# **Behavioral Responses of Bats to Cave and Mine Gates**

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## ABSTRACT

Gates installed to protect bats at caves/mines sometimes have been more harmful than helpful. To assess responses to gates, during swarming behavior I recorded bats' flight speeds, flight behavior, and vocalizations at 28 sites with and without gates from Ontario to Tennessee. Bats always circled/retreated more/passed less at gates (most at mock gates). Higher bat activity and smaller gate size corresponded with more fly/retreat-circles. Echolocation, communicative calls and flight speed did not differ consistently based on gate presence. Flight behavior did not differ based on spacing of vertical gate supports, entrance abundance, or gate position (entrance or passage), although bats generally circled more/passed less in passages. To minimize impact on bats I recommend that gates: 1.) be erected in large areas, 2.) have a bat chute/open top, 3.) be placed at entrances (unless predation is a problem), 4.) be placed on flat ground (not an incline), 5.) be erected gradually.

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## INTRODUCTION

Humans are infamous for altering their environment, often in large-scale ways. Anthropogenic alterations, such as introduction of non-native species like kudzu (*Pueraria montana*) or the zebra mussel (*Dreissena polymorpha*), prove at least annoying and at most detrimental to the native fauna and/or flora (e.g., Bergmann and Swearingen 1997; USGS 2002). Other human-induced changes, such as presence of livestock or removal of native plants, can lead to abiotic alterations as well, such as desertification (Walker 1997). In recent years people have tried to reverse some of the damage and in some cases prevent it from initially occurring. Conservation efforts, regardless of how well intended, may be ineffectual or even more harmful than beneficial. One major limitation in effective conservation is lack of sufficient data about how organisms to be protected currently behave and how they will truly be influenced by the conservation measure. Many such efforts evolve on a trial-and-error basis. This includes some measures intended to protect bats, and research on bat conservation efforts is particularly needed (Racey and Entwistle 2003).

## Roosting Requirements

Many bat species are at least gregarious, often forming colonies in the hundreds, thousands, or even millions of individuals (e.g., Davis and Schmidly 1997). Furthermore, bats have low reproductive rates for their small size; vespertilionids have an average litter size of 1.38 young with usually only one litter per year (Barclay and Harder 2003), and are long-lived (one *Myotis lucifugus* lived 34 years; Davis and Hitchcock 1995). These

factors, combined with the necessity of a specific roost microclimate for hibernation and rearing young, make bats vulnerable to disturbance. As of 2000, approximately 22% (181 species) of extant microchiroptera were listed as threatened (Mickleburgh et al. 2002). Some species require different temperatures and humidity levels for different times of the year (cold but not freezing for hibernation, warmer for pup-rearing; e.g., Twente 1955, Humphries et al. 2002). In addition to the roost itself, the surrounding habitat and availability of food is important in selecting the best roost location.

In 1986, Brigham and Fenton demonstrated the importance of suitable roosts to *Eptesicus fuscus*. By closing several building roosts used by this species and recording subsequent behavior, they found that the bats were loyal to their original roost, staying in other roosts following eviction only temporarily and returning to the original building whenever possible. Further, reproductive success dropped by more than half following evictions. Clearly, what humans perceive as "available" roosts may be abundant (i.e., many caves or buildings or trees present in an area), but these may not be *suitable* roosts, which may often be a limiting factor in population size (Brigham and Fenton 1986). Other species, such as the cave-dwelling *Myotis grisescens*, exhibit high roost fidelity, particularly concerning hibernacula (Tuttle 1976).

As these findings indicate, we need to protect specific roosts that are important to bats for reasons perhaps not always understood by humans. This is of even greater importance for species like *Myotis grisescens*, where 95% of the known global population hibernates in eight caves (Harvey 2000). By examining the characteristics of preferred roosts, protection of currently uninhabited but seemingly suitable caves and

mines can be achieved in cases where the current roost has already suffered disturbance or must be closed to bats, as in the case of mine re-openings. Roosting preferences, habits, and general ecological data remain scarce or absent for many bat species (Fenton 1985, Mickleburgh et al. 2002), thus complicating the issue of protecting "preferable" roosts in some instances.

Caves and mines are vital roosts for many bat species. Approximately 25% of U.S. bat species hibernate nearly exclusively in caves or mines (Tuttle and Taylor 1998), and approximately 50% of the bat species reported from Canada and the United States (21 of 45) depend on cave or mine roosts during part or all of the year (Sherwin 2002). Many bats, including Endangered Species such as *Myotis grisescens*, *Myotis sodalis*, and subspecies of *Corynorhinus townsendii* depend on caves for winter hibernacula and/or summer maternity or bachelor colonies (Currie 2000a). Additionally, bats dwelling in places like caves and man-made structures exhibit stronger roost fidelity than foliage roosting bats (Kunz 1982).

## Effects of Human Disturbance

Human disturbance, intentional or not, can harm bats roosting within caves or mines (e.g., Thomas 1995, Sheffield et al. 1992, Mann et al. 2002). Mann et al. (2002) found breeding *Myotis velifer* became more active when exposed to light, voices, and close proximity to people during cave tours, and other species of females in maternity roosts have been known to drop or abandon their young when disturbed (Brady et al. 1982). Mere presence of humans can wake hibernating bats, causing them to expend energy they cannot regain in the midst of winter and subsequently die (Sheffield et al. 1992, Thomas 1995, Johnson et al. 1998). Tuttle (1977) describes bat populations declining by as much as 95% due to human disturbance. Johnson et al. (1998) found a correlation between lower post-hibernation weight and human presence in the cave roosts of *M. sodalis*, and Fenton (1970) found that the greater disturbance hibernating *M. lucifugus* were subjected to, the more weight they lost.

The plight of *M. grisescens* exemplifies the harm human disturbance can cause. *M. grisescens*, which inhabits caves in parts of the southeastern United States and has been listed as Endangered since 1976 (Federal Register 1976), began to decline in number around 1960, but the reasons for this were poorly known or undocumented (Tuttle 1979). In a study including more than 100 caves in the southeastern U.S., Tuttle (1979) quantitatively showed a correlation between human disturbance and population decline in *M. grisescens*. However, the methods for assessing disturbance level were somewhat arbitrary, and Tuttle (1979) found that factors other than disturbance (and still unknown) were probably partially responsible for this decline.

### Cave Gating: History, Advances, and Effects on Bats

Early cave gates preventing human access were installed for a variety of reasons, but there is little documentation about early gating. Some caves were gated by their owners for liability purposes, while others were gated to protect the delicate formations within. Some caves were gated for commercial use (i.e., tourism), and still others, such as Shelta Cave in Alabama, were gated to protect the ecosystem within, as early as the 1960s (Tuttle 1977).

Gating of mines has a similar, though slightly differing history. In the past, abandoned mines were often closed by bulldozing the entrance or backfilling the mine tunnel (Currie 2000b). Mines not completely sealed were often closed with gates restricting airflow significantly (Currie 2000b). The same is true of early cave gates, regardless of their intended function (Tuttle 1977).

Beginning around the 1960s, gate installation became an increasingly popular method of attempting to protect bats and caves (Tuttle 1977). However, it eventually became apparent that gates erected to protect bats could also harm them. While it seems logical that non-biologically oriented gates were damaging to bats due to lack of planning, state and national park officials in the U.S. routinely installed gates during the 1960s with the intention of protecting bats (Tuttle 1977). Installation of gates seems to have been viewed as an instant solution to human disturbance during that time. Unfortunately, most gates did more harm than good (Tuttle 1977).

Cave gates erected in the 1950s through early 1970s virtually always resulted in roost abandonment by bats (Tuttle 1977). Consequently, gate-builders and bat conservationists attempted to improve gate designs to better accommodate the bats. Design improvements attempting to maintain adequate airflow, allow room for bats to fly, and prevent excessive predation were made based on limited research and largely on anecdotal evidence or casual observation. The currently accepted design, the angle iron gate, was developed by Roy Powers and first installed in 1978 (Powers 2002), but the responses of many species to any type of gate remain poorly understood, unknown, or negative (Currie 2001). This design is accepted as the standard because it reportedly does not obstruct airflow and is difficult for vandals to breach, rather than because bats are known to react best to it.

Advances have also included alternative gate locations. The first "twilight" gates (gates placed within the dark zone of a cave roost) in the United States to protect resident bats were installed in the early 1980s in Oklahoma and have since proved successful for multiple *M. grisescens* and *Corynorhinus townsendii* roost sites, as well as one *M. sodalis* roost in the same area (Martin et al. 2000, B. Howard, pers. comm. 2002). However, a dark zone gate in Alabama at a *M. grisescens* roost proved unsuccessful (K. Hudson as quoted in Currie 2001), and it remains unclear how position of the gate influences bats' acceptance of it.

Richter et al. (1993) showed that obstructing an entrance led to potentially harmful temperature changes within an Indiana cave housing *M. sodalis*. White and Seginak (1987) compared the responses of *M. grisescens* and *C. townsendii* to three gate designs at two caves using exit counts as a means of quantification. They found that bats preferred the steel bar and angle iron designs equally, while avoiding a funnel design, though the study had some design problems (no control, alternate entrance available). Ludlow and Gore (2000) tackled the question of how a cave gate affected *M. grisescens* and *M. austroriparius*. Bats emerging from two entrances of Old Indian Cave in Florida before and after a gate was removed from one entrance (the remaining entrance was never gated) were counted. This study offered evidence that at least some bat species avoid exiting through gated entrances when possible. The researchers found no difference in emergence time before and after gate removal.

The revised edition of *Bats and Mines* (Tuttle and Taylor 1988) provided a detailed account of what should be included in pre-gating studies and post-gating assessments. In 2000, Bat Conservation and Mining: A Technical Interactive Forum was held in St. Louis, MO, and in 2002 Bat Gate Design: A Technical Interactive Forum took place in Austin, TX, showing that the attentions of natural resource managers have turned to this topic. The proceedings of the bat and mine conference yielded several articles about gating, but they dealt mainly with observational rather than experimental data (e.g., Burghardt 2000, Kretzmann 2000, Posluszny and Butchkoski 2000). Navo (2000) provided quantitative data about numbers, species, and reproductive status but none about bats' behavioral responses. Despite these unknowns, thousands of gates already cover mines and caves in the US and Canada (Sherwin 2002). Little or nothing is known about the reactions of some species to placement of gates (Tuttle and Taylor 1998). While *M. grisescens* at maternity colonies do not accept gates and *Tadarida* brasiliensis "never" accept gates (perhaps due to their large colony sizes), even such basic information is not available for many other species (Tuttle and Taylor 1998).

