accessing the deposit. In many cases, the deposit was not as large as believed or of poor quality. These test holes were then abandoned. If the deposit was of good quality, miners would continue mining. A series of interconnected rows and aisles were excavated, leaving large pillars of material to support the ceiling. These tunnels range is size from 6-7.5 m high and 4.5-6 m wide. The miners continued in this fashion until the material was exhausted, at which point the mine was abandoned. Illinois Minerals stopped mining underground in 1983, when they switched to open pit mining. All of the underground mines were abandoned and left to close naturally. Tammsco continued underground mining operations until 1996 in Birk 2 (R. Fox, Unimin Specialty Minerals, personal comm.). This mine was also abandoned and left to close.

SURVEY PROTOCOL

From 2003 to 2006, a total of 45 mines was surveyed between November and April. The number of times that a mine was surveyed ranged from 1 to 5 times over the course of the study. Every bat observed was identified and counted. Clusters of *M. sodalis* that were too large to count were estimated based on an average packing density of 400 bats per square foot. To negate the effects of size on the total number of bats using a mine, we devised a new unit of measurement. A new unit was warranted because many of the mines that were surveyed were merely test holes and are not composed of rooms as many of the larger mines are. However, like the large mines, the tunnels are roughly the same width (6 m), because they were excavated with the same machinery. This new unit, the Roosting Unit (RU) is a 6m X 6m X 6m cube. Using the width of the rows and aisles on a mine map, the total RUs for each mine was estimated. The total number of all bats, as well as the total number of each species, was then divided by the number of RUs to determine the number bats per RU. This number was used as the dependent variable in our analyses.

In addition to recording how many of each species were present, physical characteristics of each mine were recorded. Temperature, standard deviation of temperature, evidence of disturbance, distance from the nearest road, distance to the nearest permanent water source, the number of adits (openings), as well as the area of the smallest adit where chosen as independent variables based on possible effects on bats.

TEMPERATURE AND RELATIVE HUMIDITY

Between 2003 and 2005, 25 dataloggers (HOBO H8 Pro Series, Onset Computer Corporation, Bourne, MA) were installed in 16 mines. An additional 10 loggers were installed in Magazine Mine and Mine 30 prior to the start of this study by the Illinois Department of Natural Resources, and were included in the analyses. Datalogger locations and dates of operation can be found in Appendix A. During the summer of 2005, all of the loggers were downloaded and new batteries were installed. Faulty loggers were removed and replaced with functioning ones. The loggers were programmed to record temperature and relative humidity every 4 hours over the course of the study. Of the 16 mines with loggers, 7 had multiple loggers installed because they were known *M. sodalis* hibernacula. The loggers were installed as near as possible to clusters of hibernating *M. sodalis*. In addition to housing populations of hibernating *M sodalis* in the winter, these mines also have bachelor colonies of male *M. sodalis*. In the spring, all of the females, and some of the males leave the hibernaculum and migrate to summer habitats. Some male *M. sodalis* do not leave the mine, they just change locations. Although *M. sodalis* require very low temperatures for hibernation, while they are active they prefer much warmer temperatures. These bachelor colonies were always located in portions of the mines that were much warmer that the portions where *M. sodalis* was observed hibernating. Loggers were placed as near as possible to these "bachelor pads" as well. Finally, these 7 mines are fairly large, offering a wide range of microclimates for the bats to choose from. In addition to installing loggers where the bats were hibernating, loggers were installed in areas of the mines that were not being used by bats. To reduce the number of data points, daily averages were calculated and used to produce a temperature graph. Figures 1 and 2 show examples of mines with stable temperatures and Figures 3 and 4 are examples of mines with unstable temperatures. In addition to calculating daily averages, 7-day, monthly, and seasonal averages were also calculated (see appendix C). A total average from loggers that were located near hibernating bats was calculated for use in a multiple regression analysis. This number was the average temperature from November through March of all the years that the logger was collecting data.

TEMPERATURE VARIABILITY

To address the importance of temperature stability, the average Standard Deviation was calculated using Microsoft Excel (Microsoft 2003) from the daily temperature averages between November and March for the loggers near hibernating bats as well as those loggers that were placed where there were no bats hibernating.

