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Internal cave gating for protection of colonies of the endangered gray bat (*Myotis grisescens*)

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Persistent human disturbance is a major cause for the decline in populations of many cave-dwelling bats and other sensitive cave-obligate organisms. Cave gating has been used to eliminate human disturbance, but few studies have assessed directly the impact of such management activities on resident bats. In northeastern Oklahoma, USA, 25 entrances of caves inhabited by two endangered species and one endangered subspecies of bats are protected from human entry with internal gates. Because cave gates may impede ingress and egress of bats at caves, we evaluated the impacts of internal gates before and after their construction at six colonies of endangered gray bats (*Myotis grisescens*) from 1981 to 2001. No caves were abandoned by gray bats after the construction of internal gates; in fact, total numbers of gray bats using the six caves increased from 60,130 in 1981 to 70,640 in 2001. Two caves harbored more gray bats after gating, and three caves had no change in gray bat numbers after gating. We also compared initiations of emergences at three gated and three open-passage caves in June and July 1999–2000. No differences in timing of initiation of emergence were found between colonies in gated versus open-passage caves. Our results support the use of internal gates to protect and thereby enhance recovery of colonies of endangered gray bats. Additional research is encouraged to confirm that our observations on gray bats are generally applicable to other species of cave-dwelling bats.

Key words: cave protection, cave conservation, emergence counts, endangered bats, Oklahoma

INTRODUCTION

Cave ecosystems harbor a variety of unique and sensitive organisms, many of which are cave obligates. Human disturbance at caves is a persistent problem internationally and has been documented as a major cause of decline of cave-dependent bats (Barbour and Davis, 1969; Humphrey and Kunz, 1976; Tuttle, 1979; American Society of Mammalogists, 1992; Węgiel and Węgiel, 1998). About 18 of the 45 species of North American bats rely substantially on caves throughout the year, and 13 use caves year-round (McCracken, 1989). As a result, cave gating has been used widely by governmental and private organizations to protect these sensitive ecosystems from pernicious impacts. In North America, Bat Conservation International (http://www.bci.org) and the American Cave Conservation Association (http://www.cavern.org) provide standards for cave gating and encourage such management activities where necessary to minimize ongoing or potential human impact.

Cave gating can be an immediate and long-term method to deter human access to critical bat roosts (Humphrey, 1978; Tuttle, 1977; Tuttle and Stevenson, 1978) and has become widely accepted as an effective remedy for human disturbance; however, few empirical studies have been published that evaluate its effects on bat populations or other cave-dependent fauna. Most conclusions about the effect of cave gating on bats have been anecdotal and note whether or not cave gating caused abandonment by bats or general population changes. Because of the possibility of abandonment after cave gating, caution is encouraged when considering and implementing any cave-gating project (Tuttle, 1977; Pierson, 1999; Ludlow and Gore, 2000), but follow-up on the effects of cave-gating on bats has been sparse.

All North American bats listed as endangered or threatened by the United States Fish and Wildlife Service are cave-dwelling species or subspecies (McCracken, 1989; Harvey *et al*., 1999; Pierson, 1999). In Oklahoma, 25 caves have been protected by internal gating systems since 1980 (Martin *et al.*, 2000), and seven have been inhabited historically by colonies of gray bats. Populations of endangered Ozark big-eared bats (*Corynorhinus townsendii ingens*), big brown bats (*Eptesicus fuscus*), eastern pipistrelles (*Pipistrellus subflavus*), northern long-eared myotis (*Myotis septentrionalis*), and a single hibernaculum of endangered Indiana bats (*Myotis sodalis*) also are protected. All gates in Oklahoma caves are placed within, and completely fill, cave passages (Martin *et al*., 2000).

We assessed effects of construction of gates inside cave passages on resident populations of the endangered gray bat in eastern Oklahoma. Our objectives were to compare: 1) population trends of gray bat colonies before and after cave passages were gated and 2) initiation of emergence of gray bats from caves that were protected with internally placed gates to those that had no manipulation of passages.

Materials and Methods

Study Area and Caves

Our study was conducted in Adair, Cherokee, Delaware, and Ottawa counties of northeastern Oklahoma in the western limit of the Boston Mountains of the Ozark Plateau. The Plateau covers about 103,000 km^2 (Huffman, 1959) in the central United States; elevations were 260–460 m above mean sea level. The area is dominated by outcrops of alternating layers of limestone and flint (= chert) and sandstone conducive to cave formation (Blair and Hubbell, 1938). It has been proposed that caves in these and other similar latitudes may have served as refugia from severe post-Pleistocene winters for *C. t. ingens* and other cave-dwelling species (Humphrey and Kunz, 1976).

