Bat conservation in China: should protection of subterranean habitats be a priority?

Jinhong Luo, Tinglei Jiang, Guanjun Lu, Lei Wang, Jing Wang and Jiang Feng

Abstract Subterranean environments are essential for the survival of many bat species and other cave fauna but these places are subject to increasing human disturbance. To examine the significance of subterranean habitats for the conservation of bats in China we surveyed bat species in 225 underground sites during 2003–2011. Our results show that 77% of bat species in China, including 30 nationally Endangered or Vulnerable species and nine endemic species, roost in caves and other subterranean habitats. The number of species in occupied roosts was 1–15. Almost 90% of the roosts surveyed contained signs of human disturbance, most of which was from recreational activities. One hundred and twenty-one roosts merit special concern because they harbour ≥ 6 species or $> 1{,}000$ individuals, or species of special concern (threatened or endemic species). Generally, larger roosts support more species and a greater abundance of bats than smaller roosts but there is no direct correlation between the presence of species of special concern and roost size. Disused tourist caves have significantly more bat species than other types of roosts. Our data demonstrate that roost disturbance by recreational activities has pronounced detrimental effects on the number of bat species and the presence of species of special concern. We discuss the social, economic and political issues that could adversely affect bat conservation in caves in China, and we recommend that protection of subterranean habitats should be a high priority for bat conservation.

Keywords Bats, China, Chiroptera, conservation priority, endemism, human disturbance, species richness, tourist cave

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Introduction

Bats are ecologically important as pollinators, seed dispersers and insect predators (Cleveland et al., 2006; Betke et al., 2008; Kalka et al., 2008; Lobova et al., 2009; Boyles et al., 2011; Kunz et al., 2011). However, populations of many bat species are declining because of threats such as climate change, habitat loss and degradation, hunting and emerging diseases (Meyer et al., 2010). Of these, habitat loss and degradation are the greatest threats to bats in most regions (Mickleburgh et al., 2002; Racey & Entwistle, 2003; Jones et al., 2009; Kingston, 2010; Meyer et al., 2010).

Subterranean sites, such as caves and mines, provide roosts for many bat species (Kunz, 1982; Hutson et al., 2001), and some of the most important maternity and hibernating sites (Kunz, 1982; Kunz & Lumsden, 2003; Murray & Kunz, 2005). Such sites are also used as mating and aggregation locations for millions of individuals (Kunz, 1982; Hutson et al., 2001). The range and densities of bats that rely on caves are determined largely by the distribution, quantity and characteristics of available caves (Murray & Kunz, 2005; Struebig et al., 2009). According to the IUCN Red List of Threatened Species (IUCN, 2010), 449 out of 1,132 extant bat species roost in caves and other subterranean habitats.

Disturbance of roosts threatens many bat species (Hutson et al., 2001), and declines of cave-dwelling bat populations were noted as early as 1952 (Mohr, 1972). Activities within or around caves, such as mining, quarrying, guano and bird nest collecting, caving, tourism, and deliberate or accidental disturbances can all have negative effects on bats (Hutson et al., 2001). In Mexico there have been dramatic declines of cave-dwelling bats caused by roost disturbance (Hutson et al., 2001) and in the USA roost disturbance was the cause of the decline of six threatened bat species (Elliott, 2000).

Currently, 121 bat species are known from China (IUCN, 2010). Although only one species (*Pteropus lylei*) is considered globally threatened, populations of 18 species are decreasing and the population trends of 79 species are unknown (IUCN, 2010). Sixty-two bat species are considered nationally threatened (Endangered, Vulnerable or Near Threatened; Wang & Xie, 2004).

Despite the high proportion of nationally threatened bat species in China and the lack of information on the ecology of these species, little research has focused on bat conservation in the country (but see Niu et al., 2007). Based on our surveys of bats in 225 underground sites during 2003–2011 and an assessment of related social, economic and political issues, we recommend that protection of subterranean habitats should be a high priority for bat conservation in China.

