ASSESSING THE STABILITY AND LONG-TERM VIABILITY OF ABANDONED MINES FOR USE BY BATS

by

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B.S., University of Maine Orono, 2000

A Thesis
Submitted in Partial Fulfillment of the Requirements for the
Master of Science Degree

Department of Zoology
In the Graduate School
Southern Illinois University Carbondale
May 2009

THESIS APPROVAL

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Graduate School
Southern Illinois University Carbondale
December 19, 2008

AN ABSTRACT OF THE THESIS OF

JEFFREY C. CORCORAN, for the Master of Science degree in ZOOLOGY, presented on 19 December 2008, at Southern Illinois University Carbondale.

TITLE: Assessing the Stability and Long-term Viability of Abandoned Mines for use by Bats.

MAJOR PROFESSOR: Dr. George A. Feldhamer

There are 12 species of bats that occur in Illinois; 5 of these species can be found hibernating in abandoned mines and caves in southern Illinois. Due to the destruction of their natural hibernacula, caves, many species of bats have found abandoned mines to be suitable replacement habitat. A complex of abandoned underground microcrystalline silica mines in southern Illinois owned by Unimin Specialty Minerals Corporation now provides hibernacula for 5 species of cavernicolous bats: the federally endangered Indiana bat (*Myotis sodalis*), little brown bat (*M. lucifugus*), eastern pipistrelle (*Perimyotis subflavus*), big brown bat (*Eptesicus fuscus*), and the northern long-eared bat (*M. septentrionalis*). Within the last 10 years the number of bats using these mines has increased dramatically, especially the Indiana bat which has increased from just over 9,000 to 43,000 hibernating in Magazine Mine. One concern of having so many endangered bats hibernating in one mine is stability. Mines were created relatively recently and are still in the process of settling. Thus, these mines might act as a potential sink, drawing in hibernating bats but potentially collapsing and killing them. Thirteen mines were surveyed for bats and for the amount of spalling that occurred over the 16-month study period from September 2006 to December 2007. Factors that could increase the amount of spalling were quantified, including temperature, moisture, and moisture variability in the material of the walls in the mines, and temperature variability. Number of hibernating bats in the mines was also documented.

Data were analyzed with logistic regression. Temperature was a significant predictor of spalling ($W^2 = 12.76$, $p = 0.0004$) when considered as a univariate variable, as was temperature variation ($W^2 = 21.89$, $p = <0.0001$). Considering multiple logistic regression analyses, moisture was the best predictor.

For the 13 mines surveyed, number of hibernating bats ranged from 0 to 3,755. Whereas all three variables were important at predicting the presence of bats, temperature variation ($W^2 = 35.98$, $p =<0.0001$) was a better predictor than temperature or moisture. In a multiple logistic regression, temperature ($W^2 = 46.75$, $p = < 0.0001$) and temperature variation ($W^2 = 20.56$, $p = < 0.0001$) were better at predicting presence of bats then was moisture. The less variation in temperature the more likely that bats will be present. Because bats prefer stable temperatures and spalling occurs more often at high variability of temperatures and very low temperatures, bats were usually in areas that exhibited little or no spalling.

ACKNOWLEDGEMENTS

I would like to thank Dr. George Feldhamer for his invaluable help and guidance. His vast expertise on mammals and writing helped me to better understand my results and to express my thoughts in an intelligible way and to put them down on paper. Dr. Feldhamer was an excellent guide through the maze we call grad school. He provided the right amount of push when needed without added pressure. I will be eternally grateful for all of his help including allowing me to stay in his home for my first month here until I was able to get my own apartment. He will always have a place to stay in my house wherever I end up.

I would also like to thank Dr. Timothy Carter who got me started at southern Illinois University and on my research. He taught me a lot of new field techniques such as tracking a bat and inserting a PIT tag into a little brown bat. He also introduced me to the Southeastern Bat Diversity Network and the Bat Blitz which was very fun and quite the learning experience. Thanks to him I am not an employee at Wal-Mart right now. He took a chance on me and I hope he and Dr. Feldhamer were not disappointed.

I would also like to thank Unimin Specialty Minerals Inc. for allowing me to use their equipment and facilities in Elco. I would also like to thank their employees who helped me to complete the moisture analysis on my rock samples and aided me in locating mines. I would like to especially thank Rick Fox and Dasha Fehrenbacher who always had answers to my questions and were always more than willing to help me get things done. I would like to thank those who volunteered to help me with my field work; Aaron Poole, Brad Steffen, Denise Stetson, David Ing, Mandy Albus, Jay Hubert, Leslie Rodman, and especially Lyann Rubert for all of her support.

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INTRODUCTION

Researchers have become increasingly aware of the importance of mines to cavernicolous bats such as the endangered Indiana bat (*Myotis sodalis*) and gray bat (*Myotis grisescens*). Of the 45 species of bats in the United States, 6 are on the federal threatened or endangered list (Harvey et al. 1999; USFWS, 1999). The six listed species of bats can be classified as cave-dwelling species or subspecies (Harvey et al., 1999; McCracken, 1989;) and 13 of the 45 U.S. species are obligate cave–dwellers year-round (McCracken, 1989). Because of the loss of natural caves from human disturbances, natural closures, and closing by owners for liability reasons, obligate cave species have used abandoned mines as roosting sites, for courtship, and most importantly for rearing young and hibernation. Approximately 62% of the bat species in the United States and Canada are believed to use old mines or caves for roosting or hibernating (Tuttle and Taylor, 1994; Altenbach and Pierson, 1995). 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).

Throughout the United States, human disturbance, alteration of caves, cave commercialization (e.g. Mammoth Cave), and deforestation are some of the factors that have forced bats out of their natural roosts and into mines. Over the past 100 years or more, many displaced bats have gradually moved into abandoned mines, which often provide microclimates similar to caves (Tuttle and Taylor, 1998). In the United States there are about 367,000 open abandoned mines scattered throughout 34 states (Meier and Garcia, 2000). Many of these mines now provide critical habitat for endangered bat species.

Hibernation allows bats to avoid the hardships of winter and food scarcity (Bogan, 2000). The metabolic rate for hibernating bats is lowest at just above 0^{o}C. If the ambient temperature falls below this, the bat must produce metabolic heat to keep from freezing (Tuttle and Kennedy, 2002). This can use up valuable fat reserves and the bat may not survive the winter if it were aroused too often to find suitable temperatures.

Criteria that make a mine suitable for bats include proximity to foraging areas and water, complex internal structure, volume, temperature and temperature stability, airflow, ventilation, presence of conspecifics and other bats species, and absence of predators (Bogan, 2000). Hibernating Indiana bats prefer temperatures between 3-6^{o}C in mid-winter (Henshaw and Folk, 1966). For efficient hibernation, Indiana bats require caves or mines with stable temperatures and relative humidities of 66 – 95% (Harvey, 2000). Stable low temperatures allow the bats to maintain a low rate of metabolism and conserve fat reserves through the winter until spring arrives (Humphrey, 1978; Richter et al., 1993). They usually hibernate in hard rock caves or mines from October to April, depending on climatic conditions (Harvey, 2000) in dense clusters of 300 to 500 bats per square foot. Some of the most important caves support over 80,000 Indiana bats each winter (USFWS, 2002). Hibernacula with the specific requirements that Indiana bats prefer are uncommon across the landscape (Bogan, 2000), which leaves them few choices but to congregate in large numbers in relatively few caves and mines.Traditionally, fewer than a dozen sites each winter house about 95% of the total Indiana bat population (Tuttle, 2003), which makes them very vulnerable to disturbances and habitat destruction. In 2007, the total population size of Indiana bats was estimated to be 468,184 (USFWS, 2007) an increase from the 2001 estimate of 380,000 but still less than the 1960 estimate of 808,505 (USFWS, 1999). It was because of their population decline and this exceptional vulnerability to destruction and disturbance during hibernation that the Indiana bat was initially listed as endangered in 1967. Abandoned mines are extremely important to the continued existence of the Indiana bat (Currie, 2000). Because Indiana bats have such narrow and unique requirements for cave microclimates, they are most at risk for extinction (Tuttle, 2003). They also show strong site fidelity to specific caves or mines (or to groups of caves or mines located in close proximity), to which they return each winter (Tuttle, 2003). There are very few caves or mines in their geographic region that meet their specific requirements for hibernacula.

Underground abandoned mines often bear striking similarities to caves with respect to the roosting habitat they provide for bats and some other types of wildlife (Altenbach and Sherwin, 2002). While mines provide much needed replacement habitat they can also be dangerous to bats due to the violent ore extraction processes (drilling, blasting, etc.) that created them before they were abandoned, as well as the lack of internal supports (Altenbach and Sherwin, 2002). Unlike caves, mines were created over relatively short periods of time and have not had sufficient time to settle into a stable form, which can make them potentially hazardous to bats (Altenbach and Sherwin, 2002).

Magazine Mine, in Illinois, is the largest known hibernaculum for Indiana bats in the state (Kath, 2002). Magazine Mine is a large abandoned microcrystalline silica mine located in the Shawnee National Forest. By 2000, the main entrance to Magazine Mine had closed by about 70% due to natural erosion and settling since mining had ended in the mid 1980s. There was concern that if the entrance completely closed off then it could restrict the use of the mine by Indiana bats. While there is a second entrance, the continuing restriction of the main entrance could also alter the microclimate habitat in the mine preferred by Indiana bats and potentially losing this important resource. The decision was made by Illinois DNR, the U. S. Forest Service, and Unimin Specialty Minerals (the owner of the mine) to stabilize the entrance and prevent the mine from completely closing. In 2001, the entrance was excavated and 49 steel arches with 6x6 timbers were installed every 1.2 meters (4 feet) along the entrance tunnel (adit) into the mine (Figure 1). The arch was designed such that it would allow the entrance to stay open maintaining free access by bats even if the entire roof above the adit collapsed. A bat gate was placed near the beginning of the tunnel and a chain-link fence was installed around the entrance to prevent people from entering the mine and disturbing the bats.

Large, complex mines with several entrances, like Magazine Mine, provide many of the microclimates important to bats for hibernation. Aside from Magazine Mine, there are several other microcrystalline silica mines whose mineral rights are also owned by UNIMIN in the area of Shawnee National Forest that provide roosting sites for hibernating Indiana bats. Most of these underground silica mines were large, allowing trucks and heavy equipment direct access (Kath, 2002). Material in these mines was extracted quickly and there was no need to erect internal support structures. Many of these mines have collapsed and the entrances have closed off over time but some large mines have remained open and attracted several bat species seeking hibernacula (Kath, 2002). This complex of mines was studied previously by Brad Steffen (2007) to determine the effects of mine characteristics on hibernacula selection by bats. He found a negative relationship between bats and temperature; lower temperatures resulted in higher numbers of bats. He also found that temperature variability also was important for bats selection if hibernation sites. The lower the variability in temperature the more bats were present in the mine. Abandoned mines have now become critical habitat to many species of bats in southern Illinois.

Abandoned mines and caves are similar in that they both have fractures and the potential for spalling. “Spalling is the chipping, fracturing, or fragmentation, and the upward and outward heaving of rock caused by the action of a shock wave at a free surface or by release of pressure” (U.S. Bureau of Mines, 1996). Related to spalling is exfoliation which is the process by which concentric scales, plates, or shells of rock, from less than a centimeter to several meters in thickness, are successively spalled or stripped from the bare surface of a large rock mass. It is caused by physical or chemical forces producing differential stresses within the rock. This can be by expansion of minerals as a result of near-surface chemical weathering, or by the release of confining pressure of once deeply buried rock as it is brought nearer to the surface by erosion (U.S. Bureau of Mines, 1996). As a result, abandoned mines can be dangerous, with cave-ins and falling rock posing possible threats to hibernating bats (Tuttle and Taylor, 1998). It can take up to an hour or more for bats to arouse from hibernation, so they are unable to quickly fly away from danger (Ducummon, 2000). This makes it impossible for a hibernating bat to respond to spalling or exfoliating events.

A significant threat to a bat roosting on the roof of a mine is spalling. After material is extracted and without supports, the roof may sag, the layers of rock may separate and fill with water, which increases the chance of spalling (Chironis, 1980). Chemical weathering, chemical reactions such as hydrolysis, oxidation, and carbonation that transforms rocks and minerals into new chemical combinations which can be softer than the original types of rocks, can also cause spalling. Although rain does not occur in a mine, water does seep through from the surface and can cause weathering. I have observed water pouring from a crack in the roof of one of the rooms in Magazine Mine almost like rain. Also, with humidity levels as high as 95%, moisture eventually will penetrate the rock. During temperature fluctuations that allow freezing and thawing, the water will expand and contract creating minute fractures, which may lead to spalling. While falling rock may be a direct hazard to bats, it can also be an indirect hazard if enough material falls before spring emergence to seal hibernating bats in a mine, potentially killing tens of thousands. Mines in many areas have become habitats of last resort to bats and provide critical habitat. Nonetheless, they may be hazardous to bats. A small spalling event was observed in Magazine Mine while conducting a winter survey that resulted in over a dozen Indiana bats being injured or killed (T. Carter, personal comm.). This event of bats being killed by falling debris and the resulting concerns of both the U. S. Forest Service and U. S. Fish and Wildlife Service were the impetus for conducting this study. These mines were studied to determine the extent to which they could potentially become a liability to endangered populations of bats and creating a "sink" or become a valuable resource for their continued survival.

OBJECTIVES

The objectives of this study were: 1) to assess the stability and safety of abandoned mines in southern Illinois that are used as hibernacula by bats, particularly the endangered Indiana bat; and 2) to determine if temperature, temperature stability, and moisture are factors in spalling.

I hypothesized that because bats are in areas that have stable temperatures and high humidity, there would be less spalling in those areas. Also spalling would be more likely to occur when temperatures fluctuate between freezing and thawing, causing the moisture in the wall to expand when frozen and then contract when thawed. Thus, material on the wall is loosened and sloughed, i.e. a spalling event. I hypothesized that the amount of moisture and temperature fluctuations would combine to increase the rate of spalling.