Each of the entrances to the 25 caves that have been gated in Oklahoma have unique physical characteristics (e.g., passage size, distance from the entrance and internal gate to the nearest bat roost, and number of entrances used by bats). Internal gates are placed to protect the nearest historical roost area to the cave entrance. Distances from the internal gates to cave entrances are 3–17 m. Passage areas where gates are located are 1.4–15 m^2. Internal gates are constructed with horizontal angle-iron bars that have 15-cm spacing between bars. The material and design maximize protection from human entry, have nominal effects on airflow (Martin, 2001), and seem to cause no obvious obstructions to bat flight (White and Seginak, 1987). With the exception of a single cave that was gated before angle-iron gates became popular, all gates in Oklahoma caves are of the angle-iron design.

Colony Estimates Pre- and Post-gating

A standard method to estimate populations of colonial gray bats from the size of guano accumulation was established by Tuttle (1976) and Harvey *et al*. (1981). We used that method to estimate the size of six gray bat colonies in eastern Oklahoma during summers 1981–1983, 1991, 1999, and 2001 (Grigsby and Puckette, 1982, 1984; Grigsby *et al*., 1993; Martin *et al*., 2000). All six colonies were protected from human disturbance by internal gates (Martin *et al*., 2000) and comprised five known maternity colonies and one bachelor colony of males and non-reproductive females. The entrance of one maternity colony cave had been covered with an external gate prior to 1980, but it has been kept permanently open since an internal gate was constructed.

Colony estimates were not made at cave 1 in 2001, cave 5 in 1982, or cave 6 in 1981 (Grigsby and Puckette, 1982, 1984; Grigsby *et al*., 1993; Martin *et al*., 2000). To estimate total numbers of gray bats in all six caves, mean numbers of gray bats from available annual estimates of colony size at caves 1, 5, and 6 were used for those missing years. We compared estimates of colony size for each cave over the six years of observation by evaluating the overlap of pre- and post-gating 95% confidence intervals. In one case each, only a single annual estimate of colony size was available pre- and post-gating; if the single annual estimate fell with the confidence interval from annual estimates of colony size, we surmised no difference pre- or post-gating.

Comparison of Emergence

Initiations of emergences were evaluated three times at each of three gated and three open-passage caves inhabited by gray bats from 15 June to 17 July 1999 and from 14 June to 21 July 2000 (n = 36). Initiation of flight emergence was recorded using multiple infrared light sources and night-vision optics (Clark *et al*., 2002). That non-intrusive method produced minimal disturbance to exiting colonies and permitted documentation of initiation times of emergence (United States Fish and Wildlife Service, 1995). Exiting bats were counted continuously in 60-s increments. As an index to initiation of emergence by gray bats, we recorded the time at which > 30 gray bats exited a cave entrance without re-entry within 60 s. A second index of emergence was recorded when > 60 gray bats exited without re-entry within a subsequent 60 s. To remove variation due to light intensity attributable to changes in sunset times over the duration of observations, each index of emergence time was converted to minutes after official sunset. Official sunset times were derived from the nearest United States Naval Observation Station to each study cave; distances between each cave and its nearest observation station were 8–15 km. Observations of emergence were not made when there was a threat of rainfall.

A randomized-complete-block analysis of variance (SAS Institute Inc., 1999) was used to compare indices of initiation of emergence by gray bats between gated and non-gated caves. Each year (1999 and 2000) was blocked, and individual caves were considered experimental units. We hypothesized that initiation of emergence would be delayed and slowed if flight was impeded by the internal cave gate. If that were true, we expected to observe increased swarming by emerging gray bats in the vicinity of the gate. Statistical significance was set at $P < 0.05$.

Results

Colony Estimates Pre- and Post-gating

No caves were abandoned by gray bats after construction of internal gates. Total numbers of gray bats in all six caves from 1981 to 2001 ranged from a low of 53,400 in 1983 to a high of 71,770 in 1999 ($\bar{x}$ ± SE = 63,134 ± 3,071.9). The total estimate of gray bats at all six caves was 60,130 in 1981, and after all six caves had been gated, the total estimate was 71,640 in 2001, suggesting that cave gating did not have a pernicious impact and may have enhanced numbers of gray bats. Only caves 2–6 had estimates of gray bat numbers pre- and post-gating (Fig. 1). Two caves actually had more gray bats in them after gating (cave 4: 95% confidence intervals of 5,953–15,047 gray bats versus 15,499–32,136; cave 6: 3,031–12,039 versus a single estimate of 12,500). Three caves had no change in gray bat numbers after gating (cave 2: a single estimate of 7,400 gray bats versus 95% confidence intervals of 5,263–9,533; cave 3: 3,693–5,640 versus 3,721–5,627; cave 5: 7,679–18,031 versus 6,675–8,752).