DISTURBANCE

Each mine was assessed for evidence of recent disturbance. Examples of disturbance included footprints, aluminum cans, ashes from a fire, and graffiti. In an effort to determine if the disturbance was ongoing, when found, footprints were smeared, beer and soda cans were crushed, and ashes were spread. We then looked for fresh evidence during return trips.

DISTANCE TO THE NEAREST ROADWAY

The straight-line distance from the nearest roadway to the entrance to the mine was determined using ArcView 3.2 by ESRI (ArcView, 1999) and recorded to the nearest meter. This was considered a measure of potential disturbance because if a mine is located near to, or in sight of a road, there is an increased chance that the mine has been disturbed.

DISTANCE TO THE NEAREST PERMANENT WATER SOURCE

The straight-line distance from the nearest permanent water source to the entrance to the mine was determined using ArcView 3.2 by ESRI (ArcView, 1999) and recorded to the nearest meter.

NUMBER OF ADITS

An adit is defined as a horizontal or nearly horizontal passage driven from the surface for the working or dewatering of a mine (U.S. Bureau of Mines, 1996). While conducting surveys, all adits to a particular mine were recorded. An adit was considered any access to the surface including entrances that were used by machinery to access the mine, as well as cave-ins that occurred after mining operations had ceased.

AREA OF SMALLLEST ADIT

Area was determined by measuring the height and width of the opening at it highest and widest parts. The shape of the entrance was then sketched onto graph paper. Using the grid, area was estimated to the nearest m^2. We chose to use the area of the smallest adit for the mines with multiple adits because it limits the amount of air that is exchanged as the mine "breathes."

STATISTICAL ANALYSES

A variety of statistical analyses was run using the data from this study. First, a trend analysis using PROC MIXED in SAS 9.1 (SAS Institute, 1999) was conducted using the survey numbers for all mines that were surveyed ≥ 3 separate occasions ($N = 19$). Since Magazine Mine and Mine 30 were only surveyed once during the course of this study, they were not included in this analysis. Secondly, all of the variables were tested for correlation using PROC CORR in SAS 9.1 (SAS Institute, 1999).

Finally a series of multiple and univariate regressions were calculated. One set of regression analyses were run using adit area and disturbance as independent variables and total bats/RU, *M. sodalis*/RU, *P. subflavus*/RU, *M. lucifigus*/RU, *M. septentrionalis*/RU, or *E. fuscus*/RU as dependent variables. All 45 mines were included in theses analyses. To determine if one of the variables was masking the effects on the others, a series univariate regression analyses were run using total bats/RU, *M sodalis*/RU, *P. subflavus*/RU, *M. lucifigus*/RU, *M. septentrionalis*/RU, or *E. fuscus*/RU as the dependent variable and adit area or disturbance as the independent variable. Because disturbance was not a continuous variable, a one-way bivariate analysis was run using the JMP program (SAS Institute, 1999).

A second set of multiple regression analyses was run using disturbance, adit area, average temperature, and average standard deviation of temperature as independent variables, and total bats/RU, *M. sodalis*/RU, *P. subflavus*/RU, *M. lucifigus*/RU, *M. septentrionalis*/RU, or *E. fuscus*/RU as dependent variables. The temperatures used in these analyses were averaged only from those loggers that were placed near hibernating bats. A total of 16 mines was included in these analyses. Again, univariate analyses were also run with average temperature and average standard deviation of temperature as independent variables and total bats/RU, *M. sodalis*/RU, *P. subflavus*/RU, *M. lucifigus*/RU, *M. septentrionalis*/RU, or *E. fuscus*/RU as dependent variables.

To address those mines that had loggers placed where there were no bats hibernating, total number of bats, as well as total numbers of all five species, located in the room with the logger was used as the dependent variable. Univariate analyses were run using the average temperature from November through March, and the standard deviation of those temperatures as the independent variables.