#### Behavioral Responses: Vocalizations, speed, and flight behaviors

Vocal communication is an important aspect of bat behavior and social living, and Suthers (1965) reported *Noctilio leporinus* "honking" to avoid collision during flight. Others have found that various species change their echolocation calls when flying with conspecifics (e.g., Obrist 1995, B. Fenton, pers. comm.). Fenton (1985) provides an extensive review of bat communication, and states that a complete or nearly complete "vocalization repertoire" is known for very few species.

Non-echolocation calls previously described include squawks (Barclay et al. 1979, Fenton 1985, and Pfalzer and Kusch 2003), trills (rapid repetition of calls; Pfalzer and Kusch 2003), barks (Fenton 1977), double note calls (Fenton 1977, Barclay et al. 1979, and Fenton 1985), multinote calls (Barclay et al. 1979), sine wave calls (Barclay et al. 1979 and Fenton 1985), and simple or complex chirping, described by Pfalzer and Kusch (2003) as cheeps or songs. Lower calls, such as squawks and barks, are generally recorded from landed bats (Fenton 1977), and some social call types are usually associated with a certain behavior (e.g., copulation; Barclay and Thomas 1979).

The variety of low and high frequency sounds bats emit for communication purposes (Fenton 1985) also include alarm and distress calls. Alarm calls are also used by birds and other animals and serve the purpose of warning conspecifics of danger. Nelson (1964) found evidence that alarm calls may vary within a single bat species based on specific circumstances (e.g., a certain type of predator). Conversely, distress calls seem to solicit help from conspecifics, attracting them rather than deterring them. Such calls have been described in several papers (e.g. Guthrie 1933, Fenton et al. 1976, Russ et al. 1998) but are still far from completely understood (B. Fenton, pers. comm.).

Interspecific communication between bats (e.g., Balcombe and Fenton 1988) may occur at multi-species swarming sites like those I used. This leads to interesting questions such as, are calls bats make when approaching gates some combination of echolocation and communication?, and does one bat's behavior depend partially on the types of calls other bats emit?

Flight speed and flight behavior together with vocalizations offer a more holistic picture of bats' responses to gates. Past observation indicated that bats increase circling behavior when encountering an entrance gate, and some bats, especially newly volant young, frequently land on the gates or even crawl (rather than fly) through them, increasing chances of being preyed upon (Tuttle 1977, White and Seginak 1987, Currie 2001). Allende et al. (2003) compared three mines with gates already in place to three newly gated mines (at which they recorded data before and after gate installation) and found bats circled 6-10 times more frequently at gated entrances than at ungated ones. However, Martin et al. (2000) reported a lack of evident circling or increased predation at several dark zone gates.

In addition to potential changes in flight behavior, bats may alter their flight speed when approaching a gate. No published papers have reported testing for a correlation between bat speed and presence of gates even though it is commonly said that bats slow down in the presence of gates (e.g., Tuttle 1977). If gates generate "traffic jams," congestion, slower emergences, or increased collisions, bats could suffer extraneous energy loss, predation, or injury from collisions. Further, changes in flight speed over time following gate installation may show if and how quickly bats adjust to the gates' presence.

## Swarming

Swarming is the late summer and early autumn activity of many bat species that hibernate in caves or mines. During swarming, bats fly in, around, and out of hibernacula during most of the night (Poole 1932, Davis and Hitchcock 1965, Fenton 1969). This behavior has been observed in species such as *M. lucifugus, M. septentrionalis, M. sodalis, E. fuscus, C. townsendii*, and *Pipistrellus subflavus* in geographical locations including Ontario, Quebec, Pennsylvania, Indiana, Kentucky and Oklahoma (Davis et al. 1968, Hall and Brenner 1968, Fenton 1969, Cope and Humphrey 1977, Clark et al. 1997). Swarming begins after young and females leave maternity colonies (Hall and Brenner 1968, Fenton 1969) and continues until bats enter hibernation.

As the swarming season progresses, sexual activity and the build-up of a hibernating population become components of this activity (Fenton 1969). During swarming, bats of both sexes and all ages (subadults as well as adults) are present (Fenton 1969). At many sites, several species are active (Davis et al. 1968, Hall and Brenner 1968, Fenton 1969, Cope and Humphrey 1977), and banding studies indicate that a different group of individuals is present each night (Hall and Brenner 1968, Fenton 1969). In at least some cases, a relatively small percentage of swarming bats hibernated at the site at which they were captured during swarming (Hall and Brenner 1968, Fenton 1969). The ephemeral nature of the swarming population's stay at any given swarming site presents the opportunity to study these bats without disturbing them at a time when they are vulnerable, such as in maternity colonies or during hibernation. The large number present at some sites during swarming, representing a cross-section of bats of

multiple species, ages, and sexes, provides an ideal opportunity to collect data about the responses of cave-dwelling bats to gates.

#### Purpose and Predictions

I hypothesized that bats change their behavior in the presence of a gate and tested the following predictions: 1) bats decrease their flight speed when approaching gates, 2) bats alter their vocalizations and emit more social calls in the presence of a gate, 3) bats change their flight behavior in the presence of a gate, 4) if bats acclimate to a gate's presence, a gate's impact should be reduced over time, 5) the level of impact of a gate will vary by bat activity level/number of bats present, 6) the size of the gate area and spacing of the vertical supports will have an impact on the level of impact of a gate, and 7) bats will behave differently when flying in a passage versus at an entrance.

To address these predictions, I examined behavioral responses of bats to gates and gate-like structures present at their cave or mine roosts by recording and analyzing data pertaining to flight speed, flight behavior, and vocalizations. To address the issue of habituation, I tested the above parameters at caves and mines which were already gated and still supported bat populations.

## METHODS AND MATERIALS

#### Study Sites

From 26 July to 3 October 2003, I collected data at caves and mines from southeastern Ontario, Canada, to middle eastern Tennessee, US (Table 1). My sample

included a variety of gates placed at entrances to caves and mines. While most gates had standard 10 cm angle iron bars, two gates at Preble Co. Mine had L-shaped bars (Figure 1). Variety in gate design included cage-like structures and a large "X" crossing each half of a Preble Co. Mine gate (Figure 2). I selected sites based on previously reported information about fall swarming behavior or hibernation at these sites.

At each site, I collected data at the entrance. At ungated sites (Table 1), I recorded data with no mock gate, after the installation of a mock gate, and sometimes again after removing the mock gate. At some sites, I first erected a mock gate perpendicular (Figure 3) to the main axis of the passage and then one that angled across the entrance. When I could enter the cave or mine, I also collected data inside the passage either where the dark zone began, 30 m (~97') from the entrance, or within at least 4-5 m of any divergence of other passages, whichever was encountered first. At sites with multiple entrances, including those with multiple gates, I recorded data at as many entrances as possible. At one site (Craigmont Mine), I erected a passage mock gate (Figure 4) and collected data. I typically left mock gates in place for about one hour.

I visited 33 caves and mines in six states and provinces and obtained some data from 28. At 25 of these sites, I obtained a full set of data for at least one parameter (calls, flight speeds, or flight behaviors). Fifteen of these sites had at least one gate, while ten were ungated. I collected data at 26 different gates (this counts Saltpetre as one gate, not three; Table 2), and at a total of 23 unobstructed entrances and passages. For the remainder of the paper, site refers to a cave or mine, while situation refers to a passage, gate, entrance, etc. Mark refers to the gate, entrance, mock gate, or future location of the

mock gate used for determining proper placement/distance of the bat detector and radar gun (e.g., center of gate at chest height).

#### Preliminary Work at Renfrew Mine

Between 26 July and 7 August, I worked at the Renfrew Mine (Renfrew Co., ON; N 45° 18.29; W 076° 54.32) to obtain preliminary data. I recorded echolocation calls near a vertical entrance (inside the mine), in two mine passages, at a metal gate inside the mine, in an open room in the mine, and at the unobstructed entrance. I also recorded flight speeds at each of these locations, with the radar gun positioned 0.9 m, 1.8 m, and 3.7 m from the gate and entrance. Additionally, I made qualitative observations of bats' behaviors in each situation. Finally, I recorded four nights of data after installation of a mock at the mine's entrance. I also recorded general observations regarding affects of weather on bat activity, usual time of arrival by bats, and other notes.

## Standard Protocol at Gated and Ungated Sites

## I. Flight speeds

I used a K-15 handheld radar gun modified to record m/s (Blake et al. 1990) to measure flight speeds of bats (Salcedo et al. 1995). During preliminary work at Renfrew Mine, I attempted to collect flight speeds with the radar gun various distances from the mark. When the radar gun was very close to the mark, the bats appeared to avoid it as an obstacle, and I obtained no flight speed data. Based on these trials, I recorded flight speeds with the radar gun mounted on a tripod parallel to the ground ~1.2 m above the

ground at the base of the radar gun. I placed the radar gun  $\sim$ 3.7 m from the mark (Figure 5), and recorded speeds for five minutes with the device facing toward the mark and for five minutes with it facing away from it (typically 180 degrees from the previous setting). Approximately 30 – 60 minutes later, I repeated this process, for a total of ten minutes of speeds in each direction. At non-horizontal entrances and slanted gates, I positioned the radar gun so that it pointed perpendicular to the mark (or as close as possible to this position). At entrances that were < 1.2 m high, I lowered the radar gun accordingly but always secured it on a tripod.

## II. Vocalizations

I recorded calls with a Pettersson D980 bat detector (Pettersson Elektronik, AB, Uppsala, Sweden) connected to an F2000 filter unit (Pettersson Elektronik, AB) set to low gain connected to a high speed sound card (DAQCard-6062E, National Instruments, USA) installed in a Dell Latitude laptop computer running BatSound Pro (Pettersson Elektronik, AB). I placed the bat detector on a tripod ~1.2 m from the ground parallel to the ground and positioned ~1.5 m from the mark (Figure 6). I set the high frequency gain on the bat detector gain to 50%, and the gain in BatSound Pro to 1. Time expansion was 10, and the sound format settings were Mono 16, 44,100 samples per second. I used a recording sampling frequency of 357.1 KHz and recorded calls for 30 seconds approximately every 10 to 20 minutes three to five times for each orientation/control at each site. In the case of non-horizontal entrances and slanted gates, I positioned the bat detector so it pointed perpendicular to the mark. At entrances with heights < 1.2 m, I

lowered the bat detector accordingly but always secured it on a tripod. At several sites, I also recorded calls away from the cave or mine entrance. I recorded calls from bats flying in open areas, in forests (clutter), and in one instance over a pond.

## III. Flight Behavior

During preliminary work at Renfrew Mine, I made qualitative observations of bats in a mine passage, in a room within the mine, near an internal permanent gate, and at an entrance to the mine. From these initial observations, I determined which behaviors were most frequent and most pertinent to my goal of learning about bats' responses to gates. Subsequently, at each site, I made observations three to four times at each situation (entrance, passage, mock gate(s), real gate(s)). I made observations over a five minute time span recording behaviors for one minute on/one minute off for a total of three minutes of observation every 5 to 20 minutes (9-12 minutes total per situation). At sites with low activity, I made observations for 5 consecutive minutes during each period, for a total of 15-20 minutes per situation.