MATERIALS AND METHODS

STUDY AREA

The mines used in this study are located in the Shawnee National Forest in southern Illinois, which are part of the Shawnee Hills Division. The Shawnee Hills Division is characterized by a high east-west embankment of sandstone cliffs and a series of lower hills. This area is characterized by rugged hills, clear streams and distinctive flora such as, shagbark hickory, tulip tree, sugar maple, and rock chestnut oak (Schwegman, 1973).

The mines are located in an area west of Elco, north of Tamms and south of Jonesboro, in Alexander County. They are situated on a deposit of unique microcrystalline silica that encompasses an area 4.6 km wide by 9.6 km long. The deposits are patchy throughout the area and were deposited during the Devonian Period. The deposits have been mined for more than 100 years.

MINING HISTORY AND UNIMIN SPECIALTY MINERALS

Unimin Specialty Minerals was formed in 1990 when Unimin Corporation merged two separate companies they had acquired in 1986 (Tammsco) and 1989 (Illinois Minerals Company). Unimin is engaged in mining microcrystalline silica (a fine, white, crystalline mineral) in southern Illinois which is the only location in the world where it is found. The deposit was originally mined manually, using picks and wheelbarrows beginning in the early 1900s. With the advent of modern mining machinery and practices, the mines became much larger, both in area as well as volume (R. Fox and D. Fehrenbacher, Unimin Specialty Minerals, personal comm.).

Before 1984, test holes were dug 20 to 100 m to find deposits on potential sites. If the deposit was of good quality and large enough, underground mining would begin. The deposits were mined in a method known as room-and-pillar mining. A series of interconnecting rows and aisles were excavated, leaving large pillars of material to support the ceiling. These tunnels range in 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 and left to close on its own over time. Since 1996, surface mining has been used to produce the crude microcrystalline silica and there are now three surface mines (D. Fehrenbacher, Unimin Specialty Minerals, personal comm.) only one of which is actively mined by Unimin. Dozens of underground mines have been abandoned and left to close naturally. Microcrystalline silica has a consistency similar to talc. It can be loose and friable which can result in sloughing material hazardous to roosting bats.

STUDY PROTOCOL

I selected 13 mines on the basis of their historic spalling characteristics: 1) high (sufficient material has sloughed from the walls and ceiling to completely cover the floor of a room), 2) medium (material has sloughed from the walls and ceiling but has only formed sparse piles and does not completely cover the floor of the room), and 3) low (no material has sloughed from the ceiling or walls and tire tracks are still evident on the floor from the equipment that was in the room 10 to 30 years ago). The size of the mine was not a factor in the selection process. I defined a room as an area where two or more corridors met. Using the random function on a calculator, I selected rooms randomly within each of the 13 mines for a total of 120 rooms. Thirty of these rooms were checked monthly, and 90 rooms were checked on a rotating quarterly schedule. Thus, I checked 60 rooms each month, 30 of the quarterly rooms and the 30 monthly rooms (Table 1).

Rooms were checked on the second or third weekend of each month for 16 months from September 2006 through December 2007.

SPALLING

To determine the amount of spalling that occurred in each room, I placed three 3.048 m x 3.048 m (10 ft x 10 ft) sheets of heavy-duty black plastic in each room. One sheet was placed in the approximate center of the room and two sheets were placed against the walls (Figure 1). Walls and ceiling of the mines are composed mainly of microcrystalline silica, which is white in color and was clearly visible on the black plastic sheets. I used a 20 liter graduated feed bucket to measure the volume of any material that had fallen onto the plastic sheets. I only measured the material when there was ≥ 2 liters of material on the plastic. If there was ≥ 150 liters of material on the plastic (i.e. it was buried), I estimated the volume using length x width x height measurements. I then smoothed out the debris as much as possible and placed a new sheet of plastic over it with the corresponding number of the original sheet of plastic.

One of the mines in my study was Magazine Mine (Figure 2), which is the largest documented Indiana bat hibernaculum in Illinois. It houses more than 43,000 Indiana bats (Kath, IL DNR, personal comm., 2008). The Indiana bats in this mine roost toward the back of the mine. Because of this, and to decrease disturbance to the hibernating bats, I only used five rooms located in the front three corridors near the main entrance.

During each visit, I also took pictures of each room and each individual sheet of plastic to have photo-documentation of the overall layout of each room and the amount of spalling that had occurred. This provided a visual record of spalling during the study period, as many of the sheets collected a small amount of material each month before they collected a measurable amount. Photos were especially useful to compare before and after major spalling events. It also helped to determine where the material had fallen from, (i.e. a wall or the roof), and provided evidence of where the most spalling occurred. I downloaded the pictures after each field session and cataloged them by date, mine, and room.

TEMPERATURE AND MOISTURE

Moisture and temperature fluctuations were hypothesized to be significant factors along with stress fractures that can lead to spalling. Temperature data-loggers (Thermochron® iButton DS 1921G, Maxim manufacturers) were installed in each room on a centrally located wall in December 2006 and collected at the end of the study in December 2007. The data loggers were placed as centrally as possible in each room. They were then downloaded using iDump and the iButton viewer software provided by the manufacturer. In addition to temperature, I also determined the moisture content of the walls. Previous studies examining these and similar mines have used humidity data-loggers; however, these had a high failure rate and only measured the air humidity. Rather than using humidity data-loggers, I wanted to determine the amount of moisture that accumulated in the rock face of the walls as a potential factor in spalling. I collected 10 g samples of material from one wall in each of the rooms during each visit and analyzed these samples using an Ohaus® Moisture Analyzer provided by Unimin Specialty Minerals at their Elco plant. This gave me the percentage of the moisture levels in the material collected each month.

BAT PRESENCE

I also counted the number of bats in each room to determine how often the room was used by bats. I recorded the number of each species when identification was possible. The ceilings in some rooms were over 20 m high, making species identification of roosting bats very difficult.

STATISTICAL ANALYSES

I used univariate and multiple logistic regression analyses to determine the significance of temperature and moisture for predicting the presence of bats and spalling events using PROC LOGISTIC in SAS 9.1 with $p \leq 0.05$ (SAS Institute, 2002). Microsoft Excel was used to determine the average daily temperature and then the standard deviation of temperatures for each month. The standard deviation of temperatures was then averaged for each room to determine temperature variation because each standard deviation was calculated using the same number of daily temperature readings. The number of bats in each room each month was considered as the dependent variable and the average monthly temperature, the temperature variation, and percentage of moisture each month were the independent variables for logistic regression. For predicting spalling events, amount of spalling each month was the dependent variable with moisture, temperature, and the temperature variation used together as the independent variables. As well as multiple logistic regressions, univariate logistic regressions were used to determine if one of the independent variables might be masking the effects of the other independent variables.

The temperature variation for each room was used in linear regressions to determine how it affected the number of hibernating bats in a room and how it affected spalling events. I also performed univariate linear regressions for bats (dependent variables) and the other two independent variables, temperature and moisture, to see if the numbers of bats hibernating were affected by these variables. A linear regression was also performed using spalling as the independent variable with bats as the dependent variable to see if there was a relationship between the two variables.

Because I was interested in hibernating bats - and spalling that occurred while bats were hibernating - I only used data collected from October through March, when bats in the mines were hibernating. Because data loggers were not installed until December 2006, temperature data when bats were in hibernation were collected December 2006 through March 2007. The next time period was October of 2007 until mid December 2007. Linear regressions were performed using SAS 9.1 with alpha = 0.05 using temperature variation as the independent variable and number of bats or spalling as the dependent variable. When data were not normally distributed they were $\log_{10}$ transformed for the linear regressions.

RESULTS

SURVEYS

During this study, bat use of the mines was documented with a total of 15,052 bats observed during hibernation and non-hibernation periods (Appendix B). From October 2006 to March 2007 and October 2007 to December 2007, 12,764 bats were observed hibernating in the mines. Because there was no way to mark bats to avoid recounts these numbers therefore include bats that were counted more than once.

Total spalling amounts for this study ranged from 0 L to a high of 258,151 L in Rhymer 1 which experienced a major spalling event of 250,625 L in December of 2007. The second highest amount of spalling occurred in Mode 2C with 150,470 L of material from a single incident. Other mines with a high degree of spalling were Mine 26, Magazine, Mine 24, Mode 2, and Birk 2. The rest of the mines experienced medium or low amounts of spalling (Tables 1 and 2).

Mean temperatures in the mines ranged from the lowest of -0.34 ˚C for February 2007 to the highest mean temperature of 19.83˚C in August 2007 (Appendix C). Monthly mean moisture content for the mines ranged from a low of 3.88% in February to a high of 19.04% in June, both of which occurred in Birk 2 (Appendix D).

UNIVARIATE LOGISTIC REGRESSION

Bats

Temperature was an important predictor of bat presence in a room. The univariate logistic regression for bats using average monthly temperature (Figure 4) was significant ($W^2 = 37.99$, p = <0.0001). The univariate analysis for moisture (Figure 5) was significant and showed that moisture was an important predictor of bat presence in a room (W^2 = 16.18, p = <0.0001). The univariate analysis for bats and average standard deviation of temperature (Figure 6) was significant (W^2 = 35.98, p =<0.0001).

Spalling

The univariate analysis showed that temperature (Figure 7) was significant for predicting spalling events in rooms (W^2 = 12.76, p = 0.0004). The univariate analysis for spalling and average standard deviation (Figure 8) of temperature was significant (W^2 = 21.89, p = <0.0001) as well. The univariate analysis for moisture was not significant (W^2 = 1.69, p = 0.193).

MULTIPLE LOGISTIC REGRESSION

Bats

The overall multiple logistic regression analysis using bats as the dependent variable with temperature variation, average monthly temperature, and moisture as independent variables was significant (W^2 = 54.45, p = < 0.0001). The temperature (W^2 = 46.75, p = < 0.0001) and average standard deviation of temperature (W^2 = 20.56, p = < 0.0001) were more likely to predict the presence of bats which increased the significance of the model. Moisture was not significant (W^2=0.487, p = 0.485).

I also performed a multiple logistic regression analysis for presence of bats using moisture, average standard deviation of temperature, and average monthly temperature as independent variables but with an added interaction term to determine if moisture and temperature affected each other. Moisture was significant (W^2 = 4.48, p = 0.0344), however, as noted above it was not significant without the interaction term. Temperature was not significant (W^2 = 0.280, p = 0.596). The temperature variation was significant (W^2 = 43.96; p = <0.0001) and the interaction between moisture and temperature was significant (W^2 = 4.065, p = 0.0438).

Spalling

The overall multiple logistic regression analysis for spalling using average monthly temperature, average standard deviation of temperature, and moisture as independent variables was significant (W^2 = 10.32, p = 0.016). Moisture was significant (W^2 = 5.17, p = 0.023) which increased the overall significance of the model. Moisture was more likely to predict a spalling event unlike the univariate analysis. Temperature variation (W^2 = 3.47, p = 0.063) and temperature were not significant (W^2 = 0.699; p = 0.403) again opposite the results of the univariate analysis.

UNIVARIATE LINEAR REGRESSION

Spalling

The univariate linear regression for spalling and average standard deviation of temperature was significant (F = 3.26, p = 0.0022, R^2 = 0.056) but only explained 5% of the relationship. The univariate linear regression for spalling and moisture was almost significant (F = 1.83, p = 0.061, R^2 = 0.041) and the univariate linear regression for spalling and standard deviation of moisture was not significant (F = 0.26, p = 0.61, R^2 = 0.002). The univariate linear regression for spalling and temperature was significant (F = 4.27, p = 0.0001, R^2 = 0.071) but only explained 7% of the association between these variables.

Bats

The linear regressions for log transformed number of bats and the three variables, average standard deviation of temperature, temperature, and moisture were all significant. The average standard deviation of temperature (Figure 9) was significant ($F = 25.52$, $p = <0.0001$, $R^2 = 0.315$) although it only explained about 31% of the variation in the relationship. Temperature (Figure 10) was also significant ($F = 3.69$, $p = <0.0007$, $R^2 = 0.062$) but again with a low R^2 value. The results were the same with moisture (Figure 11) which was significant ($F = 9.03$, $p = <0.0001$, $R^2 = 0.134$) but only explained 13% of the association between bats and moisture. The linear regression for bats and spalling was also not significant ($F = 0.46$, $p = 0.87$, $R^2 = 0.0082$) suggesting no relationship between the two variables.

DISCUSSION

There have been many studies looking at Indiana bat use of abandoned mines and the types of microclimate habitat they prefer for hibernating (Menzel et al. 2001). There has been very little if any research done on whether or not abandoned mines are safe for Indiana bats or with mine safety for bats in general. There are some articles that mention that abandoned mines could be hazardous to bats. Hall (1962) for example, mentions that hibernating bats are vulnerable to ceiling collapse. I did find that when parts of the ceiling in rooms collapsed they tended to be very large spalling events and therefore are probably the more dangerous type of spalling for hibernating Indiana bats that congregate in large clusters.

TEMPERATURE AND MOISTURE

Temperature stability is a very important component for hibernating bats. Bats need temperatures that are cold enough to decrease metabolic rate so they can survive the winter on their fat stores. A single arousal requires as much fat as 68 days of uninterrupted hibernation (Thomas et al. 1990). Optimal hibernating temperatures for Indiana bats are in the range of 4-8^{o}C (USFWS 1999). As the temperature gets closer to freezing Indiana bats will begin to use up fat stores to keep warm. Also, if temperatures start to rise above 10^{o}C during winter they will rouse from hibernation to locate a more suitable area of the mine for hibernating and use up fat reserves with no way to replace fat due to the lack of food at that time. Brack (2007) found that areas that are thermally unstable and regularly fluctuate above 10^{o}C, or areas that are stable but > 10^{o}C, are less than optimal hibernacula for many species of bats.