RESULTS

SURVEYS:

Over the course of the study, a total of 113 surveys was surveyed and 75,067 bats were observed hibernating. From December 2003 to April 2004, 24 mines were surveyed for bat use and physical characteristics (Appendix D) of the mines were recorded and a total of 7,167 bats was observed hibernating. Between December 2004 and March 2005, 32 mines were surveyed and a total of 49,852 bats was observed hibernating. Physical characteristics for 18 of these mines were recorded as they were previously unsurveyed. Thirty-four mines were surveyed between January and February 2006 and a total of 12,219 bats was observed hibernating. Physical characteristics were recoded for 3 mines, as they were previous unsurveyed. Twenty-three mines were surveyed between December 2006 -February 2007. A total of 5,829 bats was observed hibernating. During this hibernation period, no additional mine were located. Over the course of the study, *P. subflavus* was observed hibernating in 39 mines, *M. septentrionalis* and *E. fuscus* were observed hibernating in 36 mines, *M. lucifugus* was observed hibernating in 23 mines, *M. sodalis* was observed hibernating in 13 mines and *M. austroriparius* was observed in 2 mines. A complete list of the species breakdown by mine is located in Appendix E. This illustrates the trend first observed by Layne (1958) and Pearson (1962). Bats are moving into more mines and densities within mines are continuing to increase.

Of the 13 mines used by *M. sodalis*, 7 contained piles of bat feces (guano), indicating that the mines are being used in the summer while the bats are feeding. These 13 mines were also surveyed during the summer. During the summer of 2005, >10,000 bats (mostly male *M. sodalis*) were observed in 5 mines.

STATISISTICAL ANALYSES

Trend Analysis:

The number of bats hibernating in Unimin mines has been increasing since the start of this study. There was a significant positive trend across the 19 mines that were used in the trend analysis ($F = 32.23$, $p = <0.0001$).

Correlations:

Two sets of variables exhibited significant correlation. Disturbance and the number of adits as well as distance to the road and adit area showed significant positive association with Pearson Correlation Coefficient values of 0.57879 ($p < 0.0001$) and 0.46708 ($p = 0.0012$) respectively. In light of this, number of adits and distance to road were not included in the multiple regression analyses. Additionally, the distance to the nearest permanent water source was of little significance in several analyses and was deleted from further analyses.

Multiple Regression Analyses:

The overall multiple regression analysis using disturbance and adit area as independent variables and total bats per roosting unit, *M. sodalis* per roosting unit, *M. septentrionalis* per roosting unit, or *E. fuscus* per roosting unit were not significant. The overall regression for *P. subflavus*, and *M. lucifugus* did yield significant results (Table 2). In both cases, most of the variation in the data was due to the variable disturbance ($t = 4.05$, $p = 0.0002$; $t = 2.96$, $p = 0.005$ respectively).

The overall multiple regression analyses using disturbance, adit area, average temperature and average standard deviation of temperature as independent variables was significant for *E. fuscus* (Table 2). The individual parameter estimates show that most of the variation was due to average temperature (t = -2.85, p = 0.0158). There was no significance for any of the other analyses.

Univariate Regression Analyses:

Temperature: Temperature was an important variable in determining where bats would hibernate. The univariate analyses using average temperature were significant for total bats, *M. sodalis*, and *E. fuscus* (Table 3; Figures 5-7). The analyses were not significant for *P. subflavus*, *M. lucifugus*, and *M. septentrionalis*. In all the analyses, the individual parameter estimates for temperature were negative (total bats: t = -2.47; *M. sodalis*: t = -2.33; *P. subflavus*: t = -0.75; *M. lucifugus*: t = -1.23; *M. septentrionalis*: t = -1.65; and *E. fuscus*: t = -2.94).

Using the data set that included all of the loggers in the mines with multiple loggers installed, the univariate analyses were significant for total bats per room and *M. sodalis* per room (Table 3; Figures 8-9). The analyses were not significant for *P. subflavus*, *M. lucifugus*, *M. septentrionalis*, and *E. fuscus*. Similarly to the above analyses, the individual parameter estimates were negative for total bats and *M. sodalis* (t = -2.31, and t = -2.45 respectively).

