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THE EFFECT OF GATES ON CAVE ENTRY BY SWARMING BATS

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Temperate bats make extensive use of caves and mines as nursery roosts, swarming sites and hibernacula. For a variety of reasons, the entrances to many sites have been modified in the past to restrict human access. Early barrier design often gave little regard to bats, leading to massive population declines in many nursery and hibernation sites. Free access to bats has become an increasingly important design feature, as the damaging effects of early gates were recognised. However, given the large number of gates that have been constructed, relatively few studies have looked at either the short or long-term effects of gates on bat behaviour and population sizes. Even fewer studies have examined specifically the effects of different gate designs. We have looked at the immediate effects of gates on the behaviour of swarming bats as they entered a natural cave. Three gates were tested, all with vertical grille spacings of 750 mm, but with horizontal spacings of 150, 130 or 100 mm. The gate with 150 mm spacings had no significant effect on the behaviour of the bats (predominantly *Myotis nattereri).* Gates with both 130 mm and 100 mm spacing caused a significant and substantial increase in the number of bats aborting their first and often subsequent attempts to enter the cave. The consequences to swarming behaviour and long-term use of the site by bats are unknown, but we suggest that following the precautionary principle, the minimum spacing between horizontal bars in gates should be 150 mm.

Key words: bats, caves, mines, gates, grilles, hibernacula, underground, swarming

INTRODUCTION

Across the world, natural caves and artificial underground sites are used widely as roosting sites by bats and may be occupied by large breeding and/or hibernating populations (e.g., Altringham 1996). Bats form the largest mammalian assemblages on earth and single sites may be home to a significant proportion ofthe total population of some species. Such sites are clearly of major importance to bats and may restrict both population size and distribution. At an increasing rate over the last half-century, barriers have been erected in the entrances to underground sites. These barriers restrict public access to potentially dangerous sites, control access for commercial reasons, or protect cave-dwelling bats from disturbance (Tuttle 1977, 1979; Tuttle and Taylor 1998). There is no doubt that restricting public access is often necessary, since there is convincing evidence to show that disturbance can cause catastrophic declines in cave-bat populations (e.g., Rabinowitz and Tuttle 1980; Wegiel and Wegiel 1998). However, many early barriers caused severe declines in the number of bats using sites (Tuttle 1977; MacGregor 1993). Ironically, some of the gates specifically erected to protect bats were as likely to deter bats as those built for other purposes. Once this problem was recognised, new designs were used and many older gates replaced (Tuttle and Taylor 1998). A badly designed gate can cause two problems: it will either restrict access to bats and/or alter the cave microclimate (Tuttle and Stevenson 1978; Richter *et al.* 1993). The most common designs now in use incorporate a metal grille with horizontal spaces narrow enough to prevent entry by most humans, but large enough, in principle, to allow bats unimpeded entry. The section and thickness of the bars are a compromise between the demands of strength and unrestricted air flow. In the United States, the use of cave gates is widely promoted (e.g., Tuttle and Taylor 1998) and at least 1620 "bat-friendly" cave gates had been erected by 2002 (Sherwin *et al.* 2002). Bats can clearly fly through these gates, and the reduction in disturbance brought about by gating can promote the re-occupation of a site. However, relative to the large number of gated caves, there are very few studies of the effects these gates have on bats. Virtually all published studies on cave and mine gating relate to medium or long-term effects on the numbers of bats occupying hibernacula or summer nursery sites (e.g., MacGregor 1993; Ludlow and Gore 2000; Martin *et al.* 2003). Results vary greatly and depend on gate design and any modifications made to the cave or mine entrance itself during gate construction. Recent studies have yielded encouraging results (Mitchell-Jones 1995; Tuttle and Taylor 1998; Martin *et al.* 2003), but the data are often difficult to interpret since they are complicated by other factors such as inadequate monitoring before gating, the removal of old gates or alterations to other parts of the cave or mine (Ludlow and Gore 2000; Martin *et al.* 2003). Even if a substantial increase in the number of bats using a site is seen due to a reduction in disturbance, this does not mean that the gate itself is not a deterrent to bats. Few studies have looked at behaviour, in particular the response of flying bats to the gate itself. Martin *et al.* (2003) found no evidence to suggest that gates delayed the emergence of gray bats *(Myotis grisescens).* Rodrigues (1996) showed that the introduction of gates rapidly decreased the number of individuals of several species of rhinolophid and vesper bats visiting a cave. White and Seginak (1987) carried out perhaps the only published study to look at different gate designs. Virginia big-eared bats *(Corynorhinus townsendii virginianus)* and gray bats preferred to exit via a grilled gate rather than a gate fitted with a funnel, and a grille with horizontal, 19 mm diameter, round iron bars spaced 154 mm apart was preferred to 103 mm angle iron at the same spacing. However, all three gates deterred bats.