I hypothesized that because bats are in areas that have stable temperatures and high humidity, there would be less spalling in those areas. Also, spalling would be more likely to occur when temperatures fluctuate between freezing and thawing, causing the moisture in the wall to expand when frozen and then contract when thawed. Thus, material on the wall is loosened and sloughed, i.e. a spalling event. I thought that the amount of moisture and temperature fluctuations would work together and increase the rate of spalling. In the univariate logistic regression, temperature and average standard deviation of temperature were both highly significant; moisture was not significant. However, when combined with temperature and temperature variability in the multiple logistic regression moisture was a better predictor of spalling events than temperature and temperature variability. This is probably because moisture in the microcrystalline silica walls does not cause spalling events on its own but when combined with temperatures that fluctuate between freezing and above freezing the moisture in the rock surface contracts and expands and loosens the material causing it to spall. Moisture for the most part may come from the high relative humidity in the mines but some water does percolate through from the surface, but I only saw this in one room in Magazine Mine. For the moisture to cause spalling it needs to be frozen and thawed which could be why temperature variability was a better predictor of spalling events than either temperature or moisture when looked at separately.

As an example, room 11 in Magazine experienced a high percolation of water in December 2007. It had almost no spalling even with the water almost coming down like rain in the room. Spalling only occurred when the temperature decreased in January. It was below freezing and a sheet of ice about 2.5 cm thick covered the walls. The average temperature in January was about 3^{o}C. By the time I visited the room again in February (average temp -0.05^{o}C), the ice had melted and 44L of spalling was recorded. Again in March, 126L had spalled from the walls. Because of this added water, room 8 (adjacent to room 11) also seemed to be affected. Again there was almost no spalling in room 8 before January 2007. After the thaw, room 8, which never accumulated a sheet of ice, also experienced an increase in spalling: 226L in March, 0L in April, 6156L in May, and minor spalling through the summer.

Temperature and temperature variation were also an important part of predicting the presence of bats. This was expected based on previous research done by Steffen (2007). Also, Harvey (2000) found that Indiana bats chose mines and caves with stable temperatures and high relative humidity. Although I did not look at relative humidity, I did look at moisture content in the microcrystalline silica on the walls which could be an indicator of relative humidity. All three variables looked at in my study were significant when analyzed separately. The interaction between moisture and temperature also was highly significant, suggesting that the effect of moisture was dependent on temperature. This was understandable because as temperature decreases toward zero, relative humidity increases. Moisture then seeps into the material of the walls. So you would expect to find bats in rooms with high moisture content in the material on the walls and low but not freezing temperatures.

TEMPERATURE VARIABILITY

I expected that high rates of spalling would be associated with higher temperature variability. When looked at separately, temperature variability and temperature appear to be important factors predicting spalling events. The closer to zero the temperature was, the more likely spalling would occur. Whereas spalling did occur at low temperature variability, most rooms did not have any spalling events at low temperature variability. Moisture alone was not a significant factor but as a covariate with temperature and temperature variability included in a multiple logistic regression it was a good predictor of spalling where higher moisture increased the likelihood of a spalling event. This is possibly because moisture alone does not cause spalling but the interaction of temperature and temperature variability with moisture increases the possibility of spalling.

Similar results occurred with the three variables and the number of bats. Temperature and temperature variation were highly significant and moisture was not in the multiple logistic regression. When looked at separately in the univariate logistic regressions they were all significant. Temperature variability appears to mask the affects of moisture. When analyzed using the interaction term, I found the effects of moisture were dependent on temperature. Bats will be present at a high percentage of moisture and low temperatures. Brack (2007) found similar results with Indiana bats hibernating in limestone mines in Preble County, Ohio and stable temperatures. He found temperatures used by Indiana bats averaged 8.4° C ± 1.7° C. These findings are consistent with other studies on bats and microclimate habitat (Johnson et al 1997; Bogan, 2000; Ducummon, 2000; Harvey, 2000; Steffen, 2007).

SPALLING

The mines in my study that had a large number of hibernating Indiana bats tended to be large and complex. These types of mines provide a wide range of microclimates that the bats can use. A couple of these mines also experienced a high occurrence of spalling. Magazine Mine and Mine 26 were two such mines that had high spalling rates and a large number of hibernating Indiana bats. Because Magazine Mine is listed as a Priority One hibernaculum (a hibernaculum containing > 30,000 bats) I could not use any of the rooms with Indiana bats in my study. Therefore, I had to use rooms that were adjacent to the main entrance (Figure 2). These rooms experienced below freezing temperatures during the winter and high temperature fluctuations. These rooms were located at the end of the 100 foot entry tunnel. The farthest room was located approximately 25 m east of the end of the tunnel. Magazine Mine had a total amount of 11,125 liters of spalling in the five rooms I surveyed. Mine 26 also had a high occurrence of spalling totaling 37,237 liters and a large number of hibernating Indiana bats. But the areas used by the bats in Mine 26 experienced no spalling or only minor (<100 L) spalling events.

For the most part there was little (100L or less) to no spalling in most of the rooms (Table 1). Little to no spalling occurred in 92 out of the 120 rooms. Spalling > 100L over the course of the study occurred in 29 of the rooms. Five of these were from Magazine Mine, which was expected because they were chosen based on the amount of spalling that had occurred before I began the study. Also these rooms are very close to the entrance, ranging from 50 to about 100 meters, and experience freezing temperatures in the winter. I expected spalling to increase with high temperature variability and freezing temperatures, which is what I found. I also found that a high moisture content in the rock increased spalling events but only when combined with high temperature variability and low to freezing temperatures.

The greatest amount of spalling occurred in Rhymer 1 which was mostly from one large spalling event in December 2007 when approximately 251,000L of material fell from the roof in room 11. While the average temperature for that room remained at 10.5 from October through December, the amount of moisture in the material collected from the wall was very low compared to previous months. In September the moisture content was about 22%-by December it was only about 4%. This decrease in the percentage of moisture in the walls may have made the material more friable or may be a result of a clay seam losing moisture and becoming more brittle. Interestingly, the number of bats in that room decreased from 109 in October to 48 in December. The room next to it (room 12) experienced an increase of bats from 68 in November to 100 in December. Bats may have moved from room 11 to the adjoining room 12 in response to increased percentage of moisture, which was 14% in December or they may have just moved because of the spalling event.

The next highest amount of spalling was in mine Mode 2C room 3 with an estimated 151,000L of spalling from a roof fall. This mine is very small with a large entrance and is not very deep. The large spalling event happened in room 3, which is toward the back of the mine but only about 25 to 30 meters from the entrance. It occurred sometime between January and April concurrent with a decrease in average daily temperature from 7^{o}C in January to 2.7^{o}C in February and a slight decrease in the percentage of moisture in the walls. This event also shows one of the drawbacks of the mines that I visited quarterly. I have no way of knowing for sure when the spalling occurred. I can only make an educated guess that because the temperature decreased in February, which is when spalling probably happened.

There were only three other mines that had a high (greater than 1000L) amount of spalling. Mine 26 had the most spalling followed by Mine 24 and then Birk 2. Mine 26 is a large mine with almost 80 rooms and has a large number of Indiana bats hibernating in it. The bats, however, are in an area where very little or no spalling has occurred and are far away from the areas with spalling. Mine 24 is also a fairly large mine but it has about 6 adits. Therefore, it is affected more by the weather outside of the mine and experiences similar temperature and humidity fluctuations. Average daily temperatures in this mine fluctuated throughout the year from below freezing to a high of 24.5^{o} C. The one room, where spalling occurred experienced a high temperature of 24.5^{o} C in August and a low of 2^{o}C in November. Birk 2, another large mine with over 126 rooms also had more than 1000 L of spalling in only one room, room 55. Room 55 is located on the western side of the mine approximately a hundred meters from the entrance and had an almost constant temperature of 9^{o} C ± 1.5^{o} C. This room is adjacent to an area that had caved in and I suspect it may have been influenced by this unstable area.

The mines appear to be fairly stable with a few exceptions. The mines that experienced high spalling rates that also had high numbers of Indiana bats, such as Magazine Mine, Rhymer 1, and Mine 26, are fairly large with only one or two adits. Magazine Mine for example houses the greatest number of Indiana bats in Illinois but the bats hibernate far from the rooms in my study. My rooms were located toward the main entrance and were susceptible to the temperature and moisture extremes from the outside environment. The bats hibernate toward the back of the mine where there is very little material on the floors except in a few places where there were some major collapses in the past. This is a prime example of bats hibernating in an area with stable temperatures; areas exhibiting high spalling have variable temperatures.

MANAGEMENT IMPLICATIONS

Abandoned mines provide potential replacement hibernacula for cave dwelling bats when they have lost their natural hibernacula due to human disturbance. However, to date no research has been conducted to determine the safety of the abandoned silica mines in southern Illinois for Indiana bats as well as other bat species. This study attempted to address this issue, and to highlight potential management implications. In southern Illinois there is potential to manipulate some of the abandoned mines to make microclimate conditions more favorable for Indiana bats, thereby increasing the potential hibernacula.

In this study there were 4 mines with many Indiana bats using them for hibernacula. The two mines with the highest number of Indiana bats also experienced a high amount of spalling, Magazine Mine and Mine 26. I believe they are still safe for bats because the bats do not hibernate in the areas where the spalling is occurring. These areas appear to be very stable with no material on the floor from spalling events before this study began and very little or no spalling while this study was conducted. There are also several exits into and out of these mines so the potential of entombment is also very low.

The other two mines in this study with Indiana bats are Rhymer 1 and Jason Mine. Rhymer 1 is unusual because the rooms with heavy spalling are also where most of the bats hibernate. I have only observed a few Indiana bats hibernating in this mine but it is important for other species of bats. I believe that Rhymer 1 should have a culvert or arch support installed to prevent further closing of the entrance. Jason Mine already has an arch support structure installed in the entry way and only experienced a medium amount of spalling and does not need any further support structures. Jason Mine should be monitored to determine if people are trying to enter it. After the arch support and bat-gate were installed, some settling of the backfill on top of the arch occurred. This created about a 2 foot high gap between the arch and roof of the entrance, large enough for a person to enter. Some volunteers from Southern Illinois University and the U. S. Forest Service used cement and T-posts to close this gap and make it more secure. With enough force and if someone has the time and wants to get in they could eventually pry or bend the T-posts and gain entry into the mine.

The rest of the mines appear to be fairly stable. Spring Mine and Magazine 7, 8 are very stable. I would suggest that these two mines, if feasible, could be modified to increase Indiana bat habitat. But great care should be taken so as not to alter their stability. Another type of management tool could be to mitigate against possible roof collapses. This can be done with a technique called roof-bolting. This is a system of support for mines where bolts are inserted into boreholes and into the rock above anchoring the ceiling. A roof-bolting machine is used to drill 2 meter long holes into the roof and a bolt with plate between the bolt head and the roofline. This is done in a definite pattern to clamp together roof beds to form a composite beam to control roof falls (U.S. Bureau of Mines, 1996). I am unsure how well this method would work in microcrystalline silica mines. Also, costs would factor into the feasibility as well as the material and safety in these mines.

This study shows that while these abandoned microcrystalline silica mines may be less stable than some caves, the areas that bats prefer to hibernate tend to be the more stable parts of the mine. My results show that the areas in mines with a high occurrence of spalling tend to have less stable temperatures and can fluctuate between colder, below freezing temperatures, and above freezing temperatures. The areas preferred by bats have stable temperatures that average between 5^{o} C and 10^{o} C with little or no spalling. These results with respect to stable temperatures are similar to what Steffen (2007) found while looking at mine characteristics on hibernacula selection by bats in this same complex of mines.

The complex of microcrystalline silica mines in southern Illinois is not without potential risks to hibernating bats because of spalling. Nonetheless, the results of my study suggest they represent generally suitable, safe, and much needed hibernacula, especially considering the ever-growing population of wintering bats using these mines.

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Table 1: Distribution and spalling categories of the 13 abandoned microcrystalline silica mines and 120 rooms surveyed in southern Illinois from September 2006 through December 2007.

Mines	**Number of Rooms Surveyed** **Number of Rooms and Degree of Spalling**		
	High	Medium	Low
Checked Monthly			
Birk 2	5	6	4
Rhymer 1	0	4	2
Magazine Mine	5	0	0
Spring Mine	0	0	4
Checked Quarterly			
Magazine 7,8	2	2	3
Magazine 11	3	1	0
Mine 26	10	9	0
Birk 2	5	0	10
Joe-Mode 4	3	3	3
Mode 2C	2	1	0
Mode 2E	3	0	0
Mine 24	2	1	0
Mode 2	0	9	10
Jason Mine	0	4	4

Table 2. Monthly and quarterly abandoned microcrystalline silica mines surveyed From September 2006 through December 2007 with the total accumulation of spalling in liters.

Mines	Total Amount of spalling (L)
Monthly -	
Birk 2	1,897
Rhymer 1	258,151
Magazine Mine	11,125
Spring Mine	2.5
Quarterly –	
Magazine 7,8	3
Magazine 11	695
Mine 26	37,237
Birk 2	350
Joe-Mode 4	1
Mode 2C	150,470
Mode 2E	3.5
Mine 24	9,655
Mode 2	2,142
Jason Mine	730

Figure 1. Magazine Mine, located in southern Illinois, entrance with steel arch and timber support installed in 2001 to prevent closing of the entrance and allow free entry and exit by bats.

Figure 2. Picture showing the typical set-up of the plastic sheets in the rooms used in this study of the abandoned mines in southern Illinois from September 2006 through December 2007.