Temperature Variability: The average standard deviation of temperature was significant for only *P. subflavus* (Table 3; Figure 10). The results for total bats, *M. sodalis*, *M. lucifugus*, *M. septentrionalis*, and *E. fuscus* were not significant.

Using the data set that included all of the loggers in the mines with multiple loggers installed, the univariate analyses were significant for only *P. subflavus* (see table 3, figure 11). All other analyses were not significant.

Disturbance: The one way bivariate analyses were significant for *P. subflavus* and *E. fuscus*. None of the other analyses was significant.

Area of smallest adit: None of the univariate analyses using area of the smallest adit as the independent variable yielded significant results.

DISCUSSION

A few surveys of the abandoned mines have been done in the past. Layne (1958) surveyed an unknown total of mines and prospect holes from 1954-1955 for hibernating bats. Bats were observed hibernating in 11 mines, and not surprisingly, he reports *P. subflavus* was the dominant species in 9 of these mines. Additionally, *E. fuscus* was observed in 3 of the 11 mines, and *M. septentrionalis* was observed in 1 mine. Surprisingly, he also reports *Corynorhinus rafinesquii* in 2 of 11 mines, and *Lasionycteius noctivigans* were observed in 2 mines. None of the mines surveyed contained hibernating *M. sodalis*, *M. lucifugus*, or *M. austroriparius*. From 1958-1960, a total of 35 mines was surveyed by Pearson (1962), some of which he reports to still be active. Twenty-four of the mines contained hibernating bats of six species. A total of 356 bats was observed during 49 searches of the 24 mines that contained hibernating bats. A total of 221 *P. subflavus* was observed in 14 mines, 53 *M. septentrionalis* were observed in 13 mines, 40 *M. lucifugus* were observed in 8 mines, 21 *E. fuscus* were observed in 12 mines, 13 *C. rafinesquii* were observed in 9 mines, and 18 *L. noctivigans* were observed in 8 mines (Pearson 1962). In 1974 Whitaker surveyed a total of 30 silica mines. Of these, 11 contained hibernating bats of six species (Whitaker 1977). Unfortunately, we have no way of knowing which mines were surveyed during the studies conducted by Layne and Pearson. Whitaker does list Township, Range and Section information in a report to the Forest Service, and in the future it may be helpful to use that information to see if there are mines that were surveyed in the past, but were not discovered during this study. Interestingly, the species that is the main concern of this present study, *M. sodalis*, was not reported from any of the mines during any of the studies, the latest being in 1974. In fact, in his report to the Forest Service, Whitaker stated that he believed *M. sodalis* to be extirpated from southern Illinois (Whitaker 1975). The discovery of Magazine Mine led to a renewed interest in the silica mines as bat habitat for *M. sodalis*.

Magazine Mine was in operation from 1972 to 1980, resulting in ca. 84,730 m^2 of underground tunnels. The mine remained undisturbed for 15 years. In the summer of 1995, a harp-trap was used to capture bats at the entrance to the mine. A total of 5 species was caught, including *M. sodalis*. The first formal survey of Magazine Mine was conducted in 1999. More than 9,000 *M. sodalis* were observed hibernating within the mine. Magazine Mine was then included on a list of known Indiana bat hibernacula scheduled to be surveyed every other year. Indiana bats were discovered hibernating in a second mine in 2000. Mine 30, abandoned in the late 1970's, has ca. 12,549 m^2 of underground passages. A total of 495 *M. sodalis* was counted during a 2000 survey. Mine 30 was also added to the list of hibernacula to be surveyed. During the most recent surveys in 2005, >33,000 *M. sodalis* were hibernating in Magazine Mine, and >3,600 were hibernating in Mine 30. With the 2005 survey, Magazine Mine was listed as a Priority One hibernaculum (a hibernaculum containing >30,000 bats), and represents the first Priority One hibernaculum in Illinois. Given the results of early surveys conducted in the 1950's and 1960's, as well as the population explosions in Magazine Mine and Mine 30, are there more abandoned mines in the area that are being used as hibernacula by bats, specifically, *M. sodalis*? Thirty-eight of the 45 mines surveyed (84.4%) were used by hibernating bats. We expected larger mines to be used by bats simply because there is a wide range of microclimates for the bats to choose from. Surprisingly, test holes were often used by bats, sometimes in relatively high densities. Test hole 2001 is a small mine that is only 7 roosting units in size. Fifty-six bats were counted in 2006 giving a total density of 8.0 bats/RU. In comparison, Jason Mine has 157 roosting units. In 2007, 468 bats were counted, giving an index of 2.98 bats/RU. In addition to a majority of the mines being used as hibernacula, it was surprising that populations of hibernating bats are increasing in many of the mines. These population increases are occurring in all of the 5 species of bats that hibernate in southern Illinois, the most important being the Indiana bat. Mines that did not contain hibernating bats can be explained by the fact that there are no areas of the mine that are completely dark.