Bats use caves and mines as hibernacula, as summer roosts and as autumn swarming sites. Swarming occurs at underground sites and is probably the primary mating system for many temperate bat species (e.g., Davis 1964; Fenton 1969; Thomas *et al.* 1979; Kerth *et al.* 2003; Parsons *et al. 2003b;* Rivers *et al.* 2005, 2006). Swarming sites can attract large numbers of bats from very large catchment areas (Parsons and Jones 2003; Rivers *et al.* 2006), and genetic studies suggest that these sites are vital to the breeding success and genetic health of bat populations (Kerth *et al.* 2003; Veith *et al.* 2004; Rivers *et al.* 2005).

During swarming bats fly in and out of a cave repeatedly, night after night, from August to October (Thomas *et al.* 1979; Parsons *et al.* 2003b; Rivers *et al.* 2006). The introduction of a gate may disrupt normal swarming behaviour and could therefore have a significant impact on bat populations over a wide area. Gate spacing could be critical to this behaviour, since the bats may pass through the gate frequently in a single night.

Guidelines set out in the U. K. Bat Workers' Manual (Mitchell-Jones and McLeish 2004), published by the UK Joint Nature Conservation Committee, recommend that horizontal bars are spaced 150 mm apart, with a 450–750 mm spacing between vertical bars. However,. it is also noted that this gap may not prevent access by children and so a gap of 130 mm is suggested as a compromise. In the United States (Tuttle and Taylor 1998) and in Europe (Rodrigues 1996) the most widely used gate design also has a horizontal spacing close to 150 mm. Tuttle (1977) recommends a maximum spacing between horizontal bars of about 150 mm to prevent human entry, but does not suggest a minimum spacing. The choice of a spacing of 150 mm appears to be based on qualitative observation. Our aim was to quantify the immediate effect on bats entering a major swarming cave of gates with spacings between horizontal bars of 100, 130 and 150 mm, and 750 mm between vertical bars.

MATERIALS AND METHODS

The study was carried out at Slip Gill cave, Ryedale, a swarming site in the North York Moors National Park in the north of England. Mark-recapture studies of ringed bats (Rivers *et al.* 2006) have shown that this cave and its three neighbours are visited by 2,000–6,000 Natterer's bats, *Myotis nattereri,* each autumn, with 300–400 individuals swarming at Slip Gill each night. Several hundred bats of four other species also use the site each year. The study is therefore multi-species, but reflects predominantly the behaviour of Natterer's bats, which make up at least 80% of the bats on a given night. It is therefore relevant to the many swarming sites in the UK where Natterer's bat is the dominant species (e.g., Parsons *et al.* 2003b*)* and probably to many sites in Europe and North America used by *Myotis* species. The entrance is a 24 m vertical rift which narrows at the top to a roughly circular opening averaging 1.5 m in diameter. Custom built gates were made from black, 15 mm diameter plastic tubing to simulate a widely-used design in steel. These were fitted directly over the horizontal shaft, completely enclosing the cave entrance.

Three gates were assessed. The spacing between vertical bars was 750 mm for all designs but three spacings were used between the horizontal bars; 150 mm, 130 mm and 100 mm. The cave entrance is located at the base of a steep slope and the "vertical" bars of the gate were at an angle of about 30° to the horizontal.

Each gate was tested on 6–10 nights, and all experiments were carried out between 18 September and 18 October 2004. The 150 mm and 100 mm gates were tested first, with gate size randomised from night to night. The 130 mm gate was then tested. Since mark-recapture data indicate a high turnover of bats from night to night (Parsons *et al.* 2003b; Rivers *et al.* 2006), most of the bats encountering a gate on a given night are probably doing so for the first time and are hence naive. Night video recording of the cave entrance (with supplementary IR-illumination) was started 3–4 hours after sunset, when swarming was at its peak at the site (Rivers *et al.* 2006). The camera's field of view included the entire cave entrance, and the airspace at least 2 m from the entrance in all directions. The camera was set up in the same position on every night of the study. Swarming activity of the bats around the cave entrance was recorded for three, contiguous 30-minute periods:

a) activity prior to the introduction of the gate ("before");
b) activity with the gate in place ("present");
c) activity after the gate was removed ("after").

For each of the three periods, the number of bats passing through the camera's field of view was recorded. Bats entering the cave were counted. Bats approaching the cave entrance and making an aborted entry attempt were counted and the number of approaches made by individual bats was also recorded when possible. Since many bats went outside the field of view of the camera after an aborted entry, it was not always possible to say whether the next approach was made by the same or a different bat.