To observe flying bats, I illuminated the area of study with standard lights (Coleman lantern, Petzl headlight, and/or General Electric spotlight, depending mostly on entrance size) covered in clear red plastic to reduce disturbance (Finley 1959). I quantified the following behaviors: circle, fly/retreat, pass, chase, collide bat, collide gate, collide person, collide wall/ceiling/equipment/other, land gate, land other, chatter, and sudden height change. Each time I observed a bat engaging in any of these

behaviors, I made a note of this using a tape recorder. I then entered tallies of each behavior into a spreadsheet for analysis.

I counted only bats observed between the observer and the mark in the behavior tally, and the observer was always positioned outside the entrance. I also included bats passing through from the inside in the tally. I made casual notes and observations about the bats on the side of the mark (especially with gates) opposite the observer, but did not include these bats in the tally due to poor visibility. The distance the observer stood from the mark varied depending on the passage or entrance size. The observer stood so that the entire entrance or passage was visible (except in the case of very large gates) but close enough to have an adequate view of the bats' flight behaviors. Generally, the distance stood from the mark increased with increasing entrance/passage size.

I define "circling" as a single bat flying in one or more consecutive circles completed between the observer and the gate, entrance, or designated point in the passage (future site of mock gate). I counted each circling "episode" by each bat as one.

"Fly/retreat" behavior occurred when a bat flying in any direction abruptly changed direction, usually at or close to a 180° angle, and flew rapidly in the new direction. Each time a single bat engaged in one such activity was counted as one.

I defined a "pass" as the flight of a single bat passing the gate, entrance, or passage point a single time. If one bat flew repeatedly in and out of an entrance or back and forth through a gate, I counted each time it passed through the mark as one pass.

"Chasing" occurred when one bat flew rapidly after another and was only counted when the second bat (the chaser) was clearly behind (not beside or just above) the chasee.

Each time two bats flew in this formation in the observer's field of view was counted as one.

I defined "sudden height change" as a bat flying at one height level abruptly gaining or losing altitude in one sudden swoop.

"Collisions" occurred when a flying bat flew into another bat, a gate, a cave or mine wall or ceiling, or an observer. Collisions were scored whenever a bat made physical contact with any of the above items (including wing brushes, head-on collisions, etc.) but did not land on the object/person/bat.

"Landing" on a gate or other object occurred when a bat clearly touched down and rested briefly on an object (not merely colliding then flying on once recovered).

I defined "chattering" as vocalization I could hear as bats were active in the area but not including the "ticking" sound associated with the production of echolocation (Griffin 1986). I counted each continuous episode of chattering by each bat as one.

If bats engaged in more than one activity simultaneously, I counted both activities in the tally. For instance, if one bat was chasing another while they both flew in a circle, I tallied this as one chase and two circles.

#### IV. Other information

For each site, I also recorded time of arrival and departure, time first bat was seen, temperature (using a mercury thermometer), location (using a Garmin GPS II Plus), weather conditions, and general notes about bat activity level, condition of gate, shape of entrance or passage, and other site-specific data. I measured entrances and gates using a standard tape measure giving readings in both metric and standard units. For each gate, I took the following measurements: total height, total width at chest level, distance(s) between vertical supports, distance between horizontal bars, and size of angle iron or other bars. In a few cases, I obtained this information from other sources. For each mock gate, I measured the distance between vertical supports and recorded total height and sizes of horizontal bars used. When angled mock gates were erected, I measured the distance from each side and from the center to the location of the bat detector (1.5 m away).

## Mock Gates

I constructed mock gate pieces using lumber (spruce) and nails. I followed the spacing specifications and general design of the angle iron gate recommended and considered standard by the American Cave Conservation Association (ACCA; Tuttle and Taylor 1998). Horizontal pieces were 7.6 cm angle "iron" and were 2.5 cm thick. Horizontal bars were spaced 14.6 cm apart. I constructed horizontal pieces that were 0.3, 0.6, 1.2, 1.5, 1.8, and 2.5 m in length.

Vertical pieces consisted of 15 x 2.5 cm spruce with triangles cut every 14.6 cm to hold horizontal bars. I cut these pieces into 1.2, 1.8, and 2.5 m segments. For horizontal and vertical bars, I drilled holes and cut wooden dowels into pegs to connect multiple pieces to cover larger areas.

I erected mock gates at 11 sites and at nine obtained enough data for analysis. I constructed mock gates ranging in size from 1.2h x 1.5w m to 2.5h x 2.2w m and 1.8h x

3w m. At Murder Branch Cave, where the entrance was roughly 2.5 x 2.5 m, I suspended a cloth to cover the bottom 0.8 m of the entrance in both the presence and absence of the mock gate. At Renfrew Mine, Craigmont Mine, and Mullins Spring Cave, I collected data with and without a mock gate more than one night. I also collected data on two nights at Barton Hill Mine.

## Trapping

At most sites, I did not trap bats and therefore do not have data about the species composition of the swarm other than what was available in the literature/unpublished data or in some cases by examining vocalizations. At seven sites, I used a 1m X 1m Tuttle Trap suspended between trees or rock near cave or mine entrances (Figure 7), and removed any captures bats every few (<5) minutes. At one site I plucked two landed bats from the mine wall. I examined bats to determine species (when possible), sex, and age (adult or subadult) based on calcification of the finger joint. Bats were released soon after (usually <30 minutes later).

## Data Analysis

I used SPSS for Windows, version 11.5 (SPSS, Inc. 2002), for all statistical analysis. Unless otherwise noted, data were normally distributed, met the necessary assumptions for tests performed, and were not transformed prior to analysis. I used a cut off value of 1.0 or -1.0 for skewness to determine whether to transform data. For some

tests (noted in Results section), the % pass data were negatively skewed, so I transformed the data by squaring each value prior to analysis (Zar 1998).

#### I. Flight Speeds

I included situations with a minimum of ten flight speeds recorded in the analysis comparing situations across sites (e.g., speeds recorded in passages from multiple sites compared with speeds recorded at multiple gates). I compared flight speeds compared within and between sites and locations using independent samples t-tests and univariate Analysis of Variance (ANOVA) after ensuring appropriate assumptions were met. Parameters compared included time of night, date, location, and site type (gated, ungated, mock gated). The direction in which speeds were recorded is referred to as "in" and "out." For example, when the radar gun was 3.7 m from a cave gate facing toward the gate, I labeled speeds as "gate in," and bats whose speeds were recorded in this set-up were presumably influenced by the gate they had just passed through. When the radar gun was rotated 180° to face away from the gate, I labeled these speeds as "gate out," and recorded speeds of bats presumably unaffected by the gate since they had not yet encountered it.

For sites where I erected a mock gate, I compared speeds with and without the mock gate when at least three speed values were present in both situations. At each site where both perpendicular and angled mock gates were used (Renfrew Mine, Craigmont Mine, and Mullins Spring Cave), I compared speeds recorded at each using an independent t-test, and found no significant difference at any site in either "out" or "in"

orientations. Because this was true and each represented the presence of a mock gate, I combined flight speed data from perpendicular and angled gate presence when applicable. I used independent samples t-tests to compare "mock in" versus "entrance in," etc. for each site.

## II. Vocalizations

Prior to quantitative analysis, I used BatSound Pro to visually examine recorded calls while listening for social calls, assessing activity levels, types of bats present, presence of buzzes (feeding, landing, or otherwise), and other general characteristics. After examining any particularly low frequency calls found within a file, I filtered the recordings using a high pass of 23000 Hz (lower for some files with lower frequency calls) and Butterworth 8 after determining no call features would be lost in doing so.

I examined a minimum of eight files from each study site or all files if there were < 8 files. When I had spent more than one night at a site or had many more recordings, I examined more files (up to  $\sim$ 35). I used the visual and acoustical examination of calls to estimate the numbers of bat species active where I was recording up to three to four species.

I then chose sequences of eight consecutive calls (each sequence represented a single bat) representing as many species recorded as possible. I chose sequences based on the following parameters: 1) calls at least 4%-5% above background noise (based on time-amplitude display); 2) calls not overlapping in time with others; and 3) calls that were not saturated. In the few instances where some calls in a sequence were well under

5%, I ignored them but still analyzed calls >5% in the sequence. These parameters usually resulted in choosing files/sites with relatively low bat activity.

I used interpulse interval (IPI; end of one call to beginning of the next) and examination of the file as a whole to determine the presence of calls from a single individual. For each call in a sequence, I determined the duration (DUR in ms), frequency with maximum energy (FME in kHz), lowest frequency (LF in kHz), and highest frequency (HF in kHz) of each call and the IPI (ms) between calls. I measured FME, LF, and HF using a power spectrum (Hanning Window, FFT size 256), with LF and HF measured as -10 dB from the FME (peak). In instances when a plateau rather than a distinct peak was present, I used the average of the frequencies on either side of the peak as the FME. Within each sequence, I found no consistent trend for any parameter when I plotted each against individual call number. I divided the 23 call sequences (each from a different bat) into ten groups based primarily on FME and visual examination. I then used multivariate analysis of variance (MANOVA) to compare FME, LF, HF, and DUR (dependent variables) of calls between these groups (one factor, with 10 levels). Using Dunnett T3 post hoc test (SPSS, Inc. 2002), I determined which groups were statistically alike for at least three of the four parameters. I then regrouped the sequences based on these results, and ended up with seven groups, which I compared using MANOVA in the same manner.

Using data on FME, LF, HF, DUR and pattern of frequency change over time, I compared my data with published readings for various species reported by Fenton and Bell (1979, 1981), Brigham et al. 1989, Thomas and West 1989, MacDonald et al. 1994,

Betts 1998, Murray et al. 2001). I distinguished social calls from calls used primarily for echolocation based on the following general parameters: 1) social calls are shaped differently than search-phase echolocation calls, 2) social calls occur more sporadically and not in long, regular sequences, 3) social calls often utilize a different range of frequencies than other calls, 4) social calls are typically longer in duration than search-phase calls (see figures/descriptions in Fenton 1977, Barclay and Thomas 1979, Barclay et al. 1979, Fenton 1985, Pfalzer and Kusch 2003). I compared apparent non-echolocation calls to those presented in papers such as those above and, as often as possible, used terminology matching that most frequently found in such literature to describe each variety.

#### III. Flight behavior

In my analysis, I combined fly/retreats and circles (henceforth referred to as FRCs) because it was sometimes difficult to see if a bat completed an entire circle, and both of these behaviors represented an alternative to passing directly through. I then calculated the ratio of FRC to pass for sites at which a mock gate was used, and percent passes and FRCs comprised of total behaviors for each site.