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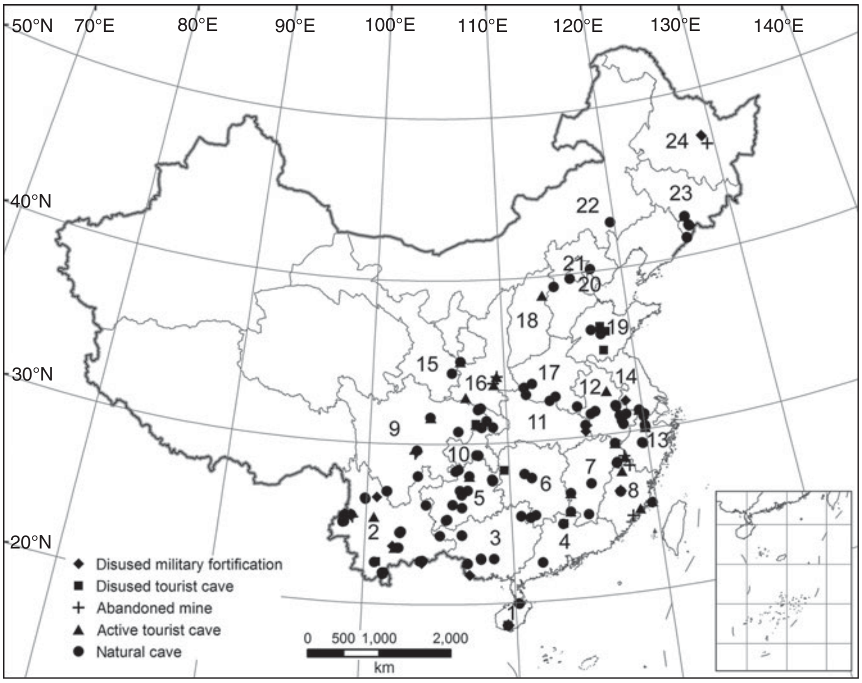

FIG. 1 China, showing the locations of potential bat roosts surveyed during 2003–2011. The provinces and municipalities where we surveyed are numbered: 1, Hainan; 2, Yunnan; 3, Guangxi; 4, Guangdong; 5, Guizhou; 6, Hunan; 7, Guangxi; 8, Fujian; 9, Sichuan; 10, Chongqing; 11, Hubei; 12, Anhui; 13, Zhejiang; 14, Jiangsu; 15, Gusu; 16, Shaanxi; 17, Henan; 18, Shanxi; 19, Shandong; 20, Tianjin; 21, Beijing; 22, Neimenggu; 23, Jilin; 24, Heilongjiang.

Methods

We surveyed bats in 225 subterranean sites in China during March–August from 2003 to 2011 (Fig. 1). Information on roost localities was collected from the literature, Internet and local residents. Local people provided information on numbers of roost entrances, frequency of visits to the roost, identity of visitors, relative number of bats and safety issues. We entered roosts with torches, in the daytime, when the situation allowed. We recorded locations, with a global positioning system, and collected information on the freshness of bat faeces, traces of human activities, and roost and colony sizes. Colony size was assessed mainly by direct roost counts except for some inaccessible roosts, for which the colony sizes were estimated by evening emergence counts. Methods for estimation of colony size followed Kunz et al. (2009a).

Roost size was measured as the combined inner space size (in m^3) of all chambers and passages of a cave. In most cases each chamber and passage was considered a cuboid and its volume determined as total length × mean height × width. As the resulting estimates of roost size were not precise we identified roosts as large or small based on the median (1,000 m^3) of the data. Additionally, if a roost was too large to be surveyed in 15–30 minutes it was regarded as large. A roost was categorized as inaccessible if its entrances were too small to allow a person to enter. The small percentage of roosts for which size could not be determined were categorized as data deficient.

Frequency of visitation to a roost was determined by interviewing elderly residents, wherever possible farmers who spent considerable time working outside throughout the year. Using the information gathered we categorized roosts as either visited or seldom visited. Seldom-visited roosts were those for which the residents questioned had not seen visitors in the previous 12 months. Within each roost that we could enter we searched for traces of human activities (e.g. footprints, food packages, cigarette butts, scratches, notches and remains of torches). If a roost was categorized as seldom visited and we found no obvious traces of human activities it was categorized as undisturbed, and otherwise as disturbed.