The effects of the gates on behaviour were assessed using ANOVA (Bonferroni corrected for multiple testing) using SigmaStat 3.0 (Systat). A two-way ANOVA was not appropriate because of the "before, present and after" design. Where necessary, non-normal data were log transformed prior to testing. When it was necessary to compare proportional data, these were arcsine square root transformed to enable parametric analysis to be conducted. All work was carried out under an English Nature licence.

RESULTS

The mean bat activity in the immediate vicinity of the cave entrance, expressed as the number of bats entering the camera's field of view per minute (Fig. 1), did not change significantly with the introduction of any of the gates [ANOVA (130 and 100 mm) or Kruskal-Wallis ANOVA on ranks (150 mm), $P > 0.05$]. With both the 130 and 100 mm grilles, there was a large increase in the mean number of bats in the presence of the grille, but the increases were not significant due to substantial night-to-night variation. There were fewer bats present during experiments on the 130 mm grille since they were carried out late in the swarming season.

The numbers of bats entering the cave on the first approach are expressed as proportions of the total number of bats seen per 30-minute period to correct for variation in the number of bats visiting each night (Fig. 2). The 150 mm grille did not significantly affect the proportion of bats entering the cave (ANOVA, $F_{2,15} = 1.07$, $P > 0.05$), but both the 100 and 130 mm grilles significantly reduced the proportion of bats entering the cave at the first

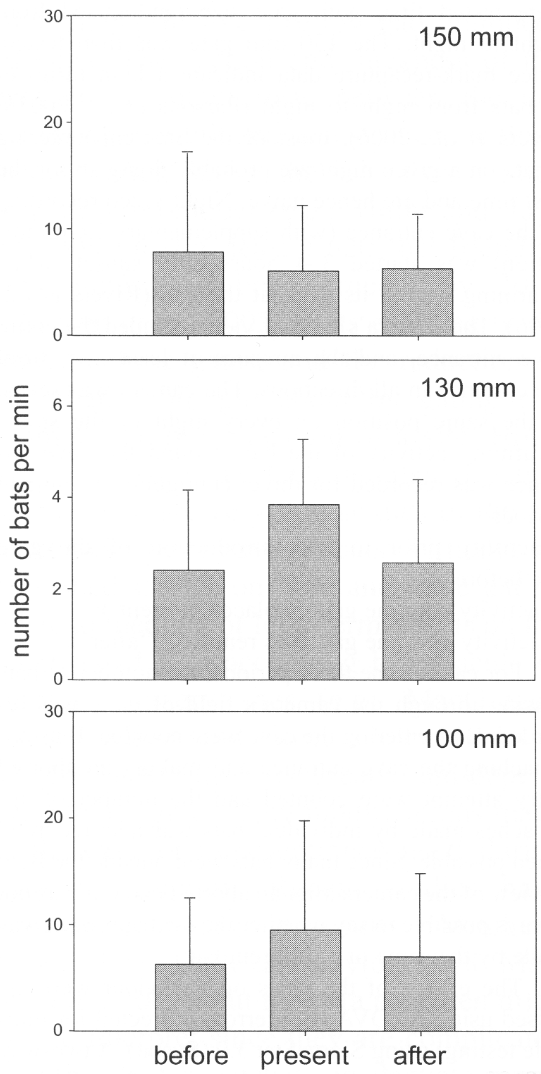

FIG. 1. The mean bat activity in the immediate vicinity of the cave entrance (number of bats entering the camera's field of view per min) in the presence and absence of grilles with three spacings between horizontal bars. Data = $\bar{x} \pm$ SD, n = 6, 6, and 10 for 150, 130, and 100 mm grilles, respectively

attempt. In the case of 130 mm grille (ANOVA on ranks, $H = 8.26$, $n = 6$, $P < 0.05$), significantly more bats aborted cave entry when the grille was present than after its removal (Dunn's test). For 100 mm grille (ANOVA, $F_{2,24} = 4.33$, $P < 0.05$), significantly more bats aborted cave entry both before and after the grille was put in place (Holm-Sidak test).

When either the 130 or 100 mm grille was in place, many bats made two or three passes of the grille before entering the cave. This circling was rarely observed in the presence of the 150 mm grille or when no grille was present.