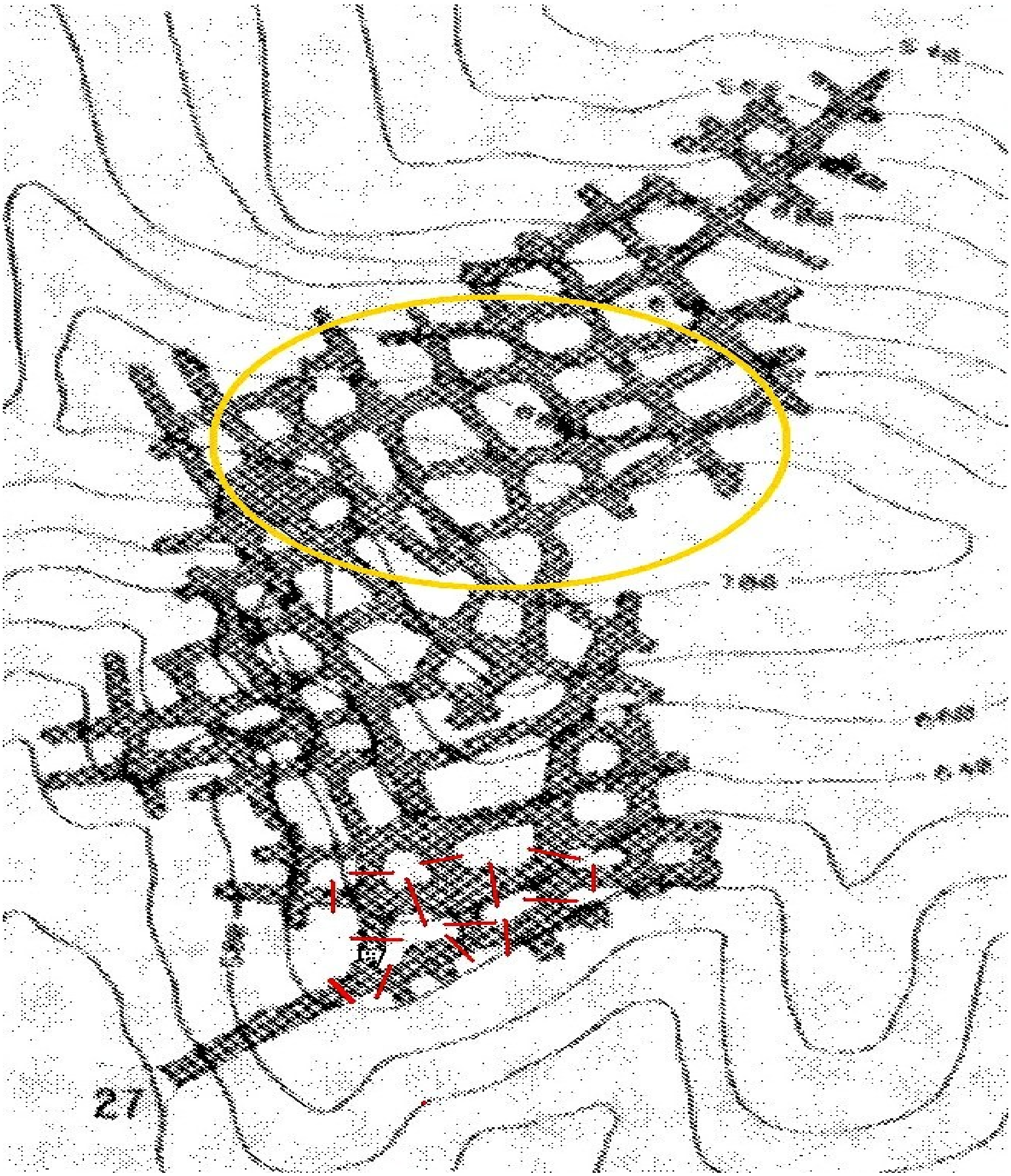


Figure 3. Map of Magazine Mine, located in southern Illinois, showing the room and pillar (white square areas) system of mining used by Unimin before turning to surface mining. The yellow circle denotes the area where the Indiana bats hibernate and the red lines indicate the rooms surveyed during this study from September 2006 through December 2007.

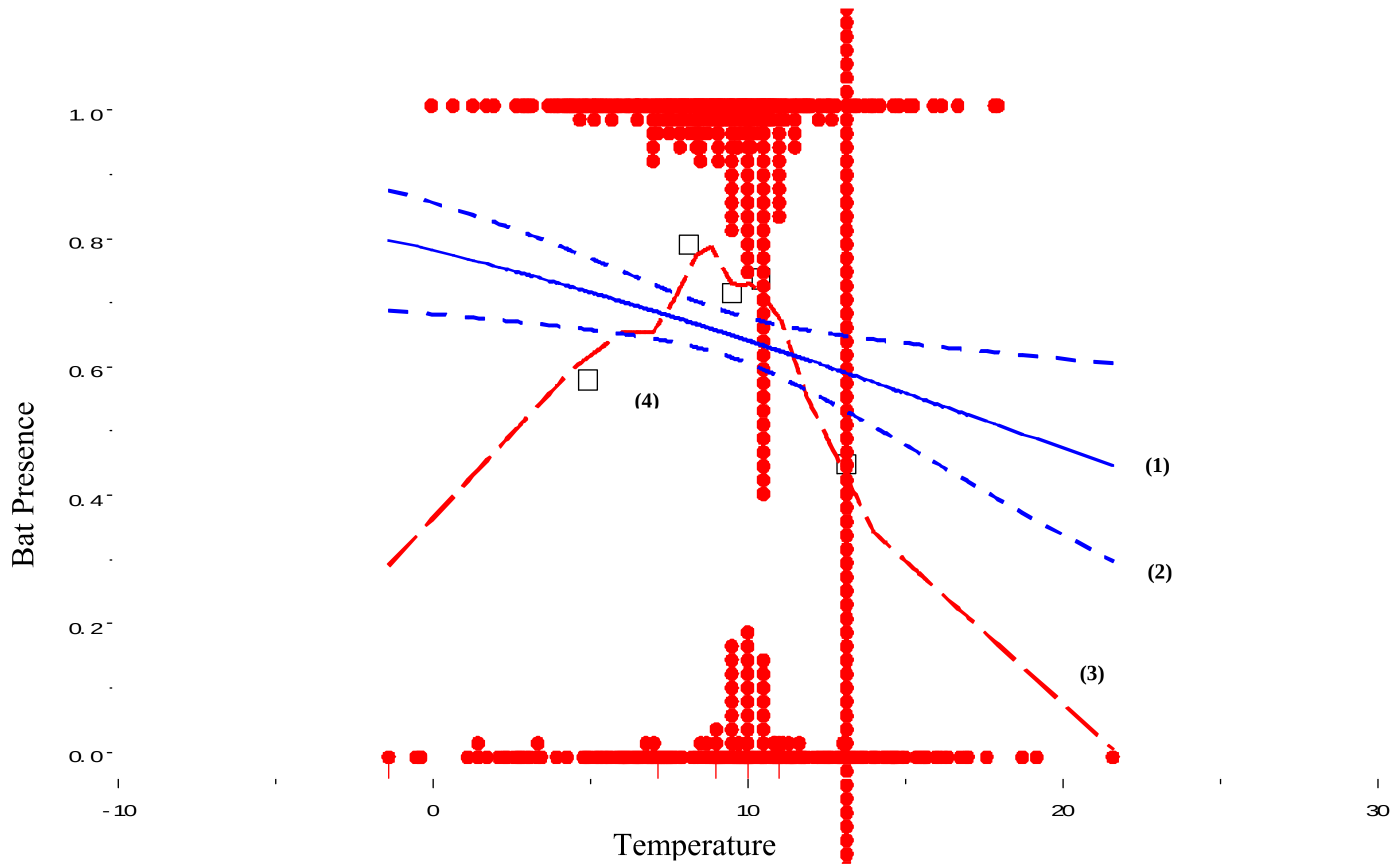


Figure 4. Univariate logistic regression for number of bats and mean monthly temperature in 13 abandoned microcrystalline silica mines in southern Illinois from September 2006 through December 2007. The dots represent the data points bat presence (top) and absence (bottom), label (1) is the regression line, (2) is the 95% confidence interval, (3) is the Lowess Curve which weights each of the data points closest to the regression line with a higher weight, and (4) are the empirical logits which is used to equalize the variance and make the residuals more normal in distribution.

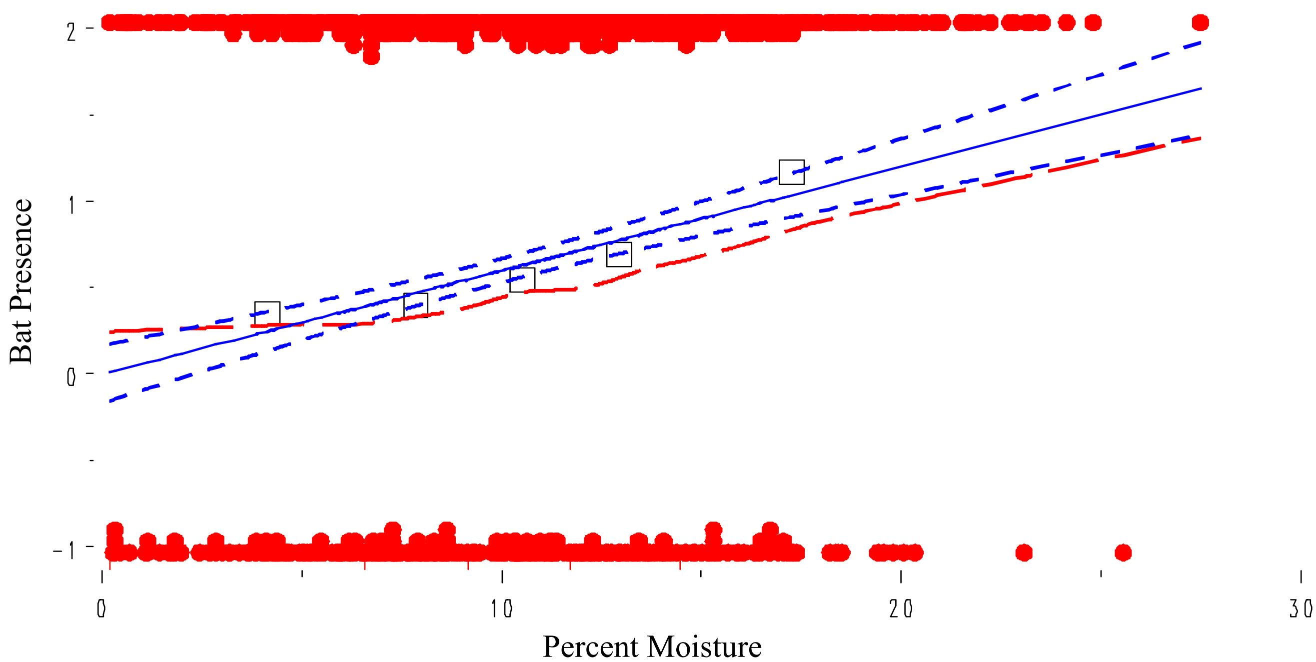


Figure 5. Univariate logistic regression for number of bats and monthly percentage of moisture in 13 abandoned microcrystalline silica mines in southern Illinois from September 2006 through December 2007. For an explanation of graph symbols see Figure 1.

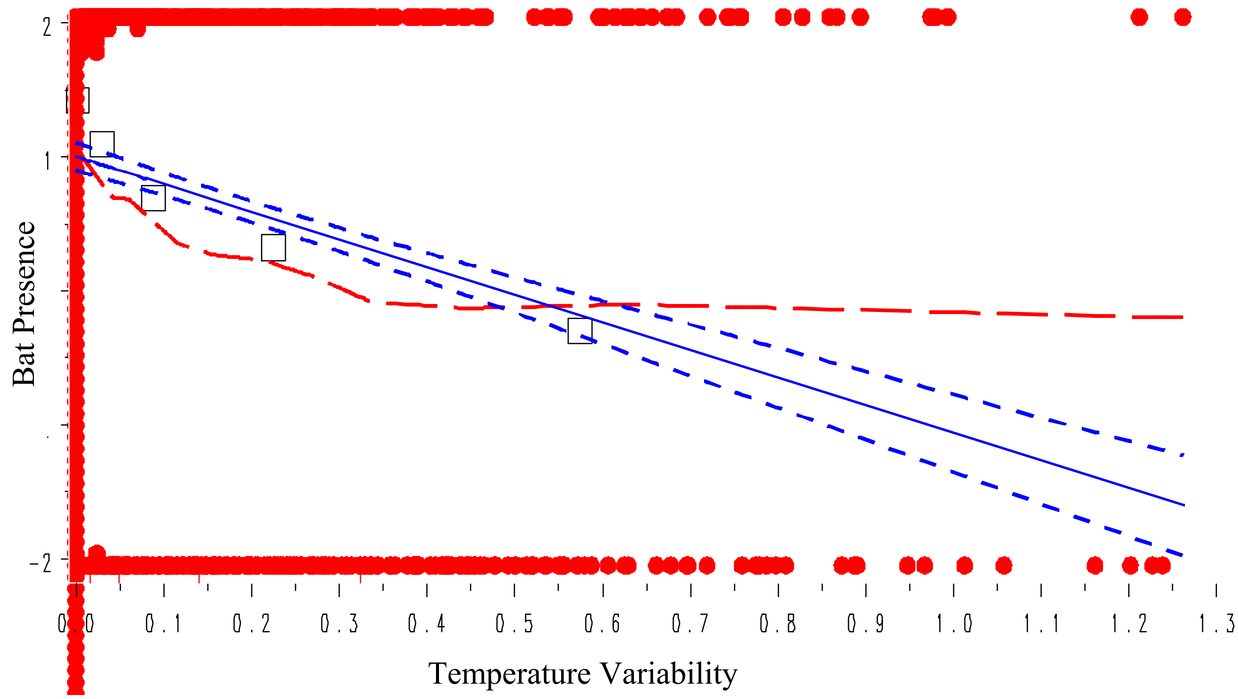


Figure 6. Univariate logistic regression for number of bats and temperature variability in 13 abandoned microcrystalline silica mines in southern Illinois from September 2006 through December 2007. For an explanation of graph symbols see Figure 1.