While conducting this study, we identified 5 mines in addition to Magazine Mine and Mine 30 that have recurring populations of hibernating *M. sodalis*. An additional 644 *M. sodalis* were counted in these mines (Barney Grace, Birk 2, Birk 3, Jason Mine, and Mine 26) during the winter of 2006. In addition to housing hibernating *M. sodalis*, all of these mines except Birk 3 have bachelor colonies of male *M. sodalis* that use the mines during the summer. Several characteristics of these mines make them suitable as Indiana bat hibernacula.

TEMPERATURE

Bats have very rigid thermal requirements for hibernation. To maximize the efficiency of energy use during hibernation, *M. lucifugus* generally hibernates within a few degrees of 5°C (Davis 1970). A variety of other species also hibernate in this general range (Kowalski 1953; Beer and Richards 1956; ter Horst and van Nieuwenhoven 1958; Hall 1962; Pearson 1962; Tinkle and Patterson 1965; Henshaw and Folk 1966; Phillips 1966; Hassell 1967). Based on this, we would expect temperature to be significant factor in determining use for all species. As expected, temperature was an important variable, and contributed a significant amount to the variation observed in the number of bats using a particular mine. It is important to note that there is a negative relationship between temperature and the number of bats: as temperature decreases, the number of bats increases. This is not surprising in light of the fact that hibernation at lower temperatures is more efficient. According to Hock (1951) the metabolic rate for *M. lucifugus* is lowest at 2°C. At 10°C the metabolic rate is roughly doubled. Of course, this holds true to a certain point: once the temperature approaches freezing, bats must expend energy to keep from freezing. For *M. lucifugus*, the metabolic rate at 0.5°C is four times greater than at 2°C (Hock 1951). It is surprising then that temperature was not significant for *M. lucifugus*. Little brown bats are very similar to *M. sodalis*, and were often observed hibernating near or even within clusters of *M. sodalis*.

In the past, optimal thermal conditions during mid-winter for *M. sodalis* lie somewhere in the range 4-8°C (USFWS 1999). Tuttle and Kennedy (2002) give a more conservative estimate of 3-6°C. There was a large range of temperatures recorded where *M. sodalis* was observed hibernating (Table 5). The average temperature during the hibernation period (Nov-Mar) was 6.99°C. The highest recorded temperature from the hibernation period (11.16°C) was recorded in Mine 30, and the lowest (-0.69°C) was recorded in Magazine Mine. Of the 7 mines being used by *M. sodalis*, only Magazine Mine has average temperatures that fall within this range. The average hibernation temperature for the other 6 mines was 8.08°C, well outside of the preferred range. Tuttle and Kennedy (2002) show that hibernacula with mid-winter temperatures between 3-6°C have increased by a total of > 97,000 *M. sodalis*, and hibernacula with midwinter temperatures outside of this range decreased by a total of >185,000 *M. sodalis*. This is not the case in southern Illinois. During the 2004-2005 hibernation period, 4,492 *M. sodalis* were observed hibernating in mines outside of the preferred range. This is consistent with the findings of Brack et al. (2003) who document increasing populations of *M. sodalis* in hibernacula with mean temperatures of 5-8°C. These 6 mines, with the exception of Jason Mine, all have populations that are stable or growing. Decreases in Jason Mine are not due to temperature, however. While these mines are not experiencing the exponential growth that Magazine Mine is, they are still sheltering a growing number of *M. sodalis*. We believe that they are extremely important because they are in close proximity to a Priority One hibernaculum and have temperatures that are only a few degrees out of the "ideal" range. This study shows that marginal hibernacula (those that fall outside of the ideal temperature range for *M. sodalis*) can serve as valuable hibernacula and are able capable of supporting increasing populations.