The conservation value of roosts was assessed using three criteria (species richness, abundance, and the presence of species of special concern) proposed by Arita (1993, 1996). Species of special concern were those categorized as Endangered or Vulnerable in China, or species endemic to China. We regard roosts that harbour ≥ 6 species or $> 1{,}000$ individuals as being of special concern.

Bat species were captured with ground-based mist nets set at entrances during emergence in the evening and sometimes in the early morning as bats returned from foraging. At least one person monitored the net, and when a bat entered it was removed with care to avoid any injury to either the bat or the handler (Kunz et al., 2009b). The handling of bats conformed to guidelines for animal care and use established by the American Society of Mammalogists (Gannon & Sikes, 2007). All fieldwork abided by the Law of the People's Republic of China on Protection of Wildlife.

Most species were identified based on their morphological characteristics. For species that were ambiguous we carried out DNA-based phylogenetic analysis of one 3-mm diameter biopsy punch from the wing-membrane

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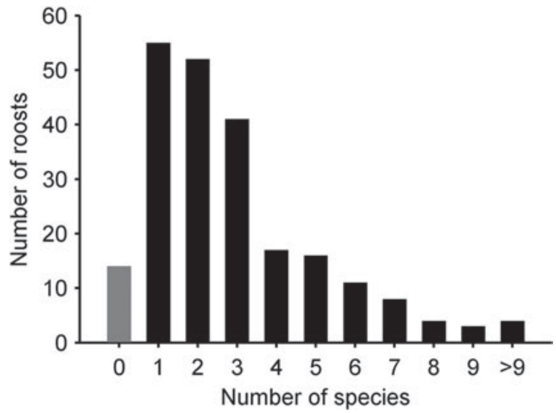

FIG. 2 The number of roosts (see Fig. 1 for locations) in the 225 subterranean sites located and surveyed that contained from 0 to >9 species of bats.

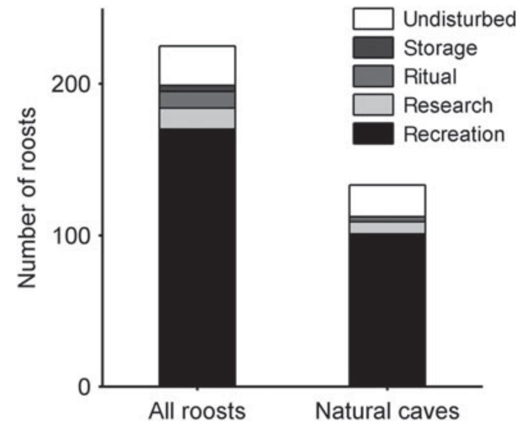

FIG. 3 The main human activities observed at the sites of the 225 bat roosts surveyed (Fig. 1), for all roosts combined and for those in natural caves undeveloped for tourism. Storage indicates sites used to store items such as firewood. Ritual indicates sites used for ritualistic or religious purposes.

per individual. For each captured bat we measured length of forearm, dorsal head and body length, and tail, ear, tibia and hind foot lengths (including claws, measured to the distal part of the claw) to an accuracy of 0.01 mm, with digital callipers. Body mass was measured to the nearest 0.01 g with a digital balance. All bats were released after handling except for a small number of individuals of taxonomic interest (e.g. newly recorded species in China). For species newly recorded in China we took additional external measurements in the field and cranial and dental measurements in the laboratory. These bats were euthanized by intraperitoneal injection of sodium pentobarbital (80 mg kg^{-1}) in accordance with the American Veterinary Medical Association Guidelines on Euthanasia (AVMA, 2007), preserved in 75 or 95% ethanol and deposited in the Museum of Natural History of North-east Normal University, Jilin province, China.