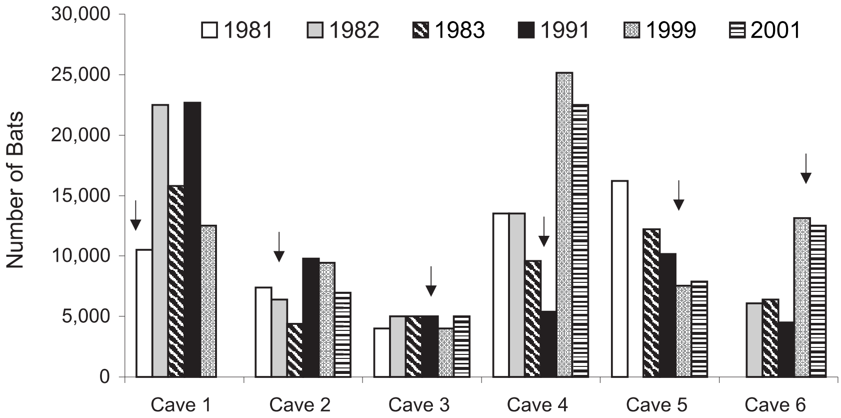

FIG. 1. Size estimates of six gray bat colonies listed chronologically beginning in 1981; bars after the arrows represent colony estimates after placement of an internal gate in the cave

Comparison of Emergence

Initiation of emergence, adjusted to minutes after official sunset, did not differ between gated and non-gated caves when initiation of a colony emergence was indexed by > 30 bats/60 s ($F_{1, 4}$ = 0.01, P >> 0.05) or > 60 bats/60 s ($F_{1, 4}$ = 0.02, P >> 0.05; Table 1). We did not observe an increase in swarming at gated caves. During 36 observations of emergence, attempted predation by a Virginia opossum (*Didelphis marsupialis*) was noted once, and it resulted in the latest emergence noted during the study (cave 1: 32 min past sunset for > 30 bats/60 s; 39 min past sunset for > 60 bats/60 s) but no capture of bats. The predation event was observed at the old external gate at the entrance of cave 1 that remained permanently open throughout the year; the internal gate was located 15 m within the cave passage.

DISCUSSION

Efforts to protect caves and organisms that they harbor from human disturbance are among the most important contemporary issues in cave conservation. In addition to cave gating, various degrees of protection can be accomplished by fencing an area around cave entrances, placing warning signs at entrances, and maintaining a close and positive rapport with landowners if caves are in private ownership (United States Fish and Wildlife Service, 1982, 1984, 1995). When human disturbance is likely, cave gating is widely believed to be the most effective deterrent to human access, but its effect on critical bat roosts has not been adequately assessed (Tuttle, 1977; Humphrey, 1978; Tuttle and Stevenson, 1978; Richter *et al.*, 1993). Apprehension is especially high over use of full-passage gates, as used in Oklahoma, and gating multiple entrances to the same cave. Gate configuration and placement also vary, and those that leave the upper part of the passage open are common in some areas of the gray bat's range. Although such a design may be less obstructive to bat flight, it does not afford the same protection from human disturbance as a full-passage gate. Although not supported by many empirical observations, recurrent claims in literature suggest that the presence of cave gates increases swarming by bats before emergence, rendering the bats more susceptible to predation and the chance of dropping young in some species (Tuttle, 1977, 1979; White and Seginak, 1987; Ludlow and Gore, 2000).