One major limitation to this study is the fact that we were only allowed to enter hibernacula once per hibernation season. Dataloggers were placed where *M. sodalis* were observed hibernating. However, there is a good chance that the animals are not spending the entire hibernation period in these locations. At the onset of the hibernation period, bats tend to roost in warm passages deep within the hibernaculum. As the hibernaculum cools, *M. sodalis* will move to colder areas nearer to the entrances (Hall 1962, Hardin and Hassell 1970). This phenomenon makes it extremely difficult to pinpoint "ideal" temperature ranges. For example, room 7G in Magazine Mine always has a large concentration of hibernating *M. sodalis* when the mine is surveyed at the end of February. However, in middle to late January, this room has temperatures that are extremely low (between 30 January and 1 February 2004 temperatures fell below 0°C). If this logger was used to determine temperature requirements for *M. sodalis* during hibernation, one could incorrectly assume that *M. sodalis* prefers temperatures that are near or below freezing during mid winter. We do not believe that this is the case, and would hypothesize that the bats were not using this room during that time. We believe that temperature, while extremely important for successful hibernation, cannot be used to accurately predict use by *M. sodalis*. There are a couple of reasons for this. First, it is impractical and cost prohibitive to place dataloggers in all of the possible microhabitats that a bat could choose from within a hibernaculum. Secondly, even if all microhabitats could be accounted for, we still have no idea where the bats are roosting, and how long they stay in that particular area. We believe that the only way to assess the suitability of hibernacula is to look at what the populations are doing. The bats know what constitutes an "ideal" hibernaculum, and will select hibernacula that most closely approximate those conditions. As a result, hibernacula with increasing populations of *M. sodalis* should be protected. For those hibernacula with decreasing populations, efforts should be made to determine the cause of the declines.

TEMPERATURE VARIABILITY

While temperature is clearly important, once temperatures are low enough for hibernation, stability of those temperatures becomes important physiologically for the bats as well. We expected that standard deviation would be significant for all species. However, this was not the case. Temperature variability was only significant for *P. subflavus* in the analysis that used only temperatures obtained from loggers near hibernating bats, and the analysis that used all of the loggers from mines with multiple loggers. One possible reason for this is that all of the mines, regardless of size or complexity, have temperature regimes that are fairly stable. It appears that temperature variability has little influence on hibernacula selection by bats at the Unimin Mining complex.

DISTURBANCE

Disturbance predicted use by both *P. subflavus* and *E. fuscus*. However, unexpectedly, the relationship is positive. This would imply that disturbance is a positive indicator of bat use. This obviously is not truly representative of what is happening. Bats are extremely vulnerable to any disturbance, both active and passive (Fenton 1983; Hill and Smith 1984; Thomas 1995). Despite these questionable results, disturbance is an especially important issue at these mines. Seven of the mines showed at least one sign of recent disturbance. Four of these are *M. sodalis* hibernacula. In most cases, the disturbance of the bats is passive, as they are roosting too high for humans to physically disturb them. Unfortunately, we do not believe that this was the case in Jason Mine. While conducting the yearly survey in 2005, an empty box of .22 caliber rifle ammunition was found a few meters away from the clusters of hibernating *M. sodalis*. While downloading the loggers in 2006,we noticed debris in a hole in the mine wall. Upon closer examination, the debris was a pile of at least 20 bat skeletons in various stages of decay. A second hole contained at least 30 more skeletons. While we have no way of identifying these bats, there is a good chance that they were *M. sodalis*. First, the box and some ammunition casings were found within a few meters from the only place in the mine where *M. sodalis* are found. Second, there was a decline of 64 *M. sodalis* between January 2004 and January 2005. In contrast, between January 2005 and January 2006, there was a decline of only 1 *M. sodalis*.