I calculated the mean percent of passes and of FRCs for unobstructed situations, real gates, and mock gates and compared them using univariate ANOVA with a Dunnett T3 post hoc test.

I classified gates based on age, dividing them into three grouping: current gate in place for 1) <4 years; 2) 4-6 years; and 3) >6 years. Using ANOVA, I compared percent

passes and FRC between gates in different age classes. I also compared activity level based on gate age.

I subjectively assigned each site to one of four categories based on bat activity level: 1) no bats/too few for data; 2) low with data; 3) moderate; and 4) high. I made these distinctions based on a combination of visually observing bats, numbers of behaviors observed and recorded, as well as overlap between and saturation of recorded calls. I compared percent passes and FRCs recorded in unobstructed passages and entrances with low, moderate, and high activity using one-way ANOVA. I also compared percent passes and FRCs among gated entrances and passages with moderate and high activity using independent samples t-tests with a two-tailed design. Since only two gated locations had low bat activity, I did not include this category in the analysis.

I divided gates into three size classes:  $<9.5m^2$ ,  $9.5-19m^2$ , and  $>19m^2$ . I compared percents passes and FRC using one-way ANOVA with Dunnett T3 post-hoc test. I divided unobstructed entrances and passages into two size classes:  $< or > 4.7m^2$ . I used an independent samples t-test to compare the percent passes and FRCs between the two classes. I also used an independent samples t-test to compare these percents between unobstructed passages and unobstructed entrances.

I also compared average and maximum space between vertical supports at gated sites. I did not make comparisons based on horizontal bar spacing because all but one site had horizontal bars spaced 14.6 to 15.2 cm apart (the ACCA standard). I made comparisons for percent pass and FRC between gates with maximum vertical support spacing <1.5 m, 1.5-2.15 m, and >2.15 m using one-way ANOVA. I also used ANOVA
to compare gates with <1.2m, 1.2-1.8 m, and >1.8 m average spacing between vertical supports.

Finally, I compared flight behavior observed at entrance gates (both mock and permanent) with behaviors observed at mock and permanent passage gates using independent samples t-tests. I also used independent t-tests to compare % pass and % FRC at entrance gates (mock and permanent) vs. unobstructed entrances.

### RESULTS

#### Swarming and Other Observations

Based on captures at 8 sites, I handled at least six species representing three genera (Table 3). I recorded echolocation calls that appear to represent seven species (MANOVA comparing all perceived groups:  $F_{24,573.34}$ =39.39; Wilks' Lambda = 0.033; p<0.0001; Table 4, Figure 8). Three to four genera appear to be represented. Based on call examination, each site had calls from at least two species, and at 23 sites at least three (Table 5). It is possible that some bats recorded at sites were merely passing by and were not actively swarming at the site.

I witnessed wide variation in number of bats swarming at any given site. At some sites known to have a few hibernating bats, I saw no bats swarming (or even nearby), but the outside temperature was <7°C. The swarming bats I observed frequently did not arrive or become active at the sites until well after dark. Bats often arrived at the caves or mines in groups, and in some cases activity began inside the cave or mine before I saw bats flying into or out of the entrances. Activity often continued inside the cave or mine

for a long time after it had ceased or nearly ceased at or outside the entrance. Bat activity often came in "spurts." Several minutes might pass with no bats present, then a group would arrive and be active in the area for several minutes, then the activity level might drop again. At the Renfrew Mine, where I spent multiple nights observing bats in a variety of locations, I saw bats land on the walls and ceiling, and some crawled into crevices and drill holes briefly before taking flight again.

In one instance, I placed a bat inside a bat bag in a helmet beside the vehicle and subsequently attempted to record another bat's calls inside the closed vehicle. When I opened the door again, I noticed that a free bat had joined the bagged bat and was crawling inside the helmet.

### Effects of Temperature & Weather

I found a strong relationship between thunderstorms and lower bat activity, and in some instances, low bat activity was associated with lower outside temperatures. At Renfrew Mine, where I collected data for approximately two weeks, I noticed a clear decrease in bat activity during rainstorms. On 2 August I observed only a single bat at the mine from 22:30 until 01:00, when there was moderate to heavy rain, thunder, and lightning. Similarly, bat activity was lower on 3 August, when thunder began in early evening and rain began around 23:00. On clear nights, bats were present until 03:00 or later, but this night, virtually no bats were present by 02:15, after a smaller number of bats than usual being present throughout the night. On 5 August, a thunderstorm began around 21:00 and lasted most of the night. Around 00:00, I heard bats inside the mine,

but not at the entrance or outside. On 6 August, rain was present from around 21:30 but was lighter and intermittent. Bats were present (particularly inside), but fewer at the entrance than usual, and even after the rain had stopped, I saw very few bats at the entrance as of 02:30.

When I visited Cornstarch Cave (TN) on 9 September and recorded a temperature of 16°C after nightfall, bats were plentiful and active. However, when I returned to this site on 1 October and recorded an outside temperature of 7°C at around the same time of night, I saw very few bats occasionally flying by or near the entrance; activity was very low. At Coach Cave (KY), many bats were active even when the outside temperature fell between 6 and 7°C.

### Flight Speeds

Flight speeds I recorded were highly variable, and at some sites, I did not obtain enough readings to assess the overall condition. I obtained enough speeds for analysis from 15 sites, mostly those with moderate levels of bat activity. When activity was low, bats had more room to fly and were not "channeled" toward the radar gun. When activity was high, bats changed direction too frequently for me to obtain many flight speeds.

At Renfrew Mine, where I obtained flight speed data for multiple nights and times, flight speeds recorded in an unobstructed passage one night differed significantly from speeds recorded in the same location on different dates ( $F_{2,205}=21.446 \text{ p}<0.001$ ), but speeds at this location did not differ by time within a single night ( $t_{59}=1.33$ , p=0.19;  $t_{34}=1.85$ , p=0.074). Speeds at the unobstructed entrance (ent. in;  $t_{29}=-0.58$ , p=0.57) and

mock angled entrance gate (mockA in;  $t_{53}$ =0.91, p=0.37) did not differ significantly by time within a single date, but speeds recorded at the real gate (gate out;  $t_{28.75}$ =3.51, p=0.001, equal variances not assumed; gate in;  $t_{24}$ =2.04, p=0.052) and mock perpendicular gate ( $t_{37}$ =3.67, p=0.001) differed significantly (or very nearly significantly) by time on 4 August, the night I had sufficient data for comparisons.

For comparison of ungated sites at which I erected a mock gate, I combined flight speed data in the presence of mock angled and mock perpendicular gates when both were present, after finding no significant difference between speeds recorded in the presence of the two varieties at each site. Of the 12 mock gate versus no gate comparisons ("in" and "out" were compared separately), flight speeds were significantly different in only three situations (two sites), and marginally significantly different at one additional site (Table 6). In all cases with significant difference, bats flew slower in the presence of a mock gate. For the two marginally significant outcomes, bats flew slower in the presence of a mock gate in one situation (passage), and faster in its presence in the second (entrance).

When comparing speeds within a single situation but between various sites, I found significant differences for 0 of 1 forest comparisons, 9 of 15 entrance in comparisons, 1 of 3 entrance out comparisons, 3 of 6 gate in comparisons, 7 of 15 gate out comparisons, 1 of 6 mock perpendicular gate out comparisons, and 5 of 10 passage comparisons (ANOVAs; based on p value of <0.05). Only one site had sufficient speed data for mock perpendicular gate in.

When I compared speeds by location type (all sites combined, but note intersite differences in preceding paragraph), "entrance in" differed significantly from all other

situations, including mock perpendicular in. Entrance out also differed from gate in; gate in also differed from passage, mock perpendicular in, and mock perpendicular out; and gate out differed from passage ( $F_{7, 1303}$ =27.31, overall p<0.0001; all p values ≤0.01 using Dunnett T3 post hoc test).

Overall, the average speed was highest when bats were exiting an unobstructed entrance ("entrance in") and lowest when bats left an entrance with a real gate in place ("gate in;" Table 7).

## Vocalizations

Based on the data presented in Lawrence and Simmons (1982) and assuming a large object, a call frequency of ~40 kHz, and a sound pressure level of 110 dB (Griffin 1986), the bats in the study could potentially detect a gate's presence via echolocation at a range of ~27 m. I found no notable and distinctive differences in calls recorded in the presence and absence of real or mock gates. Non-search phase calls noted included landing buzzes, feeding buzzes, and a drop in frequency after a call has flattened out ("honks"). I also found some sequences of echolocation calls in multiples (pairs, etc.).

I also recorded a variety of non-echolocation calls matching previously described social calls from multiple sites, including those with and without gates and sites with various levels of bat activity (from very low to very high; Figure 9 & Appendix). I recorded what I will term squawks, barks, trills, double note calls, multinote calls (including one at a very high frequency), one sine wave call and other chirp or whistle type calls, including backward slanted (ascending frequency) calls (Appendix). Overall, I

found a total of approximately ten types of social calls, not including honks, which can be classified into the following general groups: 1) barks and squawks; 2) shrieks; 3) chirps (including combinations/songs); and 4) trills/rapid calls (Appendix).

I defined barks and squawks as calls whose primary part was at very low frequencies, often audible to the unaided human ear, and matching the previously published descriptions mentioned above. Calls in this category sound harsh. Shrieks are also of relatively low frequency, but they have longer duration and sound "thinner" (more shrill, less harsh) than barks and squawks. I defined chirps as any non-echolocation call that was bent or wavy and of higher frequency and thinner quality than categories 1 or 2. I included double note, multinote, or combination ("song") calls in this category, and such calls sometimes resembled "squiggles." The final category encompassed sets of rapidly repeating, straight up and down calls in the form of trills (sometimes resembling buzzes; Appendix). Some of these sets exhibited a drop in frequency while others did not.

I found no clear relationship between presence of a gate and a change in number of social calls, though I did not measure or explore this exhaustively, nor did I find any type of call solely in the presence or solely in the absence of a gate.

# Flight Behavior

At some sites with mock gate in place bats' reaction was low or almost nonexistent. At other sites, bats seem very perturbed by the presence of a gate, and this reaction did not lessen noticeably after the gate had been place for half an hour or more. I found an increase in fly/retreat or circles (FRCs) and a decrease in passes when a gate was present, and activity level, gate size, and location of a gate at a hill bottom all corresponded to a change in behavior, while spacing of vertical supports and passage vs. entrance gate position were not correlated with significant changes in flight behavior. For all sites with a mock gate, the ratio of FRC (fly/retreat or circle behavior) to pass was higher with the mock gate in place, both before the mock gate was installed or after it had been removed (Figure 10). The percent FRC and pass comprised of total behaviors differed significantly between locations with no gate, a real gate, and a mock gate (Tables 8 and 9).