TABLE 1. Mean (±SE) number of minutes (n = 3) past sunset of emergence of colonies of endangered gray bats from three gated (1–3) and three open-passage (4–6) caves in northeastern Oklahoma (n = 36); indices of emergence are minutes past sunset when > 30 bats first exited within a 60s and minutes past sunset when > 60 bats first exited within a subsequent 60s

Cave No.	15 June–17 July 1999		14 June–21 July 2000	
	> 30 bats	> 60 bats	> 30 bats	> 60 bats
Gated				
1	23.7 ± 4.6	28.3 ± 6.1	20.7 ± 2.6	23.0 ± 2.3
2	6.0 ± 3.1	9.0 ± 3.5	15.0 ± 2.5	17.7 ± 1.7
3	13.7 ± 2.9	15.6 ± 2.3	14.7 ± 4.7	20.0 ± 4.0
Non-gated				
4	12.0 ± 2.6	13.3 ± 2.7	11.3 ± 0.7	15.0 ± 1.5
5	22.7 ± 1.8	24.7 ± 2.0	15.0 ± 1.7	18.3 ± 2.6
6	16.3 ± 2.8	20.0 ± 3.0	17.0 ± 1.5	19.0 ± 1.2

Construction of human-restrictive structures at cave entrances has changed considerably over the past 25 years. Early designs often were constructed at or over cave entrances, often with inadequate spacing between bars, which in some cases resulted in caves being abandoned by resident bats (Tuttle, 1977, 1979). In Delaware County, Oklahoma, such a gate placed over a cave entrance in 1971 resulted in abandonment of the cave by a maternity colony of about 20,000 gray bats by 1981. In Adair and Delaware counties, Oklahoma, two caves inhabited by maternity colonies of gray bats were gated in 1980 and 1982 (Martin *et al.*, 2000). Because of restrictive exterior features of their entrances, the gates were placed in twilight zones of the cave passages 9 m and 15 m inside their respective entrances. These were the first reported instances of interior-passage gates to protect cave-dwelling populations of bats in the United States. Placement of gates within twilight zones of cave passages, such as those in northeastern Oklahoma, is now an accepted protocol for cave gating elsewhere in the United States (White and Seginak, 1987). Our observations of the changes in sizes of gray bat colonies at six caves in northeastern Oklahoma since 1981 indicate that the use of such gates is a viable method of preventing human disturbance without pernicious impacts to gray bats.

Although White and Seginak (1987) evaluated effects of three gate designs on bat flight, the effect of an internal gate on emergence has not been evaluated. Speculation persists that placing gates in cave passages causes an increase in swarming by bats before they fly through the gate, which may increase susceptibility to predation as bats try to fly through the gated passage (White and Seginak, 1987; Clark *et al.*, 1996). Our observations of emergence from gated caves did not differ from those at open-passage caves, which suggests that these systems do not impede or delay exit flights of colonies of ≤ 25,000 gray bats. Cave biologists in Oklahoma also have videotaped emergences through internally gated passages at other caves with no noticeable effect on bat flight (S. L. Hensley, personal observation). Distinctions must be made, however, between external structures that are placed at a cave entrance, which are known to affect bat flight (Ludlow and Gore, 2000), and those that are currently placed within cave passages. It is speculated that relatively small colony sizes (≤ 25,000) and small gated passages (1.4–15 m^2), as used in our study, may have reduced the effect that the internal positioning of gates could have on bat flight. Additional research is needed on larger colonies of gray bats and other bat species.

Many factors can delay a colony's exit or promote an early emergence from a cave entrance. Maternity colonies have been noted to emerge later, relative to sunset, during lactation (Kunz, 1974; McAney and Fairley, 1988; Clark, 1991; Shen and Lee, 2000; Clark *et al*., 2002), and delayed emergence also may be a result of longer twilight hours in summer (McAney and Fairley, 1988). In our study, all observations were made at maternity colonies of gray bats, except cave 5 that contained a colony of males and non-reproductive females, and variation did occur between colonies (Table 1). It is apparent from previous studies that emergence for many bat species varies depending on light intensity (Prakash, 1962; Stebbings, 1968; Kunz, 1974), insect flights (Rydell *et al*., 1996), and ambient temperature and humidity (O'Farrell and Bradley, 1970; Lacki, 1984).

In many cases, passive management efforts (e.g., fencing around cave entrances, placing warning signs, and partial passage gates) may not offer enough protection to resident bats, particularly those that are declining or under special protective status. Considerable thought should be given before manipulating a cave entrance or passage to protect resident fauna. It is particularly evident that external cave gates can be restrictive to exiting bat colonies and have resulted in colony abandonment (Ludlow and Gore, 2000; Martin *et al*., 2000), and restriction of air flow and alterations to cave microclimates should be assessed (Tuttle and Stevenson, 1978; Martin, 2001). However, our data demonstrate that internal gates in cave passages can protect gray bat populations with minimal effects on colony size and egress from the cave. Additional research is encouraged to confirm that our observations on gray bats are generally applicable to other species of cave-dwelling bats.

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