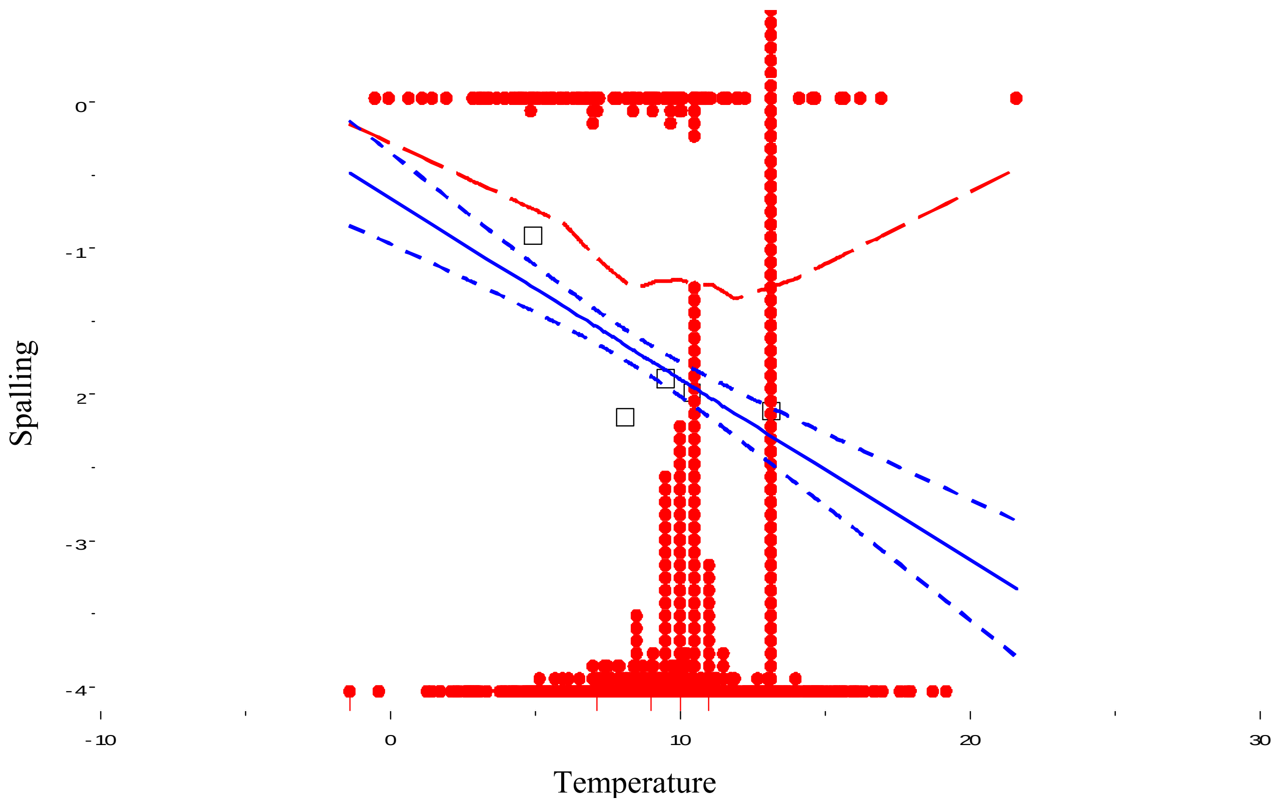


Figure 7. Univariate logistic regression for amount of spalling, in liters, and monthly mean temperature in 13 abandoned microcrystalline silica mines in southern Illinois from September 2006 through December 2007. For an explanation of graph symbols see Figure 1.

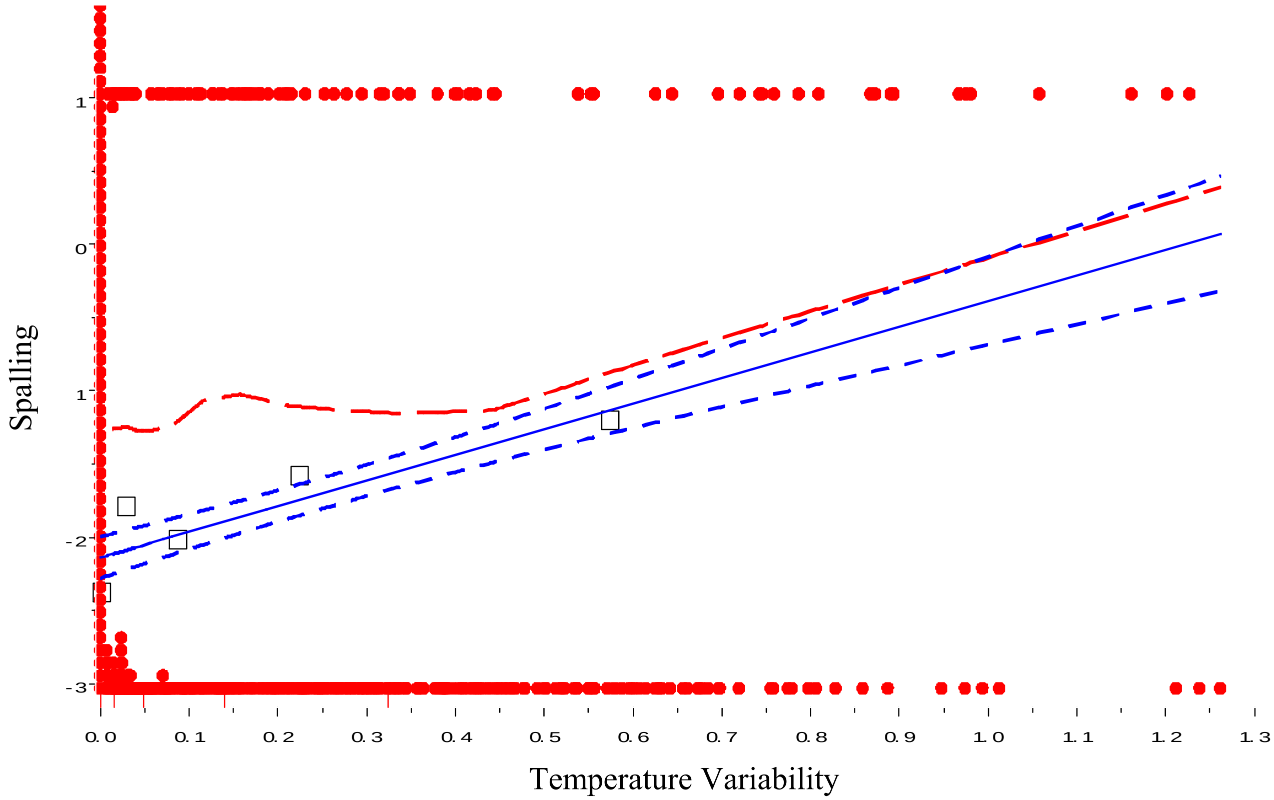


Figure 8. Univariate logistic regression for amount of spalling, in liters, and temperature variability in 13 abandoned microcrystalline silica mines in southern Illinois from September 2006 through December 2007. For an explanation of graph symbols see Figure 1.

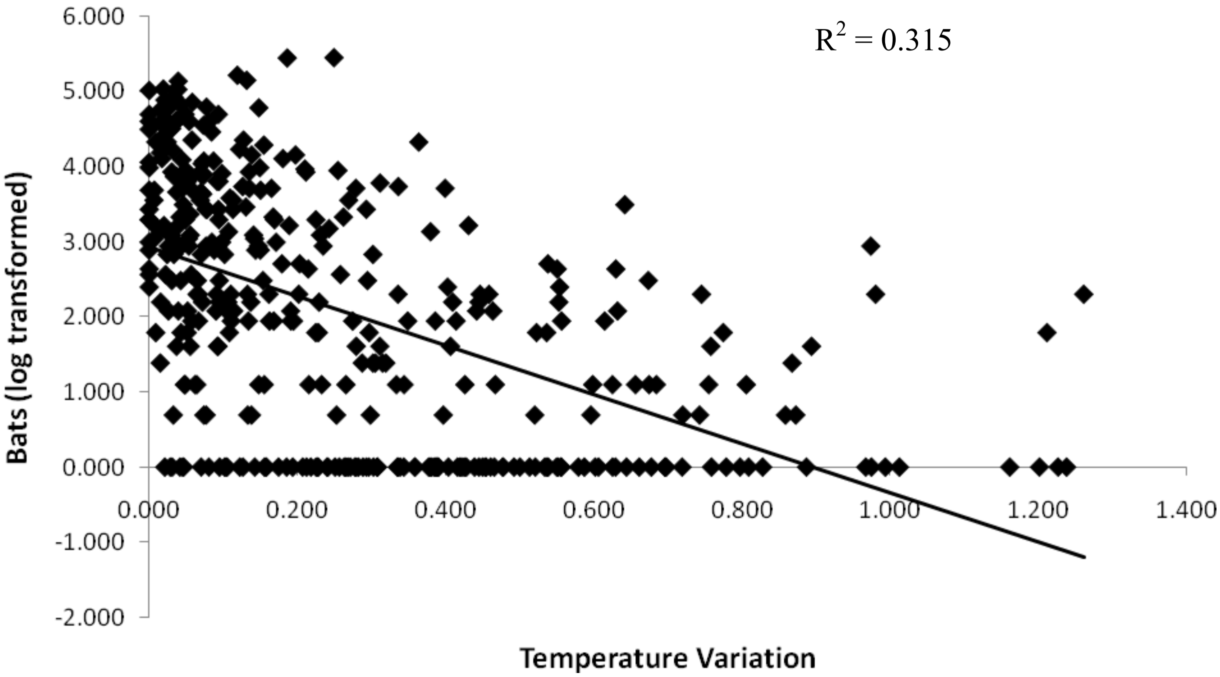


Figure 9. Univariate linear regression for log transformed bat data and temperature variability in 13 abandoned microcrystalline silica mines in southern Illinois from September 2006 through December 2007. The slope of the regression line is represented by the equation y = -3.2774x + 2.9395.

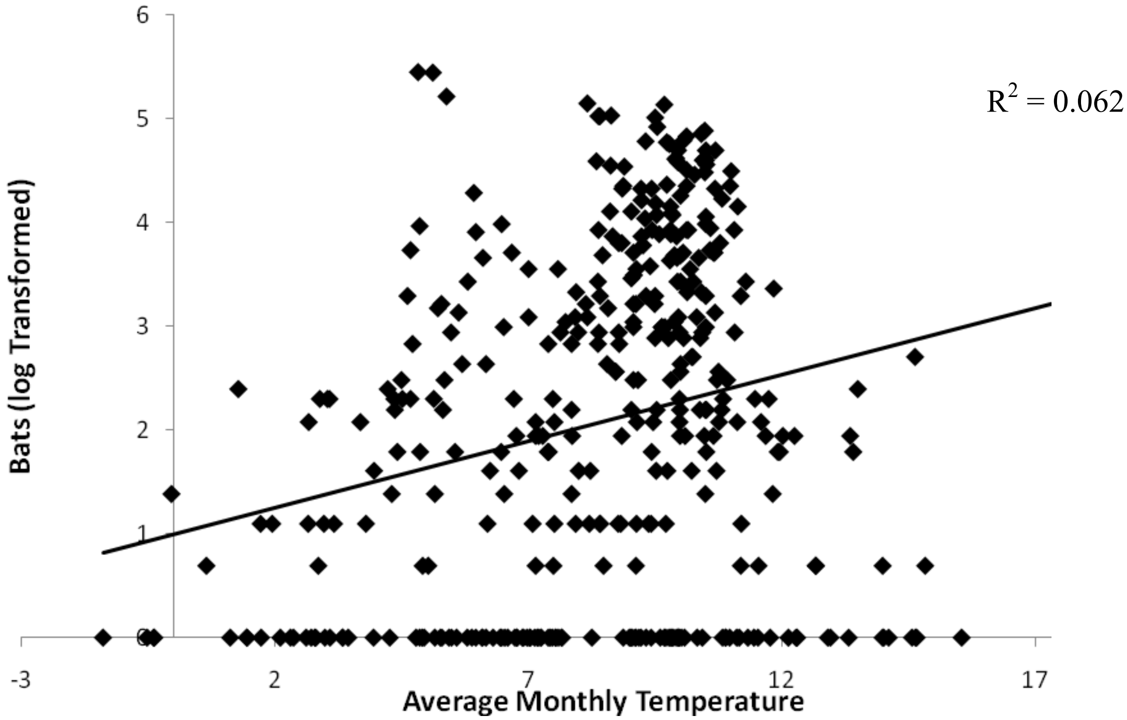


Figure 10. Univariate linear regression for log transformed bat data and mean monthly temperature in 13 abandoned microcrystalline silica mines in southern Illinois from September 2006 through December 2007. The slope of the regression line is represented by the equation $y = 0.1288x + 0.993$.

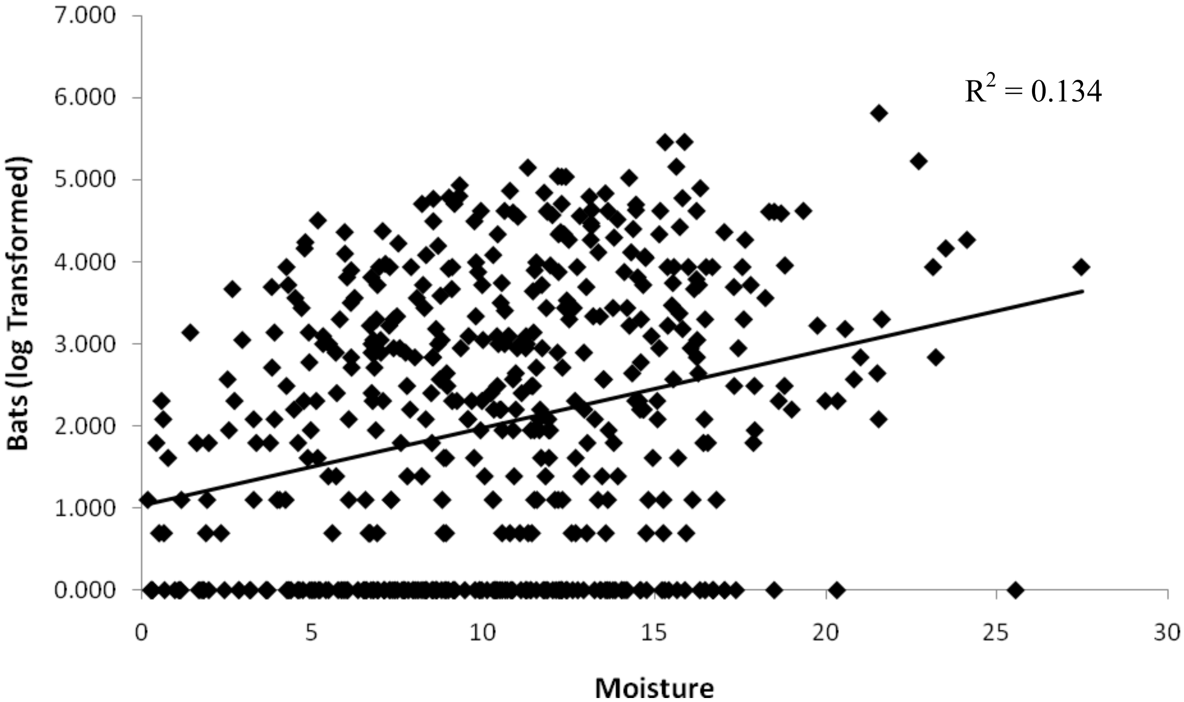


Figure 11. Univariate linear regression for log transformed bat data and monthly percentage of moisture in 13 abandoned microcrystalline silica mines in southern Illinois from September 2006 through December 2007. The slope of the regression line is represented by the equation y = 0.095x + 1.032.