When I compared flight behaviors at unobstructed entrances (n=17) to behaviors with mock or permanent entrance gates (n=29) present, bats displayed a significantly lower proportion of passes in a gate's presence ( $t_{44}$ =-4.23, p<0.00) and a significantly higher proportion of FRC ( $t_{44}$ =4.04, p<0.00) when a gate was present (Table 10). When I compared behaviors in unobstructed passages (n= 6) to those observed in passages with a permanent or mock gate present (n=5), I found the proportion of passes was marginally significantly lower in a gate's presence ( $t_{5.69}$ =-2.43, p=0.054) while the proportion of FRCs was not significantly higher when a gate was in place ( $t_{5.35}$ =2.29, p=0.067; equal variances not assumed for either; Table 10).

While the percentage of FRC ( $F_{2,19}=3.120$ ; p=0.067) did not differ significantly between gates of different ages, bats passed significantly more frequently at gates newer than four years than at gates older than six years (data transformed;  $F_{2,19}=4.76$ , overall

p=0.02; Dunnett T3 post hoc test p=0.025). I observed differences in activity levels apparently reflecting the age of gates, with higher activity found at older gates (Table 11).

Among unobstructed entrances and passages, I found no significant difference in percent passes (data transformed;  $F_{2,20}=1.397$ ; p=0.27) or FRC ( $F_{2,20}=0.923$ ; p=0.413) between sites according to bat activity level (low, moderate, and high). Four of the five values for a high level of activity, however, were obtained at one site (two locations for two nights each). At gated sites, I compared only moderate and high activity levels because only two gated sites exhibited low activity. Among gated sites, bats exhibited a significantly higher percentage of passes at gates with moderate activity than at gates with high activity ( $t_{12.82}=4.663$ ; p<0.0001; equal variances not assumed). Likewise, the percent of FRC was significantly higher at sites with high activity than at sites with moderate activity ( $t_{18}=-6.446$ ; p<0.0001).

Percent passes did not differ significantly between the three gate size groups (data transformed;  $F_{2,19}=1.766$ ; p=0.198) but the percent FRC was significantly lower for large gates (>19 m<sup>2</sup>) compared with small gates (<9.5 m<sup>2</sup>) ( $F_{2,19}=5.936$ ; overall p=0.01; p=0.021). However, for unobstructed passages and entrances, there was no significant difference in % FRC ( $t_{21}$ =-0.25, p=0.81) or % passes (data transformed;  $t_{21}$ =0.094, p=0.926) between gates classified as small (n=12) and large (n=11).

While I observed behavioral differences based on overall gate size, I found no significant difference in percent pass (data transformed;  $F_{2,19}=0.209$ ; p=0.813) or FRC ( $F_{2,19}=0.810$ ; p=0.460) based on maximum spacing between vertical supports. Likewise there was no significant difference in either behavior corresponding to average spacing of

vertical supports ( $F_{2,18}$ =0.388, p=0.684 for pass (data transformed);  $F_{2,18}$ =0.001, p=0.999 for FRC). At Aeolus Cave, which had vertical supports more closely spaced than any other site (0.6m; Figure 11), bats displayed a relatively high collision rate of 6% and flew/retreated or circled more frequently than they passed, but activity level was unusually high.

I found no significant differences in bat flight behavior ( $t_{21}$ =-1.12, p=0.28 for % FRC;  $t_{21}$ =1.09, p=0.29 for % pass (data transformed)) between unobstructed entrances (n=17) and unobstructed passages (n=6). Likewise, I found no significant difference in behavior between entrance permanent and mock gates (n=29) compared with passage permanent and mock gates (n=5) ( $t_{32}$ =-1.06, p=0.297 for % pass;  $t_{32}$ =1.52, p=0.139 for % FRC), although the sample sizes were highly uneven (Table 10).

At Craigmont Mine, where I recorded data at both unobstructed and (mock) gated entrances and passages, bats passed at a lower proportion and exhibited fly/retreat or circle behavior at a higher proportion in the passage than at the entrance (Figure 12). At Preble Co. Mine, where I recorded data at both passage and entrance permanent gates, as well as an unobstructed passage and entrance, I found no clear trend for behavior between passage vs. entrance locations. At New Mammoth Cave, bats passed less frequently (45% vs. 52%) and flew/retreated or circled more frequently (48% vs. 38%) at the inner gate than the outer one, but bats at the inner gate were in a cage-like situation, with gate on two sides and cave wall on two sides.

I did not witness any collisions with walls, other bats, people, or anything else in the absence of a gate. At 54.5% (12 of 22) of real gates and 50% (7 of 14) of mock gates,

I observed at least one collision. I saw the highest incidence of collisions among bats flying at Coach Cave (gated) where they accounted for 15% of total behaviors (n= 184). The breakdown of behaviors at Coach Cave is compared with those at Wolf River Cave, where bats exhibited a low proportion of FRC, a high proportion of passes, and no collisions (Figure 13). The average percent collisions at real gates and mock gates was 2%.

I found no significant difference in % passes (data transformed;  $t_{20} = -0.519$ ; p = 0.609) or % FRC ( $t_{20}=0.28$ ; p=0.78) between sites with a single entrance (n=6) compared with multiple entrances (n=16).

The proportion of bat passes was marginally significantly lower at gates located at the bottoms of hills (n=6) than at those located on flat ground (n=15) ( $t_{19}$ =2.04; p=0.056). I found no significant difference in % FRC based on a gate's location relative to a hill ( $t_{19}$ =-1.6; p=0.13). A summary of factors related to changes in bat behavior is seen in Table 12.

### DISCUSSION

Calls I recorded correspond with previously described calls of *Myotis lucifugus*, *M. leibii*, *M. sodalis*, *M. septentrionalis*, *M. grisescens*, *Eptesicus fuscus*, *Nyctersis humeralis* (possibly), *Pipistrellus subflavus* (possibly), and *Corynorhinus rafinesquii* (Table 4, Figure 8). MANOVA results indicate the presence of about seven species, but I believe I recorded at least eight (and possibly nine) species, as a great deal of intraspecific call variation/overlap between species can exist (even calls within one short sequence from a single bat were sometimes of very different frequency, at times enough that some calls overlapped with those of other species) depending on flight situation (e.g., Parsons and Jones 2000), presence of conspecifics (e.g., Obrist 1995), individual variation (e.g. Brigham et al. 1989, Betts 1998) and other factors (e.g., Obrist 1995, Barclay 1999, Murray et al. 2001). Distinguishing species of Myotis is known to be especially difficult (Parsons and Jones 2000), and species with similar call parameters, such as *M. lucifugus*, *M. leibii*, and *P. subflavus* (Fenton and Bell 1981, MacDonald et al. 1994, Fenton 1995) may have been lumped together by the statistical analysis.

I recorded most calls in or facing into caves and mines and large numbers of bats were often present, so excessive echo and/or saturation obscured call clarity at many sites; thus, I selected calls from "clean" files only when measuring parameters to estimate species number, which may have resulted in the omission of some species.

A commonly reported observation is that bats land on (MacGregor 1993) or are slowed by gates, then fall prey to feral cats, raccoons, snakes, or other sly predators (e.g., Tuttle 1977, White and Seginak 1987). I found no consistent significant lowering of flight speeds based on gate presence (Tables 6 and 7), as is sometimes claimed in literature (e.g., Tuttle 1977). While speeds recorded at a gate were sometimes lower, overall the bats I studied appeared to use directional changes (such as fly-retreat and circling behavior), rather than speed reduction, to avoid collision with an obstacle. Further, I rarely witnessed bats landing on gates, which may be due to improved gate designs with larger flight spaces. Additionally, bats present during swarming are typically not young just beginning to fly (Hall and Brenner 1968, Fenton 1969), and newly volant

bats may be more likely to land and be eaten. I did not observe a predator taking or attempting to take bats at any site (or even present in the vicinity), but we were not quiet or unobtrusive, so our presence is a likely cause.

I recorded both social calls and honks, believed to alert another bat of an impending collision (Suthers 1965) at many sites, including those with low activity and where only one bat was within range of the bat detector microphone. Similarly, many of the "songs" (complex cheeps/double note call combinations) were recorded at Hubbard's Cave, where bat activity was low, indicating social calls are an integral part of swarming, or perhaps merely the presence of multiple bats, even if numbers are low.

The ratio of FRC to pass was higher in every incidence after a mock gate was in place, probably partially reflecting the bats' surprise at the sudden appearance of an obstacle. The behavioral gradation I saw, wherein bats' flight behaviors were significantly different between no gate, a permanent gate, and a mock gate indicates that while bats may adjust somewhat to the novelty of a gate, they continue to be affected by the gate, despite passage of time. Even gates in place for ten or more years (e.g., Renfrew Mine, Aeolus Cave) still restrict the area through which bats can fly and the flight behavior I witnessed supports this.

In addition to newness, size may be a reason bats circled more at mock gates than permanent gates (Tables 8 and 9), since permanent gates in this study were almost always larger than mock gates. However, size alone does not explain bats' evasive behavior, since I found no correlation between size (of entrance or passage) and circling in the total absence of gates.

Bats' apparently more negative reaction to smaller gates is probably the result of restricted access or a traffic jam effect. Since I found no significant differences in flight behavior based on size at unobstructed passages and entrances, the presence of an obstacle may be a key component in the bats' problems with a smaller area. The lack of significant differences in percent pass or FRC based on spacing of vertical supports, may be because vertical supports at every gate were at least (0.6m) apart, the minimum recommended by the American Cave Conservation Association (ACCA— 1.2-3m is considered ideal; Tuttle and Taylor 1998).

During swarming or evening emergence while females and young are in maternity colonies, dealing with large numbers of other bats most likely already creates a challenge for bats, and the presence of an obstacle may further complicate their flight, both physically and acoustically. Flying in the presence of a gate is most likely similar to flying in clutter (e.g., within a forest), and indicates bats must pay more careful attention to their surroundings or risk collision. Bats must deal with the twofold challenge of receiving "extra" echo from the gate (distraction) and fitting between the bars while avoiding collision with the gate, other bats, and cave walls and ceilings (actual physical risk).

I witnessed no collision with anything in the absence of a gate, and while many of the gated sites higher had bat activity than ungated locations, activity alone does not explain the collisions observed. At some of the sites where I installed mock gates, bat numbers were quite low (e.g., Mullins Spring Cave) yet we still observed collisions, and

at sites such as Renfrew Mine, Craigmont Mine, and Jamesville Quarry Cave, very large numbers of bats were present, yet we observed no collisions in the absence of a gate.

Variation in bats' reaction to mock gates at different sites could represent species variation, or factors such as number of bats present, entrance size, or whether bats present had previously encountered a gate. Following removal of the mock gate, bat behavior returned to pre-gate levels, indicating that the continued presence of the obstacle (gate) is what elicits behavioral changes in bats, and that the gate's novelty alone does not appear to have a lasting effect on their flight behavior.