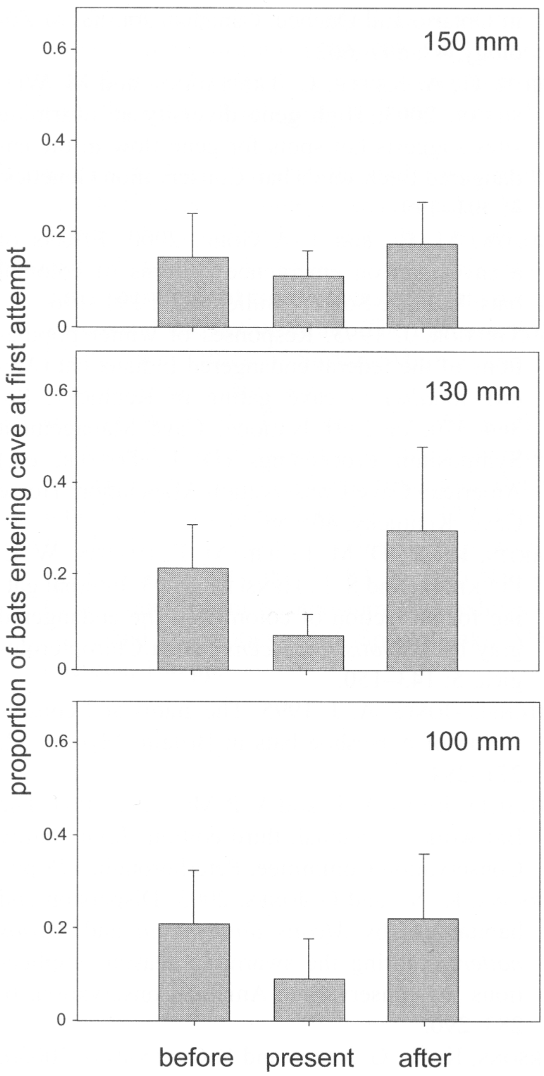

FIG. 2. The proportion of bats that entered the cave at the first attempt in the presence and absence of grilles with three spacings between horizontal bars. Data = $\bar{x} \pm$ SD, n = 6, 6, and 10 for 150, 130, and 100 mm grilles, respectively

Furthermore, the change in behaviour was more marked than these results suggest; with a hand-held nightscope it was possible to observe individual bats making up to twelve aborted entry attempts before entering the cave but as these did not always stay within the fixed camera's field of view, quantitative data were not collected.

Although 130 and 100 mm grilles disrupted normal behaviour, this brief exposure to the narrower grilles did not have a lasting effect: behaviour returned to normal immediately after removal of the grille.

DISCUSSION

The results show clearly that cave gates with horizontal bars spaced closer together than 150 mm have a significant effect on bats entering the swarming cave, causing approximately twice as many bats to abort their first, and often subsequent, entry attempts. Removal of the gates after 30 min showed that they had no lasting effect on bat numbers when in situ for such a short period. Rodrigues (1996) also reported that bats spent more time circling after the insertion of gates (with a horizontal bars set 150 mm apart) and reduced their flight speed and approach height.

To determine the long-term effects of gates they would need to be in place continuously, with monitoring of bat numbers before and after placement. Unambiguous results would not be guaranteed due to the unpredictability of the bats' behaviour and the effects of weather (Parsons *et al.* 2003a, 2003b), and whilst the information would be valuable, such an experiment should not be undertaken lightly. The erection of gates with horizontal bars set about 75 and 150 mm apart (300 mm vertical) led to the complete abandonment of two caves in Alabama by nursery colonies of 25,000 and 5,000 *M. grisescens* in just one or two years (Tuttle 1977). In addition to deterring entry, these gates also provided feeding opportunities for predators such as raccoons. White and Seginak (1987) noted that snakes made use of gates to catch emerging bats. The altered behaviour in front of grilles (this study and Rodrigues 1996) may increase the risk of predation by both ground and aerial predators.

Although the results are clear, we have simply shown that bats are unable or reluctant to pass through narrow grilles. What impact this has on swarming behaviour and ultimately mating success is unknown. In the short-term it clearly disrupts normal traffic into and out of the cave. In the long term it may lead to a reduction in the number of bats using a cave, which could have significant consequences, particularly in regions where alternative swarming sites are scarce.

A grille spacing of 150 mm is already advised at all sites visited by greater horseshoe bats (Mitchell-Jones and McLeish 2004), although lesser horseshoe bats, *Rhinolophus hipposideros,* appear to have adapted well to 125 mm grilles at several nursery roosts (J. Messenger, pers. comm.). We suggest that *M. nattereri* and perhaps other small species (in the UK: *M. bechsteinii, M. daubentonii, M. mystacinus, M. brandtii, Plecotus auritus* and *Barbastella barbastellus*) also require this larger spacing between bars. Rodrigues (1996) suggested that gates are only appropriate at hibernation and nursery sites used by certain species. One of the species she supports the use of gates for is *M. nattereri,* but we show that this too is affected by gates. The most appropriate policy would be not to use gates unless it is necessary and grilles with spacings of less than 150 mm should not be used without very good reason. Given the paucity of published data on the effects of gates, bat activity should be carefully monitored before and after the placement of a gate at any site important to bats. Fences are a possible alternative (Tuttle 1977), but they are not always practical and their design too must be carefully considered if they are to give bats unimpeded entry and deter human disturbance.

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