APPENDIX A: Total number* of bats counted for each species in each of the mines surveyed in southern Illinois during this study from September 2006 through December 2007.

Mine	Total Number of bats						
	PESU	**EPFU**	**MYSO**	**MYLU**	**MYSE**	**UNKNOWN**	**Total**
Birk 2	2849	35	32	23	77	678	3,694
Rhymer 1	2305	31	11	23	64	560	2,994
Magazine Mine	117	15	0	12	16	160	320
Spring Mine	9	0	0	1	11	3	24
Magazine 7,8	393	2	0	4	24	0	423
Magazine 11	22	8	6	3	3	0	42
Mine 26	1549	30	1056	317	68	735	3,755
Joe-Mode 4	77	4	0	5	14	14	114
Mode 2C	4	0	0	0	0	1	5
Mode 2E	25	0	0	4	1	0	30
Mine 24	0	0	0	0	0	0	0
Mode 2	3188	6	1	59	84	40	3,378
Jason Mine	166	7	3	11	3	83	273
Totals	10,704	138	1,109	462	365	2,274	15,052

*Total numbers include recounts of bats.

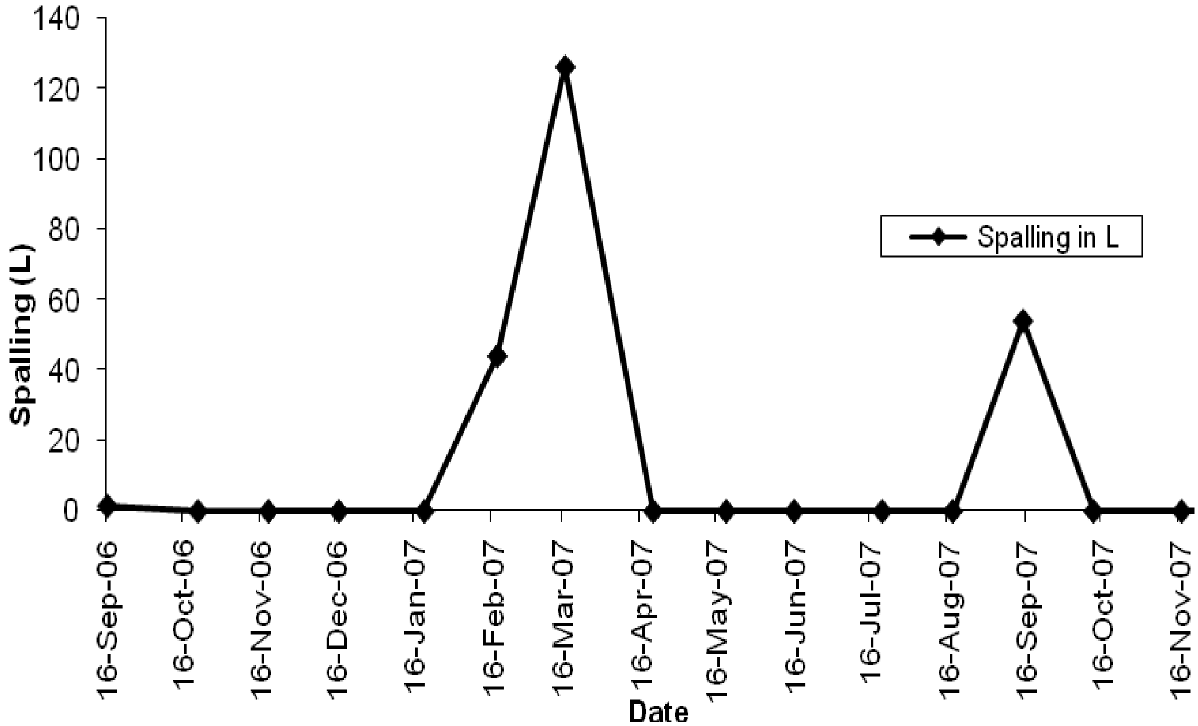
APPENDIX B: Mean monthly temperatures (˚C) for the abandoned mines in southern Illinois surveyed during this study from December 2006 through December 2007. Temperature dataloggers were placed in a centrally located wall in each room used in the study.

MINE	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Birk 2	9.21	8.02	6.38	8.20	8.77	10.04	10.85	11.01	11.88	11.77	11.16	9.78	9.16
Rhymer 1	10.11	9.71	9.06	9.76	9.95	10.35	10.50	10.50	10.56	10.60	10.73	10.51	10.94
Magazine Mine	4.48	2.55	-0.34	3.06	4.29	5.82	6.39	6.77	7.06	7.26	7.36	5.55	4.88
Spring Mine	7.68	5.22	2.08	6.95	8.03	11.16	12.93	13.92	15.33	14.85	13.52	9.42	6.36
Magazine 7,8	10.55	9.52	8.26	9.61	10.09	10.74	11.04	11.45	11.85	12.06	11.91	11.64	10.79
Magazine 11	7.92	5.23	2.12	7.93	9.25	12.82	15.02	15.95	17.24	16.72	14.77	11.74	5.98
Mine 26	7.43	6.61	4.90	6.64	7.14	8.01	8.41	8.62	8.88	9.04	9.16	8.86	8.17
Joe-Mode 4	8.19	6.59	4.21	7.24	7.98	9.43	9.99	10.37	10.81	11.03	11.03	9.67	7.54
Mode 2C	No Data	4.04	2.74	7.51	8.48	11.62	13.39	14.58	16.01	15.40	13.86	9.60	6.66
Mode 2E	No Data	4.00	2.53	5.74	6.52	8.00	8.65	9.05	9.58	9.68	9.79	8.14	6.10
Mine 24	7.58	4.83	1.11	8.49	9.31	13.95	16.59	17.89	19.83	17.74	14.86	9.49	6.18
Mode 2	9.62	8.74	7.39	9.08	9.46	10.26	10.62	10.92	11.21	11.27	11.15	10.73	9.80
Jason Mine	9.39	8.26	6.24	8.39	9.08	10.34	11.10	11.65	12.17	12.39	12.19	10.65	9.19

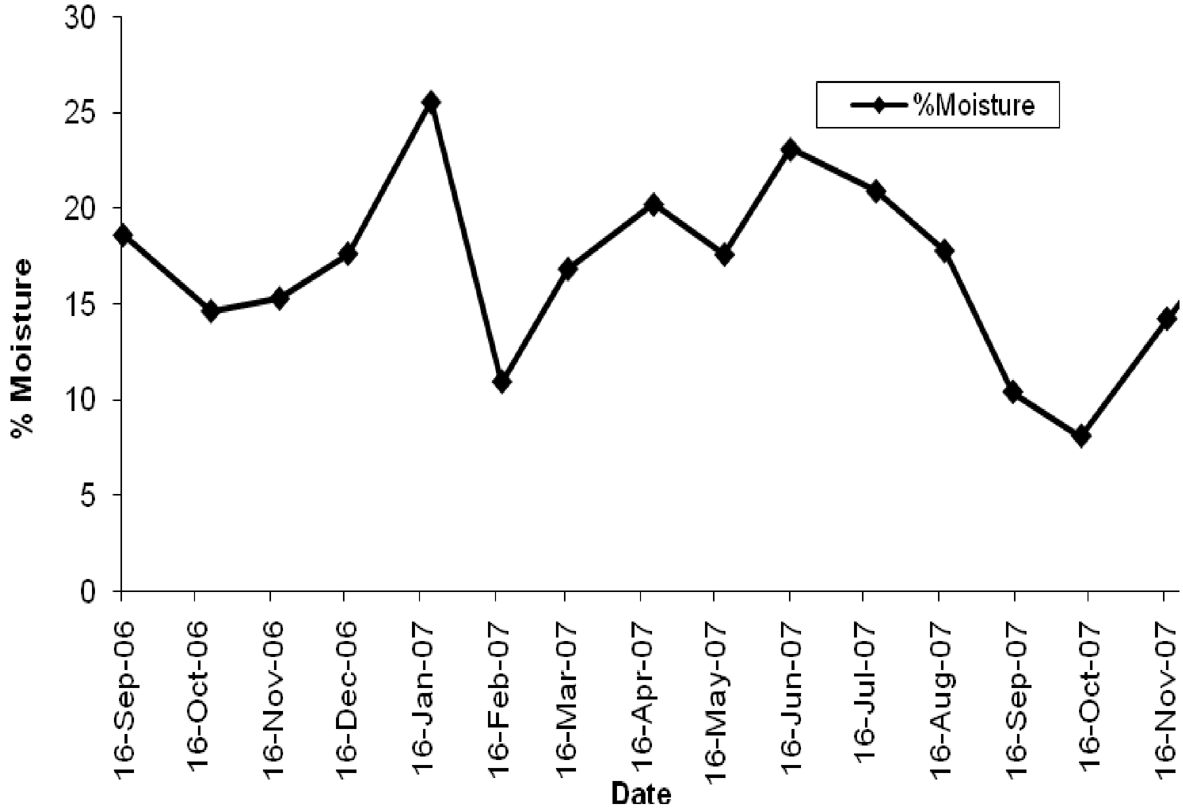
APPENDIX C: Percentage of mean monthly moisture content for each abandoned mine in southern Illinois surveyed in the study from September 2006 through December 2007. Rock samples were removed from a centrally located wall in each room in the study during each visit.

MINE	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Birk 2	13.3	10.8	15.29	11.24	11.63	3.88	11.38	11.05	12.83	19.04	10.19	12.08	9.04	8.93	10.68	12.9
Rhymer 1	8.92	11.73	11.78	12.39	9.70	7.63	12.43	12.41	8.68	10.29	10.65	10.39	8.69	8.07	8.03	7.02
Magazine Mine	13.30	13.89	15.29	11.24	13.05	3.88	11.38	16.53	12.83	19.04	13.81	12.08	9.04	8.84	10.68	12.90
Spring Mine	6.47	8.52	10.64	8.25	3.95	4.71	9.60	4.01	6.80	6.10	9.55	6.39	5.78	4.77	4.81	4.57
Magazine 7,8	11.72	-	-	10.97	-	-	11.52	-	-	9.59	-	-	7.68	-	-	7.10
Magazine 11	8.44	-	-	8.42	-	-	11.18	-	-	12.14	-	-	9.84	-	-	8.90
Mine 26	-	-	15.54	-	-	12.29	-	-	14.92	-	-	12.27	-	-	14.46	-
Joe-Mode 4	-	5.85	-	-	6.63	-	-	9.37	-	-	9.89	-	-	6.44	-	-
Mode 2C	11.30	-	-	5.83	-	-	7.50	-	-	9.30	-	-	5.77	-	-	-
Mode 2E	-	11.33	-	-	8.82	-	-	12.01	-	-	9.85	-	-	7.26	-	-
Mine 24	-	-	8.38	-	-	6.22	-	-	8.83	-	-	9.71	-	-	8.92	-
Mode 2	11.59	-	-	11.83	-	-	10.82	-	-	10.51	-	-	5.46	-	-	9.14
Jason Mine	-	13.59	-	-	12.68	-	-	12.03	-	-	10.55	-	-	8.81	-	-

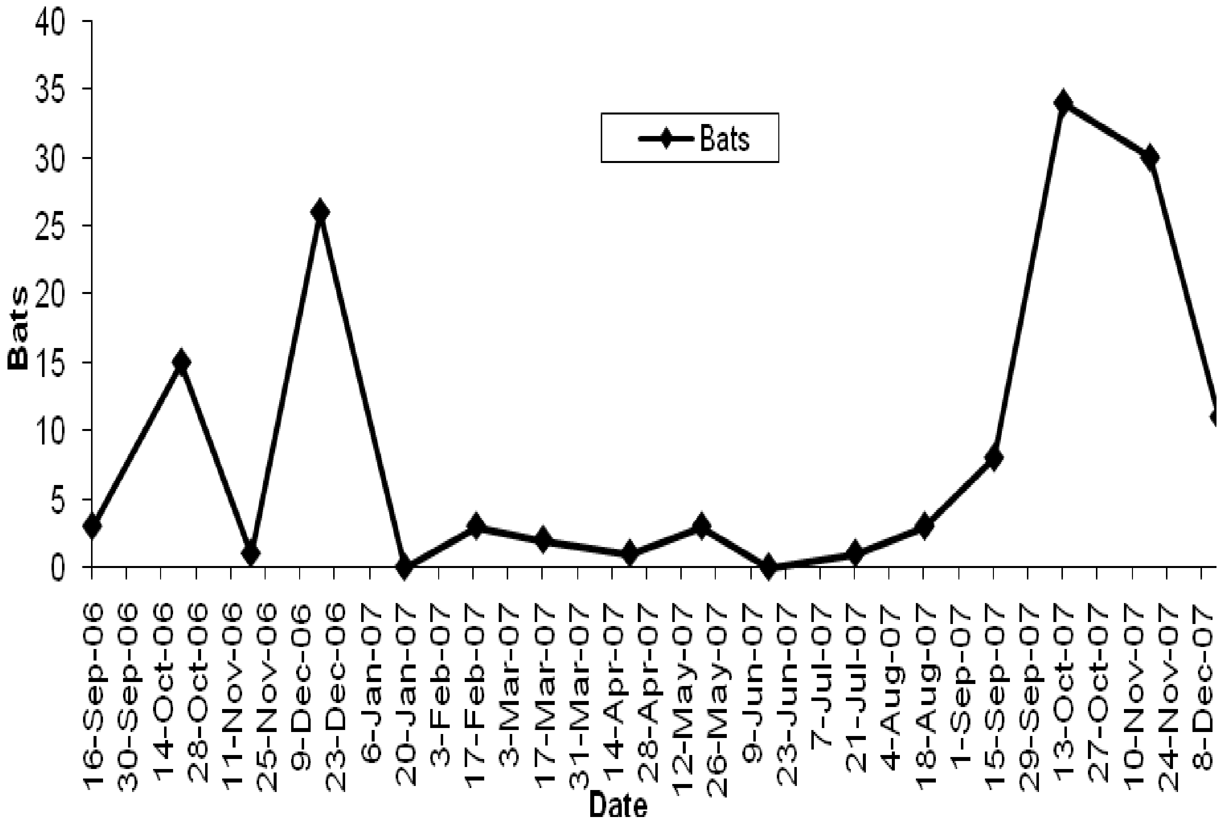
APPENDIX D: Spalling amounts for each month during the study in Magazine mine, room 11 in southern Illinois from September 2006 through December 2008. This is an example of a room with a high percolation of water from a fracture in the ceiling and experiencing below freezing temperatures in a mine with a high number of hibernating Indiana bats.