In some cases the disturbance is ongoing. Rhymer 1 is a medium-sized mine that is located only 15 m from the road. In the winter, with little foliage cover, the entrance can be seen easily from the road. On the first trip into the mine dozens of beer cans and a fire pit were discovered. Because the mine is so easy to access, it was often checked during the summer when we were in the area. Every time that we went into the mine, we found additional evidence of disturbance. As a result of this continued disturbance, we expected the number of bats using the mine to decline. This was not the case. Rhymer 1 was first surveyed on 14 December 2003. There were 768 bats hibernating in the mine. As of 14 January 2006, there were 1143 bats using Rhymer 1 (Appendix E).

AREA OF SMALLEST ADIT

This variable did not contribute in any way to hibernacula selection. This is somewhat surprising in that the size of the entrance will directly affect the amount of airflow into or out of a mine, regulating the temperature regimes within the mine. There are some extraordinary examples of what can happen to bat populations when an entrance is modified. When both entrances to Hundred Dome (Coach) cave were modified in the 1960s, the population of 100,000 *M. sodalis* declined to 50 individuals by 1991 (Richter et al. 1993). Another example is Great Scott Cave in Missouri. During the mid 1980s, the population of *M. sodalis* declined by 80% due to an increase in temperatures. This decline coincided with the construction of a bat-friendly closure on the lower entrance to the cave. However, the upper entrance was cemented closed to prevent access by humans. This prevented warm air from escaping the cave, raising temperatures. When the upper entrance was restored, temperatures immediately returned to historical levels that are well within the range suitable for *M. sodalis* (Kennedy 2002). Clearly, modifying entrances can have serious detrimental effects on hibernating populations of *M. sodalis*.

IMPLICATIONS

The Unimin mine complex is an extremely important resource for bats. Nearly all of the small- and medium-sized mines as well as many of the test holes contain growing populations of hibernating bats. Additionally, the population growth in most of the mines is greater than could be expected from reproductive success alone. Thus, new individuals of all 5 species are immigrating to southern Illinois every year to hibernate. While the Unimin complex is an important resource for bats in general, it is critical habitat for *M. sodalis*. Magazine Mine alone houses up to 10% of the known population of *M. sodalis* and this population has been growing every year since the initial survey.

STABILIZATION AND PROTECTION

Of equal concern from a wildlife conservation standpoint is that these mines are closing naturally. If left alone, dirt and rock from above the mine entrance sloughs off with rain and erosion. Over time this sloughing will result in the mine entrance being closed. Some mines are relatively stable, and are closing slowly. Others are closing rapidly and soon will no longer be accessible to bats. By 2000, the entrance to Magazine Mine was only 7 m wide by 3 m high, a 70% reduction since it was abandoned 1980 in (Kath 2002). In 2001, the original adit to the mine was excavated, and 49 steel arches and timbers were installed every 1.2 m along the adit to allow access even if there is a total collapse. A fence was erected around the lower entrance, and a bat gate was installed in the upper entrance. The survey numbers clearly show that the alterations made to the mine have had no negative impacts on the hibernating colony. After the discovery of .22 ammunition casings, Jason Mine became the second mine to be stabilized and secured, with construction done in 2005. Although Jason Mine was closing, and the entrance needed to be excavated, the mine was very stable within a few meters of the entrance. Because of this, only a 10 m long tunnel was required. A bat gate was then welded to one of the middle steel arches. A third mine, Mine 30, was stabilized and secured in 2006. Two 10-m tunnels were erected in the lower and upper entrances. These tunnels and bat gates do two things: they ensure that the mine will always be accessible to the bats, while at the same time excluding humans.

PROTECTION PRIORITIES

While these tunnels and gates are very effective, they are also very expensive. The tunnel alone at Magazine Mine was completed at a cost of nearly $110,000. This begs the question: Which mines do we protect? Because *M. sodalis* is an endangered species, mines where they hibernate should be the first to be protected. After these mines, we believe that priority should be given to mines that have recurring stable populations of >100 hibernating bats. Below is a prioritized list of mines that we feel should be protected.