I found no evidence that bats respond better to dark zone (passage) gates than entrance gates (Table 10), as some have claimed (e.g., B. Howard, pers. comm.), although reduced risk of predation (rather than preferable bat reaction) is usually the reason given for passage gates (e.g., Tuttle 1977, Kennedy 2003). While the difference was not statistically significant (and sample sizes were highly uneven in some comparisons), bats engaged in more FRCs and fewer passes proportionally in passages (with or without a gate) than at entrances (with or without a gate; Table 10), indicating a slight preference for entrances/entrance gates over passages/passage gates. A likely cause is that in an enclosed space, bats must deal with walls on two sides, in addition to acoustical complications due to increased opportunities for echo. Adding an obstacle (e.g., gate) to this situation creates a "third wall" for bats to negotiate physically and acoustically. The situation may differ when bats simply emerge and return (while in maternity colonies) rather than swarm.

While I sometimes saw bats fall to the ground following a collision, I never saw a bat stay on the ground for longer than a minute before flying away, apparently without serious injury. In the absence of humans to frighten off predators, such bats may be eaten, but based on what I witnessed, being consumed by predators or suffering serious injury or death resulting directly from collisions are not the primary threats bats face from gates, with the possible exception of newly volant young.

Instead, bats appear to suffer from gates in more indirect ways, like energy expenditure, lost time, and exclusion from valuable roosting sites. Directional changes, circling, and recovering from collisions all result in expenditure of energy and time that could be used seeking a mate, finding an ideal hibernation spot, or seeking food. Excessive loss of energy could be especially detrimental just before bats enter hibernation or when mothers are pregnant or feeding young. Loss of time could be especially harmful for swarming bats attempt to visit multiple potential hibernation sites in one night and for mother bats forced to leave non-volant pups for longer than usual.

While gates appear to cost bats energy and time, the most significant danger they pose is probably roost exclusion. I did not track tagged bats, but I could sometimes track the actions of a single bat for several minutes, and while some bats circled around before passing through a gate (or passed directly through), others changed direction as they neared the gate and did not appear to return. Numerous reports, beginning with Tuttle 1977, describe bats abandoning their newly gated roosts. A gradual return of bats to gated roosts has been observed in some instances (e.g., D. Dalton, pers. comm.), supporting the idea that bats may habituate somewhat to presence of a gate. The

relationship I found between gate age and bat activity level (Table 11) also supports this idea.

Over the past four decades, bat gating has advanced greatly with regard to abiotic factors (air flow, resistance to humans, etc.), and these advances should be built upon by viewing gate design from a flying bat's perspective. This should cover all Chiropteran species occurring in a region, not only one or two listed as Endangered, since many roosts are used by multiple species at least some time during the year. Use of night vision or Infrared viewing and videoing devices may be useful for future studies regarding flight behavior at gates, and larger mock gates could isolate the variables of gate size and newness.

Since bats seem to react more poorly to newer gates, I recommend assembling gates gradually over a period of several months, when possible, to give bats a chance to adapt, hopefully making them less inclined to flee a newly gated roost. Based upon my findings, a bat friendly gate should: 1.) be placed at as large an area as possible, 2.) always have a bat chute/open top/further spaced horizontal bars higher up when possible, 3.) be placed at an entrance, rather than in a passage, when possible (unless predation is a known problem), and 4.) be placed on flat ground rather than an incline.

# CONCLUSIONS

 Bats' flight behavior was significantly different at mock gates, permanent gates, and unobstructed passages/entrances. While bats circled and retreated most at mock (=new) gates, even at sites where gates had been

place for years, bats reacted significantly differently than they did to unobstructed locations.

- In every case, the ratio of fly/retreat or circle to pass increased when a mock gate was erected.
- I found no consistent or significant difference in bats' flight behavior in passages as opposed to at entrances, either in the presence of absence of a mock or permanent gate.
- Gate size appears to affect flight behavior, probably because of a bottleneck/traffic jam effect.
- Sizes of unobstructed entrances or passages with no gate do not appear to affect flight behavior.
- Spacing of vertical supports of gates in this study does not appear to influence flight, probably because they are all at least two feet (0.6 m) apart, the recommended minimum (ACCA).
- When there was higher bat activity, bats exhibited a higher rate of circling and fly/retreating than when fewer bats were active.
- 8. At some sites where a mock gate was used, bats circled with much greater frequency, while bats at other sites changed their behavior only minimally.
- Higher activity levels were found at older gates, indicating bats may acclimate to a gate's presence somewhat and return in larger numbers year after year.

- 10. I found no consistent correlation between flight speed and presence or absence of a mock gate at previously ungated sites.
- There does not appear to be an overall relationship between types of echolocation or social calls emitted in the presence versus absence of a gate.
- 12. Bats emit a variety of non-echolocation calls during swarming.
- Each swarming site in this study had a minimum of two species present;
   the majority had at least three.

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	State/	County/	<u>#</u>	Gated?	<u>Data</u>	<u># Bats</u>
Cave/Mine	Province	Area	Ents.	<u>(#)</u>	Collected	<u>Hibernating</u>
		Rock				
Mullins Spring		Castle				
Cave	KY	Co.	2+	No	Full	
Jesse James		Edmon-				
Cave	KY	son Co.	2	Yes	Full	
		Carter				
		Caves				
		SRP				28,000
		(Carter				Myotis
Bat Cave	KY	Co.)	2	Yes (2)	Full	sodalis <sup>1</sup>
		Rock				
Goochland		Castle				
Cave	KY	Co.	1+	Yes (1)	Full	
		Carter				
		Caves				
		SRP				
		(Carter	•			~2,000-
Saltpetre Cave	KY	<u>Co.)</u>	3	Yes (2)	Full	5,000 5
0 1 0	1737	Edmon-	2	37	E 11	80,000 <i>M</i> .
Coach Cave	KY	son Co.	~3	Yes	Full	grisescens°
D' C	1737	Edmon-	1 .	37	F 11	3,6/0 M.
Dixon Cave	KY	son Co.	1+	Yes	Full	sodalis"
Lana Caua	WW	Edmon-	1 .	Var	E11	493 M.
Long Cave	KI	Son Co.	1+	res	Full	sodalls
Murder Branch	VV	Co	1  or  2	No	En11	
Iamoguillo	K I	Cu.	1 01 2	INU	1'ull	
Quarry	NV	daga Co	3+	$N_{0}(0)$	Full	4 700 <sup>a</sup>
Quality	111	Warren	51	110 (0)	Tull	4,700
Graphite	NV	Co	11	$Ves(\sim 10)$	Full	180.000 <sup>a</sup>
Barton Hill	111	Essex	11	105 (10)	1 un	100,000
Mine	NY	Co	4	No(0)	Full	50 000 <sup>a</sup>
	111	00.	•	110 (0)	1 411	several
Walter						thousand
Williams		Ulster				(8,100 <i>M</i> .
Preserve Mine	NY	Co.	5	No (0)	Full	sodalis) <sup>a</sup>
Preble Co.		Preble				/
Mine	OH	Co.	7	Yes (9)	Full	36,000 °
Elm Rock Rd.		Athens		× /		
Mine	ОН	Co.	1	No	Full	
Goose Run		Athens				
Mine	OH	Со	1	No	Full	
		Perry	Many			
Lost Run Mine	OH	Co.	(>5)	No	Full	
Ironton Mine		Law-				
(aka Woody		rence				
Mine)	OH	Co.	2+	Yes (2)	Full	

Table 1. General information about cave and mine sites used in this study.

		Renfrew				10,000+
Renfrew Mine	ON	Co.	2+	Yes (1)	Full	(1970) <sup>h</sup>
Craigmont		Renfrew				10,000+
Mine	ON	Co.	1+	No	Full	(1970) <sup>h</sup>
Hubbard's		Warren				
Cave	TN	Co.	3	Yes (3)	Full	
Wolf River		Fentress				2,415 <i>M</i> .
Cave	TN	Co.	2	Yes (1)	Full	sodalis <sup>e</sup>
Cornstarch		Fentress				
Cave	TN	Co.	1+	No (0)	Full	
New						
Mammoth		Camp-				310 <i>M</i> .
Cave	TN	bell Co.	1	Yes (2)	Full	sodalis <sup>d</sup>
		Benning				
Aeolus Cave	VT	-ton Co.	1	Yes (1)	Full	50,000+ <sup>a</sup>
Glen Park			40 (in			
Caves (K-		Jeffer-	syste			
Cluster Cave)	NY	son Co.	m)	No (0)	Partial	3,000 <sup>a</sup>
		Warren				1
Little Bat Cave	TN	Co.	1+	Yes (1)	Partial	~12 <sup>a</sup>
Snake Hollow		Hocking				
Mines	OH	Co.	2+	No (0)	Partial	
		Rock				
		Castle				
Climax Cave	KY	Co.	2+	No (0)	None	
		Carter				
		Caves				
		SRP				
		(Carter				~2,000-
Laurel Cave	KY	<u>Co.</u> )	3	No (0)	None	5,000 5
Duds & Haile		Putnam	6	<b>N7</b> ( 11)	N	
Cave	IN	<u>Co.</u>	~6	Yes (all)	None	
Bible Spring		Marion				
Cave	IN	Co.	I	No (0)	None	
Catacomb		Marion				
Cave	TN	Co.	4+	No (0)	None	

\*Sources: <sup>a</sup>A. Hicks, pers. comm., <sup>b</sup>Currie 2002, <sup>c</sup>D. Swanson, pers. comm., <sup>d</sup>H. Garland, pers. comm., <sup>e</sup>K. Bobo, pers. comm., <sup>f</sup>KSNPC 2003, <sup>g</sup>Chris Chandler, pers. comm., <sup>h</sup>Fenton 1970. Note: Under data collected: Full = data about flight speeds, vocalizations, and flight behavior collected;

Partial = data about one or two parameters; None = site was visited but not enough bats were present for data collection.

Table 2. Size, age, position, and general information about gates at sites used in this study.