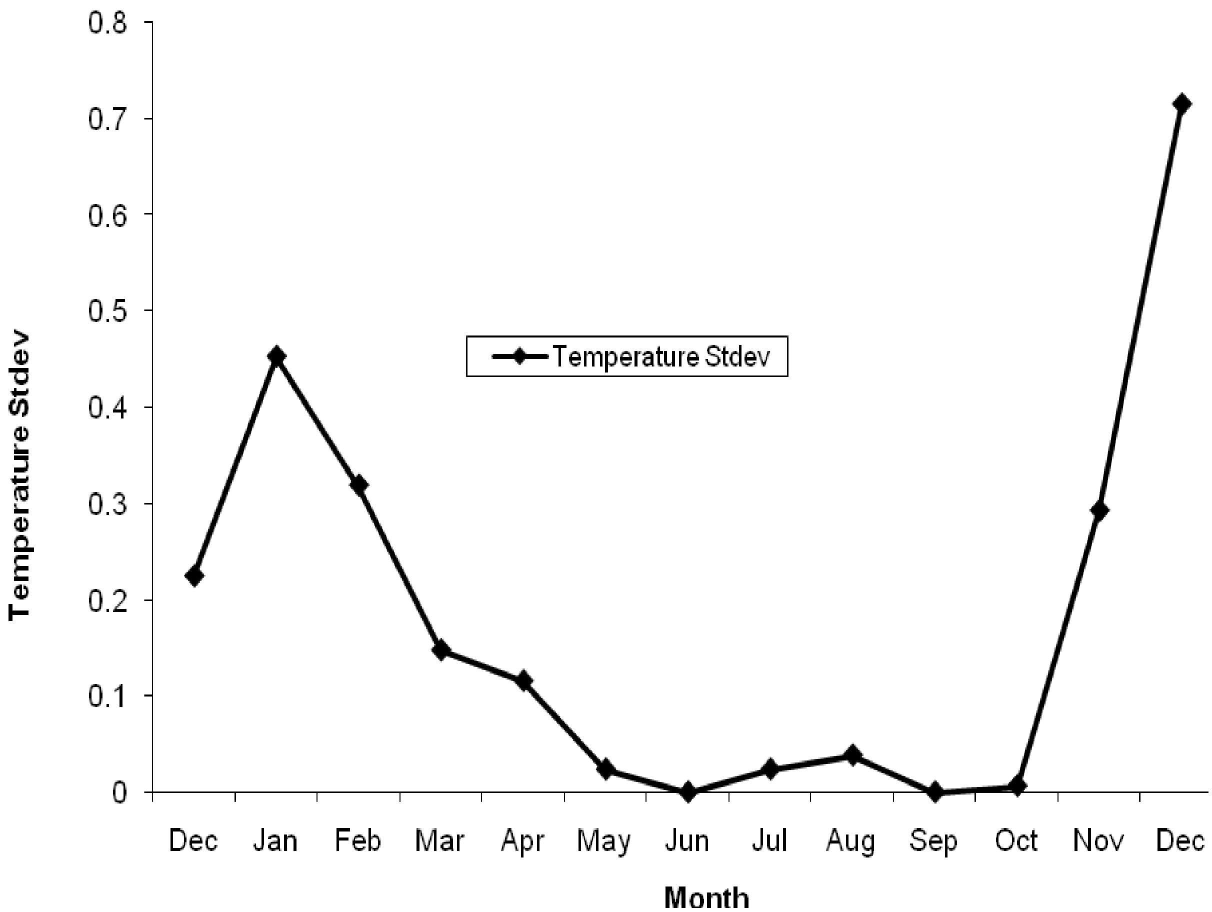
APPENDIX E: Percentages of monthly moisture content for Magazine mine, room 11 in southern Illinois from September 2006 through December 2008. This is an example of a room with a high percolation of water from a fracture in the ceiling and experiencing below freezing temperatures in a mine with a high number of hibernating Indiana bats.



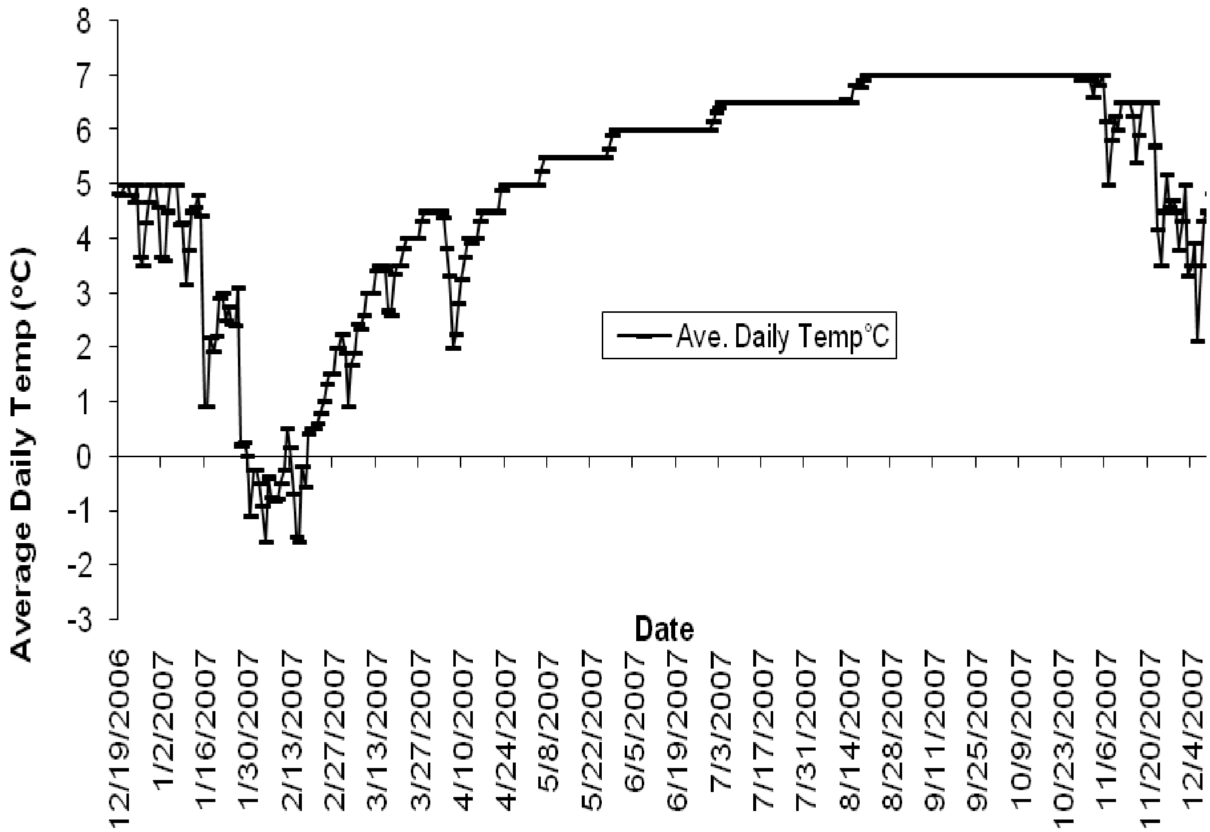
APPENDIX F: Number of bats counted during each monthly survey of the study in Magazine mine, room 11 in southern Illinois from September 2006 through December 2008. This is an example of a room with a high percolation of water from a fracture in the ceiling and experiencing below freezing temperatures in a mine with a high number of hibernating Indiana bats.



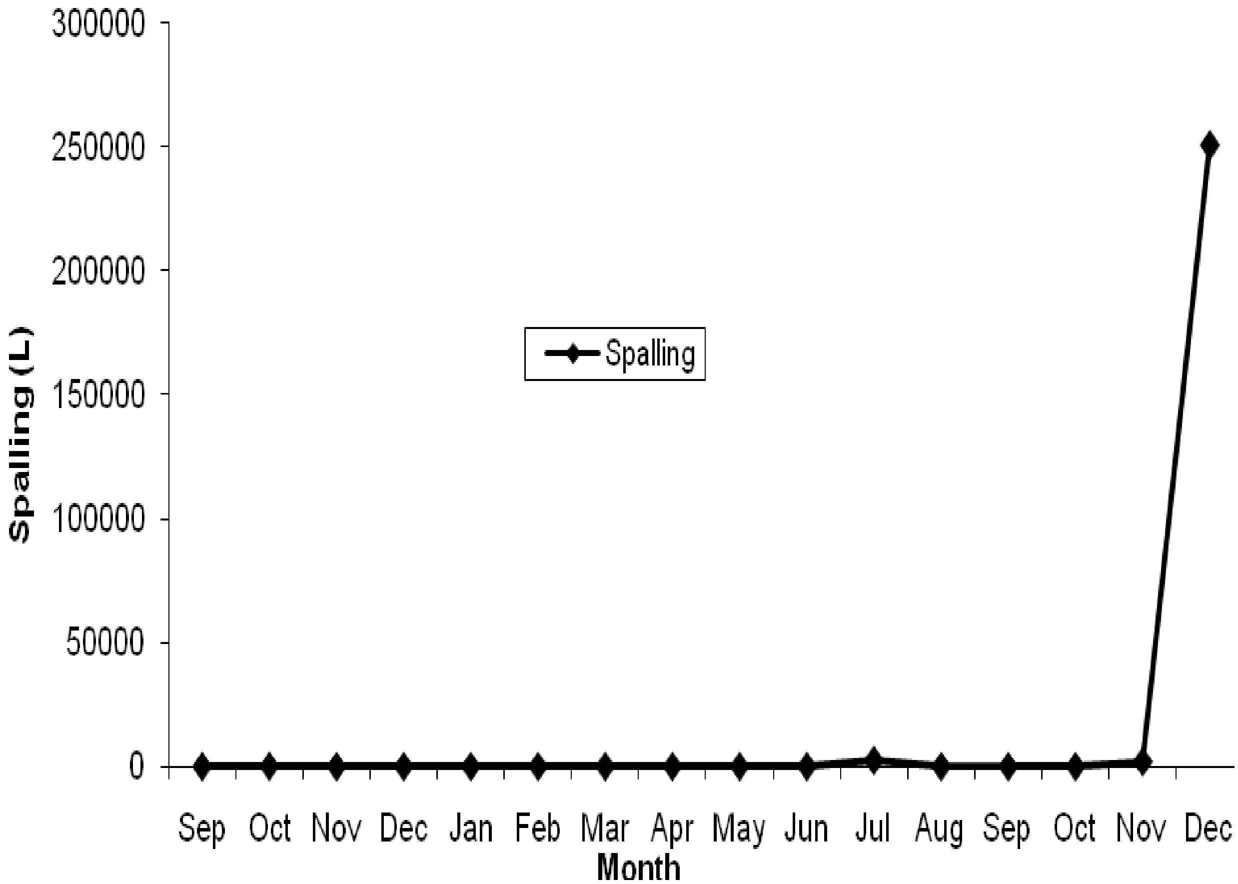
APPENDIX G: Monthly temperature variations for Magazine mine, room 11 in southern Illinois from December 2006 through December 2008. This is an example of a room with a high percolation of water from a fracture in the ceiling and experiencing below freezing temperatures in a mine with a high number of hibernating Indiana bats.



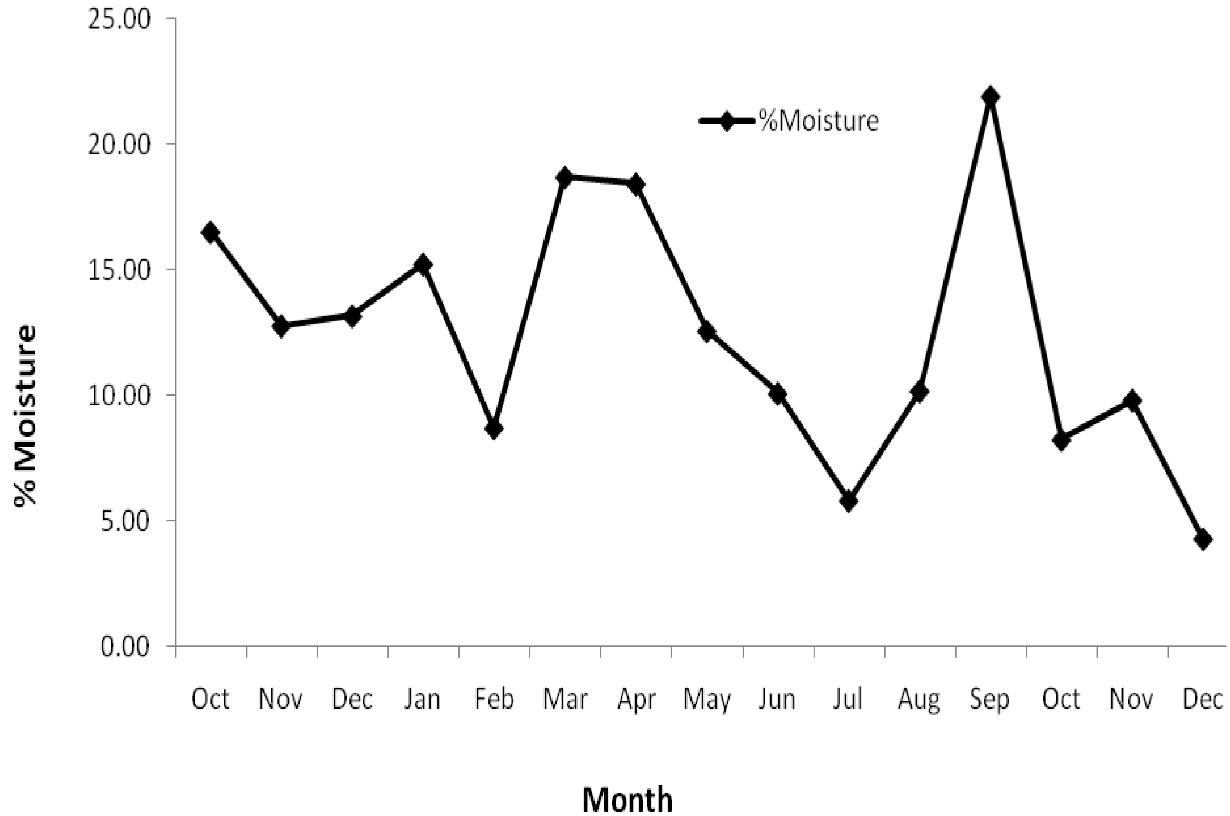
APPENDIX H: Average daily temperatures recorded in Magazine mine, room 11 in southern Illinois from December 2006 through December 2008. This is an example of a room with a high percolation of water from a fracture in the ceiling and experiencing below freezing temperatures in a mine with a high number of hibernating Indiana bats.