1. Barney Grace - There were 381 *M. sodalis* counted in 2006. This number increased from 360 *M. sodalis* in 2004, but decreased from 519 in 2005. Additionally, bachelors have been present every summer between 2004 and 2006. Although the bachelors are not necessarily adversely affected by the passive disturbance that is known to occur, the hibernating bats may be at risk. According to the landowners, the mine is their property, and they have a right to enter whenever they want. It is our opinion that they will continue to enter the mine regardless of the season, greatly reducing the chances of successful hibernation for a good number of *M. sodalis*. We believe that the mine should be stabilized and gated as soon as possible.

2. Mine 26 - There were 195 *M. sodalis* counted in 2006. This number increased from 153 *M. sodalis* in 2004 but decreased from 317 in 2005. Bachelors were present in 2005 and 2006. The entrance is relatively stable and located 768 m from the road. This mine contains a large cave-in. The cave-in drops about 10 m form the surface, and could potentially be very dangerous to the public. There was evidence of disturbance noted on the initial survey, but no further evidence has been seen to date. However, disturbance is not always evident. While the need for protection is not immediate, when funds become available, Mine 26 should be protected.

3. Rhymer 1 – This mine does not contain any *M. sodalis*, but as stated above, disturbance is regularly occurring in this mine. This poses a large liability risk for Unimin. The evidence of disturbance in the mine is always beer cans. This implies that people are spending prolonged periods of time in the mine. There is a real possibility that someone may be injured. Within the mine, there is a hole in the floor that drops down about 13 m to a lower level, which we walked within 1 m of before we saw it on our first trip into the mine. However, do we protect habitat for non-threatened species? If not, then Rhymer 1 should be closed permanently during the summer. If yes, then a tunnel and gate should be installed.

FUTURE RESEARCH

Continued monitoring: As stated above, Magazine Mine and Mine 30 are on the list of Indiana bat hibernacula to survey every other year. It is our belief that all of the mines being used by hibernating Indiana bats should be on this list, and regularly surveyed. With the exception of Jason Mine, all of the mines that are currently being used by *M. sodalis* have hibernating populations that are increasing or stable. Additionally, a survey of all the mines should be conducted every five to ten years until the mines are all closed or protected. Magazine Mine was dormant for more than 15 years during which time it had little bat use. Many of the mines were in operation longer that Magazine Mine and have been available to bats for less time. Perhaps these mines have not reached a temperature regime that is suitable for hibernation, but will in the future as the entrance collapses and airflow changes. Perhaps, bats have just not found the mine yet. If the mines are surveyed periodically, any mines that have increased usage can be identified, protected, and stabilized if appropriate.

Modifications: One of the major contributing factors to the decline of many bat species is habitat destruction. Many natural caves that served as bat hibernacula have been altered by human activities, such as saltpeter mining or commercial cave tours. In many cases, modifications to entrances have altered temperature regimes with the caves rendering them unsuitable to the bats that used them in the past. Currently, Tuttle and Kennedy are attempting to restore several Indiana bat caves in Kentucky to historical conditions, in order to reestablish suitable temperatures. At the Unimin complex, we have the opportunity to create suitable habitat for bats. One mine has already been modified with some success. The mine has 4 adits, allowing considerable airflow within the mine. One of the adits was at nearly the lowest portion of the mine, causing all of the cold air to "leak" out of the mine. In this lower adit, a corrugated metal culvert was installed for access, and the rest of the opening was sealed with dirt in 2005. The resulting changes in temperature regimes, in terms of actual temperature and temperature variability, can be clearly seen from the logger that was placed about 20 meters from the entrance that was sealed. During the months of October through January, the average temperature was 7.75 °C, and the standard deviation of those temperatures was 2.49. During the same period after the entrance was sealed there was slight increase in the average temperature (from 7.75°C to 8.27°C). However, there was a considerable decrease in the amount of temperature variability (from 2.49 to 0.51). While conducting surveys during the hibernation period immediately following the closure, >500 more bats were observed hibernating in the mine, including 28 *M. sodalis*, a drastic increase from 2 *M. sodalis* observed during the two previous hibernation periods. This clearly illustrates that simple modifications can have dramatic impacts on the internal temperature regime of a mine.