		Gate		<u>Maximum</u>	Average	Year	Notes/Reason
	Gate	size	Gate	vertical bar	vertical bar	Current	for Gate
Site & Gate	location	<u>(m)</u>	type	spacing (cm)	spacing (cm)	installed	<b>Installation</b>
Renfrew	Р	~2.5h x	Angle	~165	~165	1995	Not first gate
Mine		2.2 w	iron				installed
Graphite	Е	1.8 h x	Angle	229	229	1997	Unstable
Mine, A		4.3 w	iron				rock; entrance
							area
							crumbling
Graphite	Е	1.8h x	Angle	188	170	1997	
Mine, B		4.2w	iron				
Graphite	Е	0.6 h x	Angle	91	91	1997	
Mine, C		3.4 w	iron				
Graphite	Е	0.9 h x	Angle	76	76	1997	
Mine, D		1.5 w	iron				
Aeolus	Е	2.2 h x	Flat	61	61	Mid-	Protection of
Cave		5.1w	metal			1980s	bats
			bars				
			in				
			side-				
			ways				
			V-				
			shape				
Preble Co.	Р	2.8 h x	Angle	99	81	1997	
Mine, inner		4.7w	iron				
AI							
Preble Co.	Р	3h x	L-	178	84	1997	
Mine, inner		5.2w	shape				
L-gate			(5.1 x				
			7.6				
			cm				
<b>D</b> 11 G			bars)	100	0.1	100-	
Preble Co.	E	4 h x	Angle	109	91	1997	
Mine, outer		5.4 W	iron				
AI Dualata Ca	Г	2.7.1	т	102	102	1007	
Preble Co.	E	3./hx	L-	183	183	1997	
Mine, outer		5.8 W	shape				
L-X gate			(5.1 X				
			/.0				
			CIII hora)				
			Ual S)				
			vitii				
			hare				
			across				
Goochland	р	4 2h x	Angle	312	242	2002	Bat protection
Cave	1	10.5w	iron	514	<i>∠</i> -т∠	2002	Dut protection
Juit		10.0 W	11.011				

Salt Cav gate	petre e, Main	Outside E	2.21	Angle iron	145	105	2003	Bat protection; part of building
			2.3n x 5.4w					entrance
Salt Cav "win	petre e, ndow''	Outside E	1.1h x 1.8 w	Angle iron	165	165	2003	Bat protection; part of building structure over entrance
Bat	Cave,	Е	5.8h x 8.9w	Angle iron	287	176	2000	Bat protection
Bat	Cave, B	Е	2.5h x 8.3w	Angle	297	238	1997	Bat protection
Iron Min	ton e	Е	1.8 h x 6.2w	Angle iron	224	142	2001	
Jess Cav	e James e	Е	2.6h x 4w	Angle iron	206	130	1993	
Lon	g Cave	Е	1.8 h x 12.3w	Angle iron	305	300	1994	
Dix	on Cave	Е	4.5h x 13.4w	Angle iron	295	266	1995	
Coa	ch Cave	Е	4h x 4.3w	Angle iron	274	274	1993	
Hub Cav Nor	bard's e, th gate	E	~5.5h x 11+w	Angle iron with open top	378	308	1999	Bat protection
Hub Cav Sou	bard's e, th gate	E	12h x 9.2w	Angle iron with bat chute	109	107	1980s	Bat protection
Hub Cav gate	bard's e, West	E	1.9w (front) x 1.9h	Angle iron	201	147	1998	Bat protection; cage-like gate (left side: 0.54 m, right side: 1 m)
Littl Cav	le Bat e	Е	1.4h x 1.5w	Angle iron cage	147	147	2001	Bat protection; cage-like gate
Wol Cav	f River e	Е	2.5h x 7.7w	Angle iron	295	267	2000	Bat protection

New Mammoth Cave, inner gate	2.2 m f. E.	2.9h x 2.6w	Angle iron	122	99	1989	Bat protection; heavy vandalism; 2.2 m from other gate
New Mammoth Cave, outer gate	E	3.1h x 1.8 w	Angle iron	152	152	2001	Bat protection; heavy vandalism; installed after continued breaching of 1 <sup>st</sup> gate

Notes: E = entrance; P = passage; AI = angle iron. New Mammoth Cave's inner gate had horizontal bars spaced 11.4 cm apart. All others were 14-15.2 cm apart.

Table 3.	Species, nun	nbers, ages	, and set	tes of bat	s captured	l at sites.	Bats were	captured
only from	n the eight sit	tes below.						

Site	Location	Date	Species captured (sex/age*)
Jamesville			Myotis septentrionalis (M/A), M. sp. (4M/A;
Quarry Cave	NY	8/20/03	3F/A)
K-Cluster			M. septentrionalis (F/A), M. lucifugus (1
Cave	NY	8/22/03	M/A; 1 F/A)
			<i>M. septentrionalis</i> (M/A), <i>M. lucifugus</i> (F/A),
Graphite Mine	NY	8/25/03	<i>M. sp.</i> (2 F/A, 1 M/A)
Mullins			M. septentrionalis (M/A), M. leibii (F/A), M.
Spring Cave	KY	9/4/03	<i>sp.</i> (M/A)
Jesse James	KY		
Cave		9/26/03	M. grisescens (3 M/A)
	KY		Eptesicus fuscus (M/A), Pipistrellus
Long(s) Cave		9/27/03	subflavus (2 M/A, 1 F/A)
Coach Cave	KY	9/29/03	M. grisescens (3 M/A, 1 F/A)
Renfrew Mine	ON	8/3&7/03	E. fuscus (F), M. sp. (F)

\*M=male; F=female; A=adult

<u> </u>	DUR	FME	LF	HF	Species	Label in
Site	<u>(ms)</u>	<u>(kHz)</u>	<u>(kHz)</u>	<u>(kHz)</u>	Designation	<u>Figure</u>
Hubbard's	4.4	45.3	43.1	50.6	А	1
Hubbard's	6.2	46.6	43.4	55.8	А	2
Barton Hill	3.6	48.8	41.4	57.9	А	3
Barton Hill	3.7	46	43	59.2	А	4
Goose Run	3.2	50.8	45.8	58.5	В	5
Renfrew	2	50	45.4	62.2	В	6
Murder Branch	2.54	51.6	46.5	63.3	В	7
Murder Branch	1.95	51.2	42.9	63.9	В	8
Murder Branch	2.1	51.1	46.6	70	В	9
Cornstarch	2	49.8	44.7	56.8	В	10
Elm Rock Rd.	1.65	60.7	53.8	70.6	С	11
K-Cluster	1.9	59.9	51.9	66.7	С	12
Jamesville Quarry	2.7	60.1	51.7	67.5	С	13
Murder Branch	1.86	84.3	69.9	96.8	С	14
K-Cluster	1.5	67.3	56.2	83.9	С	15
Murder Branch	1.79	75.1	58.9	89.2	С	16
Little Bat Sample	2.95	35.9	31.8	42.1	D	17
K-Cluster	6.5	31.9	30	43.7	E	18
K-Cluster	7	29.8	27.4	35.3	E	19
Little Bat	3.1	53.8	49.8	58.7	F	20
Hubbard's	2.7	54.8	49.8	58.8	F	21
Wolf River	2.2	54.2	49.4	63.4	F	22
Little Bat	10.8	21.2	18.3	23.5	G	23

Table 4. Sample call sequences: averages from sequences of eight calls per bat (corresponds to Figure 8). Species designation is based on MANOVA results.

Table 5. Approximate number of species apparent based on vocalizations recorded, and species otherwise known from sites, and species previously known to each site.

Site	<u>State</u>	<u>Approx. #</u>	<u>Species</u>	Species previously known (source)
		Species	Captured	
		Recorded	-	
Craigmont	ON	[No good call	N/A	Myotis lucifugus, M. septentrionalis,
		files]		Eptesicus fuscus (Hitchcock 1965),
		_		Pipistrellus subflavus, (, Myotis leibii
				(B. Fenton, pers. comm.)
Goose	OH	2-3	N/A	M. lucifugus, M. septentrionalis, and
Run				P. subflavus, E. fuscus (L. Andrews,
				pers. comm.)
Aeolus	VT	2-3+	N/A	M. lucifugus, M. sodalis, P.
				subflavus (VCA 2003), M.
				septentrionalis (S. Parren, pers.
				comm.)
Murder	KY	2-3+	N/A	Corynorhinus towsendii, C.
Branch				rafinesquii, M. lucifugus, E. fuscus,
				P. subflavus (T. Wethington, pers.
				comm.)

Coach	KY	2-3+	Myotis grisescens	<i>M. grisescens, M. sodalis, M. lucifugus, E. fuscus, P. subflavus</i> (T. Wethington, pers. comm.)
Long(s)	KY	2-3+	Eptesicus fuscus, Pipistrellus subflavus	<i>M. sodalis, M. grisescens</i> (MCNP 2003), <i>M. lucifugus, E. fuscus, P. subflavus</i> (S. Thomas, pers. comm.)
Jamesville Quarry	NY	3+	M. septentrionalis, M. sp.	<i>M. sodalis</i> (Currie 2002), <i>M. lucifugus</i> , <i>M. septentrionalis</i> (A. Hicks, pers. comm.)
Mullins Spring 9/25	KY	3+	N/A	<i>M. lucifugus, P. subflavus,</i> <i>Lasionycteris noctivagans</i> (as of 1990; T. Wethington, pers. comm.)
Cornstarch	TN	3+	N/A	<i>M. sodalis, M. lucifugus, P. subflavus</i> (H. Garland, pers. comm.)
Lost Run	OH	3+	N/A	No data (L. Andrews, pers. comm.)
New Mammoth	TN	3+	N/A	<i>M. sodalis</i> (Currie 2002), <i>M. lucifugus</i> , <i>M. leibii</i> , <i>P. subflavus</i> , <i>E. fuscus</i> , <i>L. noctivagans</i> (at least in past; H. Garland, pers. comm.)
Barton Hill 8/24	NY	3+	N/A	<i>M. sodalis</i> (Currie 2002), <i>M. lucifugus</i> (A. Hicks, pers. comm.)
Preble Co.	ОН	3+	N/A	<i>M. sodalis</i> (Currie 2002), <i>M. lucifugus</i> , <i>M. septentrionalis</i> , <i>E. fuscus</i> , <i>P. subflavus</i> (D. Swanson, pers. comm.)
Renfrew	ON	3+	E. fuscus, M. sp.	M. lucifugus, M. septentrionalis, M. leibii, , E. fuscus, P. subflavus, L. borealis (Fenton 1970, B. Fenton, pers. comm.)
Goochland	KY	3+	N/A	C. townsendii, C. rafinesquii, M. lucifugus, M. sodalis, M. septentrionalis, E. fuscus, P. subflavus, Lasionycteris noctivagans (T. Wethington, pers. comm.)
Jesse James	KY	3+	M. grisescens	<i>M. grisescens, M. sodalis</i> (T. Wethington, pers. comm.)
Bat	KY	3+	N/A	<i>M. sodalis, M. lucifugus, E. fuscus,</i> <i>P. subflavus</i> (C. Ainsley, pers. comm.), <i>M. septentrionalis</i> (T. Wethington, pers. comm.)
Saltpetre	KY	3+	N/A	<i>M. sodalis, M. lucifugus, E. fuscus,</i> <i>P. subflavus</i> (C. Ainsley, pers. comm.), <i>M. septentrionalis</i> (T. Wethington, pers. comm.)
Graphite	NY	3+	M. septentrionalis, M. lucifugus, M. sp.	M. sodalis (A. Hicks, pers. comm.)
Walter Williams Preserve	NY	3+	N/A	M. sodalis (Currie 2002)