To examine the potential effects of roost type (natural cave not developed for tourism, disused military fortification, active tourist cave, abandoned mine and disused tourist cave), roost size and human disturbance on species richness we used generalized linear modelling (GLM), with species richness as the dependent variable, roost type as a factor, and roost size and human disturbance as covariates. Only the main effects were considered, and the least significance difference method was used for pair-wise comparisons. Partial correlations were conducted to examine the relationship between the presence of species of special concern and roost type, roost size, human disturbance and species richness. We performed all statistical analyses with *SPSS v. 19.0* (SPSS, Chicago, USA).

Results

In our surveys 57 bat species, in seven families, were found to roost in caves and other subterranean habitats. Of these, 11 species had not previously been documented to roost in caves (on either the China Species Red List or the IUCN Red List; Wang & Xie, 2004; IUCN, 2010) and six species are endemic to China (Supplementary Table S1; for specimens collected see Supplementary Table S2). The number of species in occupied roosts was 1–15 but only c. 10% of these roosts harboured ≥ 6 species; 75% contained ≤ 4 species (Fig. 2, Supplementary Table S3).

Our literature search indicated that a further six bat species have been documented using caves for roosting in China. Combining information from the China Species Red List (Wang & Xie, 2004), the IUCN Red List (IUCN, 2010) and bat species recorded in our survey and by other researchers, we determined that a total of 101 bat species (77%) are roosting in caves and other subterranean habitats in China (including Taiwan). This includes 30 nationally Endangered or Vulnerable species (Wang & Xie, 2004), and nine endemic species (Supplementary Table S1).

Of the 225 underground sites we surveyed, there were 133 natural caves not developed for tourism, 34 disused military fortifications, 34 active tourist caves, 13 abandoned mines and 11 disused tourist caves. Almost 90% of the sites were disturbed and only 15% of the natural caves were free of disturbance (Fig. 3). Up to 46% of sites harboured threatened or endemic species, 30 sites harboured ≥ 6 species and 25 sites contained $> 1{,}000$ individuals, giving a total of 121 roosts that warrant special consideration for protection (Supplementary Table S3). Recreation was the most common cause of disturbance, affecting 85% of the disturbed roosts and 90% of the disturbed caves (Fig. 3).

Results of the GLM revealed that species richness was positively correlated with roost size ($\chi^2 = 22.75$, df = 1, $P < 0.001$) but negatively correlated with human disturbance ($\chi^2 = 7.05$, df = 1, $P < 0.01$). Large roosts contained a mean of 3.29 species and small roosts a mean of 2.17 species (least significance difference comparison, $P < 0.001$). Twenty-three of the 25 roosts with > 1,000 individuals were large roosts. Disturbed roosts contained a mean of 2.59 species whereas undisturbed roosts had a mean of 3.86 species (least significance difference comparison, $P < 0.05$). Roost type had a strong effect on species richness ($\chi^2 = 17.56$, df = 4, $P < 0.01$). Caves formerly used for tourism contained a mean of 4.78 species whereas abandoned mines contained a mean of 1.83 species (least significance difference comparison, $P < 0.001$). However, other pairwise comparisons indicated that species richness did not differ significantly between roosts in abandoned mines, active tourist caves, disused military fortifications or natural caves (least significance differences, all $P > 0.05$).

Partial correlations indicated that the presence of threatened and endemic species was positively correlated with species richness ($P < 0.001$) and negatively correlated with roost disturbance ($P < 0.05$). The presence of species of special concern was not directly correlated with roost size ($P = 0.30$) or roost type ($P = 0.68$).

Discussion

Seventy-seven percent (101 of 131) of the bat species in China, including 30 species categorized nationally as Endangered or Vulnerable and nine endemic species, have been documented to roost in caves and other subterranean habitats for at least part of each year, with some roosts harbouring up to 15 species. The total number of bat species is a combination of the number of species recognized by IUCN (except *Pipistrellus alaschanicus,* which has been renamed *Hypsugo alaschanicus,* Horáček et al., 2000; and *Rhinolophus rouxii,* which may be the same species as *Rhinolophus sinicus*, Zhang et al., 2009) and 12 species recorded recently (Zhang et al., 2007, 2010; Feng et al., 2008; Sun et al., 2008; Wu et al., 2008; Kuo et al., 2009; Zhou et al., 2009; Jiang et al., 2010; Wang et al., 2010; Wu & Thong, 2011).