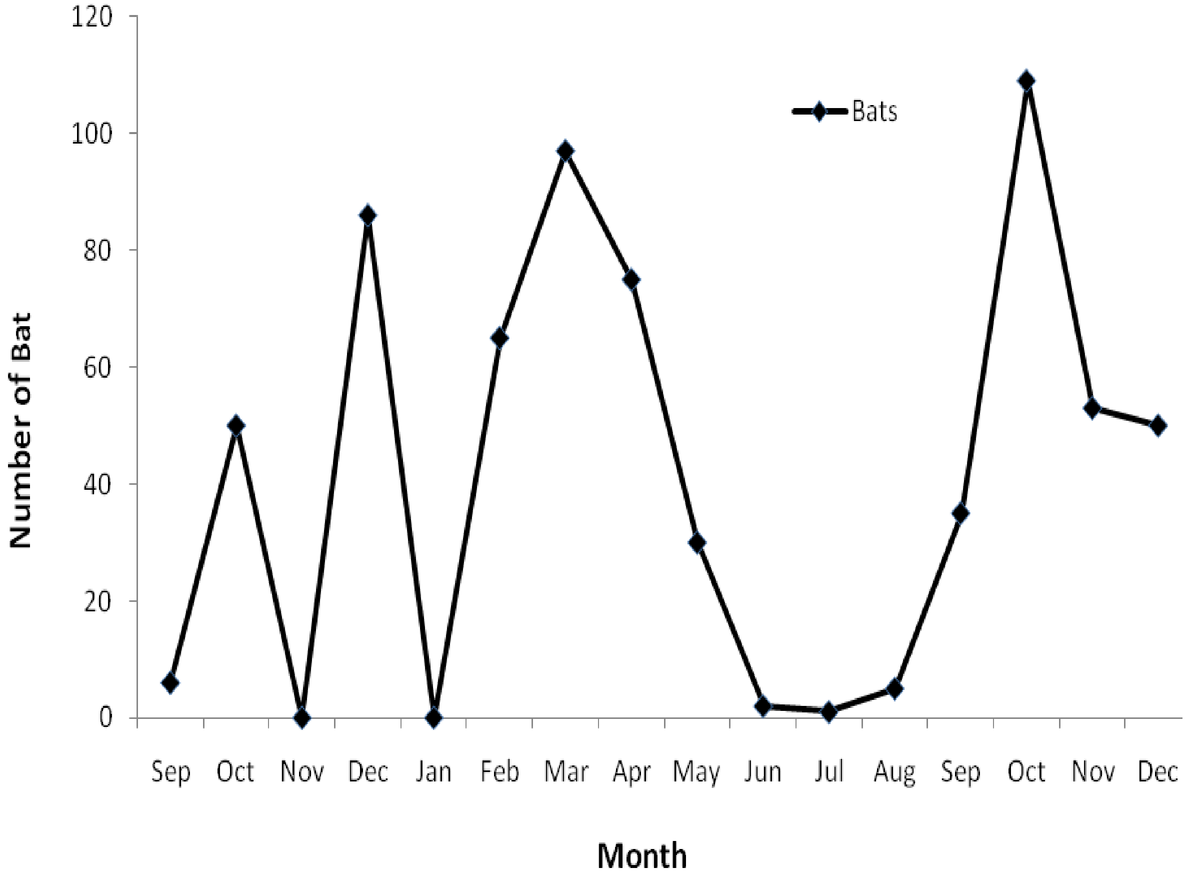
APPENDIX I: Spalling amounts for each month during the study in Rhymer 1, room 11 in southern Illinois from September 2006 through December 2008. This is an example of a room with a couple of major spalling events but being fairly stable throughout the rest of the study and with a high number of hibernating bats.



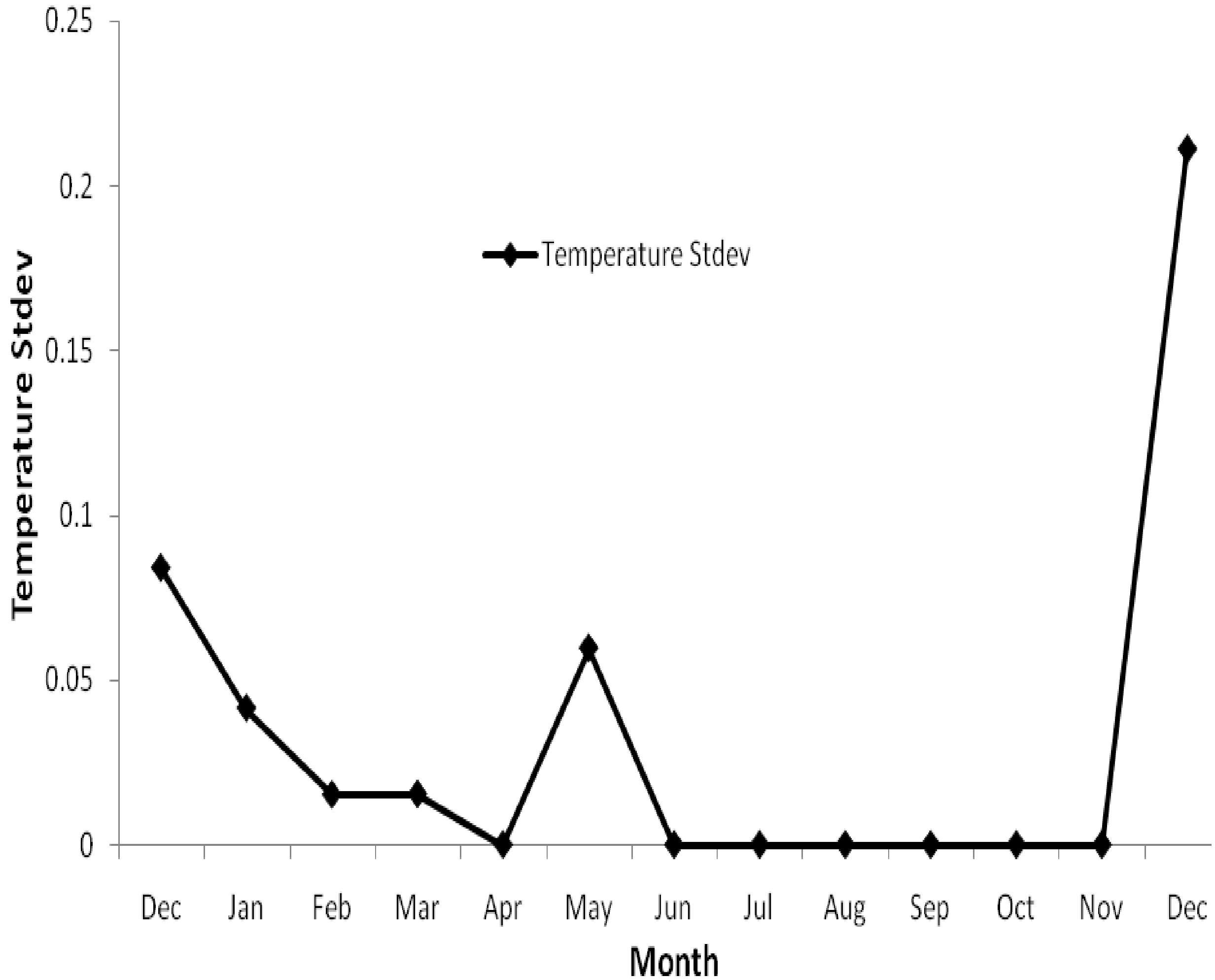
APPENDIX J: Percentage of monthly moisture content for Rhymer1 room 11 in southern Illinois from December 2006 through December 2008. This is an example of a room with a couple of major spalling events but being fairly stable throughout the rest of the study and with a high number of hibernating bats.



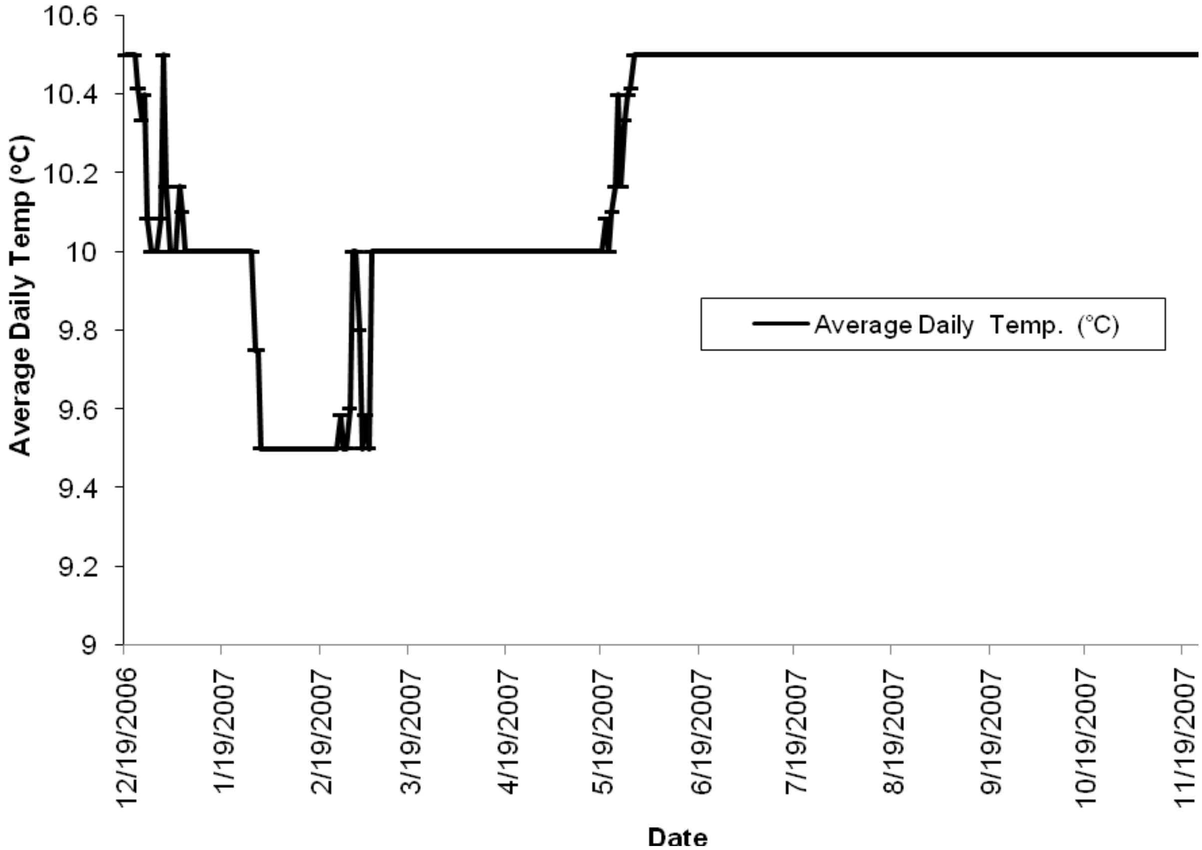
APPENDIX K: Fluctuations in number of bats for each month of the study in Rhymer 1, room 11 in southern Illinois from December 2006 through December 2008. This is an example of a room with a couple of major spalling events but being fairly stable throughout the rest of the study and with a high number of hibernating bats.



APPENDIX L. Monthly temperature variations for Rhymer 1, room 11 in southern Illinois from December 2006 through December 2008. This is an example of a room with a couple of major spalling events but being fairly stable throughout the rest of the study and with a high number of hibernating bats.



APPENDIX M: Average daily temperatures recorded in Rhymer 1, room 11 in southern Illinois from December 2006 through December 2008. This is an example of a room with a couple of major spalling events but being fairly stable throughout the rest of the study and with a high number of hibernating bats.



VITAE

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Major Professor: Dr. George A. Feldhamer

Publications:

- Seamans, M.E., J. Corcoran, and A. Rex. 2004. Southernmost record of a spotted owl-barred owl hybrid in the Sierra Nevada. Western Birds 35:173-174.

Conference Presentations:

- Corcoran, J.C., B.J. Steffen, G.A. Feldhamer, T.C. Carter, 21 – 25 June 2008. *Abandoned Micro-crystalline Mines: Long-Term Viability for Use by Hibernating Bats.* Annual Meeting of The American Society of Mammalogists. Brookings, SD.

- Steffen, B. J., J.C. Corcoran, T. C. Carter, G. A. Feldhamer, 12 – 15 March 2007. *Effects of Mine Characteristics on Hibernacula Selection by Bats in Southern Illinois*. Annual Meeting of the Illinois Chapter of the Wildlife Society. Moline, IL

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May 2006 – July 2006

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Department of Forest Science: Oregon State University
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