Elmrock Rd.	ОН	3+	N/A	<i>M. septentrionalis, P. subflavus, M. lucifugus</i> (K. Schultes, pers. comm. 2003)
Ironton	ОН	3+	N/A	<i>M. sodalis, M. septentrionalis, M. lucifugus,</i> <i>P. subflavus, E. fuscus</i> (L. Andrews. pers. comm.)
Little Bat	TN	3+	N/A	<i>Corynorhinus rafinesquii, P. subflavus, M. lucifugus (?)</i> (H. Garland, pers. comm.)
Wolf River	TN	3+	N/A	M. grisescens, M. sodalis (Currie 2001), M. lucifugus, E. fuscus, C. rafinesquii, P. subflavus (H. Garland, pers. comm.)
Mullins Spring 9/04	KY	3-4+	M. septentrionalis, M. leibii, M. sp.	<i>M. lucifugus, P. subflavus,</i> <i>Lasionycteris noctivagans</i> (as of 1990; T. Wethington, pers. comm.)
Barton Hill 8/23	NY	3-4+	N/A	<i>M. sodalis</i> (Currie 2002), M. lucifugus (A. Hicks, pers. comm.)
Dixon	KY	3-4+	N/A	M. sodalis, M. grisescens (MCNP 2003), M. lucifugus, E. fuscus, P. subflavus (S. Thomas, pers. comm.)
K-Cluster (Glen Parks)	NY	3-4+	M. septentrionalis, M. lucifugus	<i>M. sodalis</i> (Currie 2002), <i>M. lucifugus</i> , <i>E. fuscus</i> , <i>P. subflavus</i> (A. Hicks, pers. comm.)
Hubbard's	TN	3-4+	N/A	M. grisescens, M. lucifugus, M. sodalis (in past, at least), M. leibii, E. fuscus, P. subflavus

\* = Possibly an incomplete listing of previously known species.
 Note: For species previously reported, not all sites were surveyed during the same time of year. For instance, some species information reflects hibernating bats only.
	<u>X ± SD (m/s;</u>	<u>n (mock,</u>			
Site/locations	mock, none)	none)	<u>df</u>	<u>t</u>	<u>p</u>
Craigmont/mock ent out vs. ent out	4.47±0.47,	12, 17	27	-1.95	0.062
	<i>4.12±0.48</i>				
Craigmont/mock passage vs. passage	3.56±0.53,	16, 34	48	1.92	0.060
	3.92±0.66				
Cornstarch/mock in vs. ent. in	3.63±0.13,	4, 17	19	3.24	0.004
	4.31±0.41				
Cornstarch/mock out vs. ent. out	4.41±0.57,	11, 4	13	-0.35	0.736
	4.28±0.91				
Jamesville/mock in vs. ent. in	3.69±0.55,	7, 4	9	0.28	0.784
	3.80±0.81				
Jamesville/mock out vs. ent. out	4.56±0.77,	7, 7	12	-0.74	0.476
	4.31±0.42				
Mullins Sprg2./mock out vs. ent.	4.34±0.52,	33, 25	56	2.28	0.027
out	4.65±0.51				
Mullins Sprg.1/mock in vs. ent. in	4.24±0.39,	10, 21	29	-0.75	0.462
	4.12±0.41				
Mullins Sprg.1/mock out vs. ent.	4.37±0.45,	62, 32	9	2.99	0.004
out	4.67±0.52				
Walter Wms./mock in vs. ent. in	4.43±0.25,	3, 8	9	0.47	0.649
	4.58±0.49				
Renfrew 8/04 mock in vs. ent. in	4.51±0.46,	94, 31	123	1.59	0.114
	4.68±0.65				
Renfrew 8/04 mock out vs. ent. out	4.78±0.53,	27, 13	38	-0.85	0.40
	4 64+0 42				

Table 6. Flight speeds at ungated sites in presence and absence of a mock gate.

Notes: **Boldprint** indicates a significant difference ( $p \le 0.05$ ); *Italics* indicates a marginally significant difference. n indicates number of speeds recorded.

Table 7.	Flight speed	averages	(m/s) by	location	(multiple sit	es combined).
	0		(		· · · · · · · ·	

•	1	•	/ /	` <b>1</b>	/
LOCATION*	Mean	<u>SD</u>	<u>N</u>	# caves /mines	<u># nights sampled</u>
Entrance in	5.14	1.04	225	6	12
Entrance out	4.49	.603	105	3	9
Forest	4.36	1.02	41	2	2
Gate in	4.06	.664	98	4	11
Gate out	4.26	.830	239	6	11
Mockp gate in	4.40	.484	52	1	3
Mockp gate out	4.50	.581	114	4	6
Passage	4.58	.804	437	5	10
Total	4.55	.868	1311	14	24

\*Location refers to radar gun's: 1.) placement with relation to the cave/mine: unobstructed entrance, in forest away from cave/mine, real gate, mock gate perpendicular to entrance, or unobstructed passage, and 2.) direction: in = gun facing toward gate, entrance, or further into cave; out = gun facing away from gate, entrance, or cave's interior.

Table 8. Means for each situation based on percent of total behaviors observed.					
Situation	% Passes	<u>% Fly/retreat + Circle</u>			
No gate (n=23; 19 passages/entrances, 14 caves & mines)	68%	23%			
Real gate (n=22; 22 gates, 14 caves & mines)	50%	37%			
Mock gate (n=14; 10 gate locations, 9 caves & mines)	25%	60%			

Note: Numbers do not add up to 100% because other behaviors (not passes or FRCs) were also observed.

Table 9. P-values for each situation based on percent of total behaviors observed (Tukey HSD Post Hoc Test).

<u>Comparison</u>	<u>% Passes</u>	<u>% Circle + Fly/retreat</u>
No gate vs. real gate	0.006	0.021
No gate vs. mock	0.000	0.000
gate		
Mock gate vs. real	0.002	0.001
gate		

F =23.28; overall p<0.001 F = 21.966; overall p<0.001

Table 10. Passage and entrance flight behaviors. Percents indicate percentage of total observed behavior that passes or fly/retreat-circle comprised. Values for real and mock gates were combined.

		<u>Mean %</u>		<u>Mean %</u>	
Situation	<u>N (n)</u>	Pass	<u>% Pass SD</u>	<u>FRC</u>	<u>% FRC SD</u>
Entrance	17 (1,536)	69.4	19.0	20.6	17.3
(unobstructed)					
Passage	6 (1,142)	62.8	13.4	29.2	11.8
(unobstructed)					
Entrance gate	29 (4,240)	42.6	21.6	43.4	19.1
(all)					
Passage gate	5 (675)	31.2	26.4	58.2	26.1
(all)					

Notes: N = number of entrances/passages/gates for each situation; n = total number of all behaviors from all sites within situation. Only sites with  $\geq$  20 total behaviors are included in table. FRC=fly/retreat + circle. Numbers do not add up to 100% because other behaviors (not passes or FRCs) were also observed. New Mammoth Cave's inner gate was not included in either passage or entrance gates because of its unique orientation.

Table 11. Bat activity levels compared by years current gate has been present.	Activity
level was assigned based on visual observation, number of behaviors recorded,	and
acoustical analysis.	

	<u># Sites with</u>	<u># Sites with</u>		
Years gate	Low Bat	Moderate Bat	# Sites with High	Total #
present	Activity	Activity	Bat Activity	Sites
< 4 years	3 (37.5%)	3 (37.5%)	2 (25%)	8
4-6 years	3 (27.3%)	6 (54.5%)	2 (18.2%)	11
>6 years	1 (12.5%)	2 (25%)	5 (62.5%)	8
Total	7	11	9	27

Total711927Note: Percent values indicate percentage of all gates in one age class that had each level of bat<br/>activity.

Table 12. Summary of factors related to significant differences in bats' flight behavior. Percents indicate percentage of total observed behavior that passes or fly/retreat-circle (FRC) comprised.

Factor	<u>% Passes</u>	<u>% FRC</u>	<b>Comments</b>
Gate size	No difference	Higher at small gates	No difference in
			unobstructed
			entrance/passage
			size
Closer-spaced	No difference	No difference	All $\ge 0.6$ m apart
vertical supports			_
Newer gate	Higher at newer	No difference	Activity lower
	gates		at newer gates
Gate at hill bottom	Marginally lower	No difference	
vs. flat ground	at hill bottom		
Gate in passage (vs.	No difference	No difference	
entrance)			
Higher bat activity	Lower at gated	Higher at gated sites	No difference at
	sites		ungated sites
Only one entrance	No difference	No difference	

Figure 1. Profile of standard Angle Iron bars (L) and L-bars (R) at Preble Co. Mine, OH. Most sites had the Angle Iron bars. The horizontal bars on both gates are  $\sim$ 15 cm apart.



Figure 2. An outer gate at Preble Co. Mine, OH. Note large "X"s. Gate is 3.7m high x 5.8m wide.



Figure 3. Mock gate erected perpendicular to the entrance of Mullins Spring Cave, KY. Gate is 1.2 m high x 2.5 m across.



Figure 4. Interior mock gate erected perpendicular to the passage of Craigmont Mine, ON. Gate is 1.8 m high x 3.1 m across.



Figure 5. Radar gun placed 3.7 m from gate and 1.2 m above the ground at New Mammoth Cave, TN.



Figure 6. Bat detector placed 1.5 m from gate and 1.2 m above the ground at Jesse James Cave, KY. Note standard angle iron gate with closed "door" at bottom center.



Figure 7. 1 m x 1 m Tuttle trap used for capturing bats at some sites.



Figure 8. Echolocation calls recorded (corresponds to Table 4). X-axis is time in milliseconds; Y-axis is frequency in kHz. 150 kHz Spectrogram, FFT size 1024, Hanning window.





Figure 9. Honk recorded at Ironton Mine, OH. X-axis is time in milliseconds; Y-axis is frequency in kHz.





Figure 10. Flight behaviors in presence and absence of mock gates.

Note: Numbers (1 & 2) indicate different nights at the same location. Letters (A & B) indicate two different gate orientations at the same location on the same date.

Figure 11. Aeolus Cave gate, VT. Note closer spacing of vertical bars (0.6 m apart). Gate is 2.2 m high x 5.1 m wide.





Figure 12. Behaviors by proportion at Craigmont Mine.

Figure 13. Extreme examples of bat behavior at two gated sites. Wolf River Cave had moderate bat activity, while Coach Cave had high activity; Coach's gate was 10 years old; Wolf River's was three years old; Coach's gate was at a hill bottom; Wolf River's gate was on flat ground. Both gates had vertical supports at least 1.8 m apart on average; Coach's gate was 4h x 4.3w m (classified as medium), while Wolf River's was 2.5h x 7.7w m (classified as large). Neither gate had a bat chute or opening.