Our results showed that undisturbed roosts supported a greater number of bat species than disturbed roosts and that species of special concern were more commonly found in roosts devoid of human disturbance. This has important implications for bat conservation in China given that 77% of the bat species roost in subterranean sites but that only about 10% are free of human disturbance. Disturbance of roosts by recreational activities could cause severe problems for bats, which can be woken by human noise in the day (Mann et al., 2002) and affected indirectly by changes in aspects of cave microclimate such as carbon dioxide concentration, temperature and humidity (Pulido-Bosch et al., 1997; Gunn, 2004).

Research activities in caves in China are increasing. For example, there were only a few people studying bats at the end of the 20th century but there are now at least five research groups studying bats in mainland China (J. Feng, pers. comm.). Although this could improve our understanding of cave ecosystems it could also be a new threat to bats and other cave-obligate organisms if researchers are not sufficiently aware of the conservation considerations required when working in caves. Research activities can cause declines in bat colony sizes, depending on the intensity and frequency of disturbance (Hayes et al., 2009). As most researchers are generally interested in their own research subjects, researchers studying cave fauna other than bats can unintentionally pose potential threats to bats, and vice versa.

Based on the criteria of Arita (1993, 1996), 121 of the 225 roosts examined deserve special consideration for protection. In general, larger roosts merit greater conservation concern because they support more bat species and greater numbers of individuals than smaller roosts. The absence of a correlation between roost size and the presence of species of special concern suggests that a conservation plan based solely on roost size would not be adequate for the protection of the cave bats of China. The greater number of species of bats in disused tourist caves indicates that this type of roost also deserves greater conservation attention. Improperly installed gates, for example, could cause species to lose their preferred roosts.

Prioritization is essential to minimize biodiversity loss because the location of and threats to biodiversity are distributed unevenly (Brooks et al., 2006). Our results suggest that protection of subterranean habitats should be a high priority for bat conservation in China. Up to 46% of the roosts surveyed harboured either threatened or endemic species of bats (i.e. those that are most critical indicators of conservation concern; Brooks et al., 2006; Miller et al., 2006) and, although 77% of bat species in China rely on underground roosts, only 10% of these were free of human disturbance. Awareness of cave ecosystems and cave-dwelling species in China is poor, not only among the public but also among some government managers and researchers (Whitten, 2009; Zhang et al., 2009). An increasing number of caves in China continue to be exploited for tourism without prior environmental impact assessments (Song et al., 2004). By 2005 > 400 caves in China had been developed for tourism (Wu & Zhuang, 2007) but there is no government agency or conservation NGO directly concerned with caves (Whitten, 2009). Any person, whatever their occupation, age or intention, may visit any cave without restriction.

Our findings indicate that prioritization of the protection of underground habitats for bats in China is warranted. For the development of management guidelines and policies, however, more ecological data on bats and caves are required, with an emphasis on population assessment and monitoring. To support this we are now actively communicating with government managers responsible for wildlife conservation and cave resource management by sharing our data with them. We recommend that bat researchers and other researchers specializing in caves should promote the conservation of cave ecosystems in China.

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Biographical sketches

Jinhong Luo studies the conservation biology and sensory ecology of bats. Currently he is investigating the impacts of climate change, noise pollution and roost disturbance on bats. Tinglei Jiang specializes in the taxonomy of Chinese bats and works on geographical variation in echolocation calls. Guanjun Lu and Lei Wang are working, respectively, on the phylogeography and echolocation behaviours of bats, and both have interests in the taxonomy of Chinese bats. Jing Wang studies the habitat selection of bats, with a special interest in understanding the effects of human activities on habitat use by horseshoe bats. Jiang Feng carried out some of the earliest research on the echolocation behaviour of bats in China. Currently, he leads a large research group studying the evolutionary biology, behaviour ecology and conservation biology of bats.